SOFT MAGNETIC MATERIALS

CONFERENCE

September 4-7, 2019, Poznań, POLAND

100th anniversary of the Poznan University of Technology

ABSTRACTS

Institute of Molecular Physics
Polish Academy of Sciences

Faculty of Technical Physics,
Poznan University of Technology

Polish Materials Science Society

Poznań, 2019

Institute of Molecular Physics, Polish Academy of Sciences
Faculty of Technical Physics, Poznan University of Technology
Polish Materials Science Society

24th SOFT MAGNETIC MATERIALS CONFERENCE

ABSTRACTS

Poznań 2019

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Abstracts

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24th SOFT MAGNETIC MATERIALS CONFERENCE

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SCHEDULE

Wednesday, September 4, 2019

16^{00} - 19^{00} **REGISTRATION**

19^{00} - ... **Choir concert and welcome party**

Thursday, September 5, 2019

9^{00} - 9^{30} **OPENING**
B. Idzikowski, R. Czajka

SESSION I Magnetocaloric effect and magnetic domain structures
Chaired by: B. Idzikowski

9^{30} - 10^{00} **Victorino Franco**
Condensed Matter Physics Dept., Sevilla University, Sevilla, Spain
Magnetocaloric Effect: From Energy Efficient Refrigeration to Fundamental Studies of Phase Transitions

10^{00} - 10^{30} **Rudolf Schäfer**
IFW Dresden, Dresden, Germany
Imaging of Magnetic Domain Dynamics at Power Frequency

10^{30} - 11^{00} A.J. Moses (0-45), K.P. Shinde (O-12)

11^{00} - 11^{30} coffee break

Thursday, September 5, 2019

SESSION II Magnetic softness of nanocrystalline alloys and atomic scale properties

Chaired by: R. Czajka

11^{30} - 12^{00}	**Akihiro Makino** New Industry Creation Hatchery Center, Tohoku Univ., Sendai, Japan ***Industrialization and applications of high B FeSiBPCu nanocrystalline alloys with improved magnetic softness***
12^{00} - 12^{30}	**Roland Wiesendanger** Universität Hamburg, Hamburg, Germany ***Novel Techniques for Revealing Atomic-Scale Properties of Magnetic Materials***
12^{30} - 13^{00}	M. Yamaguchi (O-49), J. Gutiérrez (O-29)
13^{00} - 13^{15}	conference photo
13^{15} - 14^{30}	lunch

SESSION III Properties of electrical steels, particularly grain oriented

Chaired by: R. Lemaître

14^{30} - 15^{00}	**Thierry Belgrand** thyssenkrupp Electrical Steel, Gelsenkirchen, Germany ***Grain Oriented Electrical Steel, a smart asset for energy change management***
15^{00} - 16^{30}	T. Matsuo (O-19), M.B.S. Dias (O-15), M.F. de Campos (O-26), M. Enokizono (O-03), P. Rodrgiguez-Calvillo (O-17), C. Appino (O-22)

POSTER SESSION I

Chaired by: P. Anderson, K. Ishiyama

16^{30} - 18^{30}	Posters: P-001 - P-075, P-085, P-106, P-118, P-121, P-134

SESSION IV Soft magnetic systems, in particular amorphous or nanocrystalline composites

Chaired by: K. Hameyer

18^{30} - 19^{45}	N. Lupu (O-42), I. Škorvánek (O-37), A. Masood (O-08), J.M. Barandiaran (O-34), M. Lindner (O-11)
20^{15} - ...	banquet

Friday, September 6, 2019

SESSION V Ferromagnetic nanostructures, power transformers, applications of grain oriented steels
Chaired by: A. Kedous-Lebouc

9^{00} - 9^{30} **Thierry Waeckerlé**
Aperam Alloys Imphy, Imphy, France
Evolution and recent developments of 80%Ni permalloys

9^{30} - 10^{00} **Maciej Krawczyk**
Faculty of Physics, Adam Mickiewicz University in Poznan, Poland
Coupling between spin waves in planar ferromagnetic nanostructures toward exploitation in magnonic devices

10^{00} - 11^{00} K. Hameyer (O-36), S. Siebert (O-32), P. Ripka (O-35), A. Lasheras (O-14)

11^{00} - 11^{30} coffee break

SESSION VI Mostly bioactive magnetic nanosystems
Chaired by: R. Micnas

11^{30} - 12^{00} **Robert D. Shull**
National Institute of Standards and Technology, Gaithersburg, USA
Comparison of FORC Analysis Methods for Ni Nanorods in a Hydrogel

12^{00} - 13^{00} E. Hristoforou (O-05), J.Y. Law (O-48), J. Hall (O-47), B. Schauerte (O-16)

13^{00} - 14^{30} lunch

SESSION VII Amorphous and nanocrystalline soft magnetic materials and characterisation methods
Chaired by: J.G. Landgraf

14^{30} - 15^{00} **Jean-Marc Grenèche**
Inst. des Molécules et des Matériaux du Mans, Le Mans Univ., France
Soft Magnetic nanostructures investigated by ^{57}Fe Mössbauer spectrometry

15^{00} - 15^{30} **Naoki Ito**
Hitachi Metals, Ltd., Metglas Yasugi Works, Yasugi, Japan
Recent progress in amorphous and nanocrystalline magnetic materials

15^{30} - 16^{15} L.K. Varga (O-30), T. Zhou (O-24), P. Tomczak (O-23)

16^{30} - 19^{30} bus transportation and sightseeing of VW Września

Saturday, September 7, 2019

SESSION VIII Energy loses, high-frequency applications and sensors
Chair: J.M. Barandiaran

9^{00} - 9^{30} **Fausto Fiorillo**
Istituto Nazionale di Ricerca Metrologica (INRIM), Turin, Italy
Energy losses in soft magnetic materials: an overview

9^{30} - 10^{00} **Arkady Zhukov**
Department of Material Physics, University of the Basque Country, San Sebastián, Spain
Soft Magnetic Wires for Sensor Applications

10^{00} - 10^{30} O. Maloberti (O-09), S. Dobák (O-06)

10^{30} - 11^{00} coffee break

SESSION IX Theory of spin-orbital magnetoresistance, magneto-mechanical models and other magnetic field dependent effects
Chair: E. Hristoforou

11^{00} - 11^{30} **Anna Dyrdał**
Faculty of Physics, Adam Mickiewicz University in Poznan, Poland
Emerging Magnetoresistance Effects in Spin-Orbitronics

11^{30} - 13^{00} P. Rasilo (O-07), L.F. Kiss (O-25), T. Ślęzak (O-51),
Ł. Karwacki (O-50), M. Zdunek (O-46), S. Mamica (O-13)

13^{00} - 14^{30} lunch

SESSION Xa Mostly ferrites and electrical steels
Chaired by: P. Ripka

14^{30} - 16^{45} A. Stöcker (O-39), T. Okubo (O-02), A. Ostaszewska-Liżewska (O-33),
W. Pluta (O-40), Y. Ying (O-04), G. Shilyashki (O-01),
C. Beatrice (O-10), N. Leuning (O-20), V. Kolesnikova (O-41)

SESSION Xb Selected phenomena in magnetic systems –modelling and experiment
Chaired by: J. Wysłocki

14^{30} - 16^{45} U. Ahmed (O-27), A. Stupakov (O-28), J. Goraus (O-21),
P. Łopadczak (O-44), N. Usov (O-18), J. Bednarčík (O-53),
M. Hasiak (O-31), J. Panigrahi (O-38), J. Sadowski (O-43)

Saturday, September 7, 2019

POSTER SESSION II

Chaired by: C. Appino, I. Škorvánek

16^{45} - 18^{45} Posters: P-076 - P-157 excluding P-085, P-106, P-118, P-121, P-134

18^{45} - ... **CLOSING**
B. Idzikowski, R. Czajka

20^{00} - ... **Poznań Old Town Guided Tour**

Sunday, September 8, 2019

9^{00} - 16^{00} **Excursion to Castle in Kórnik**

INVITED LECTURES

Grain Oriented Electrical Steel, a smart asset for energy change management

T. Belgrand[1]

[1]*thyssenkrupp Electrical Steel, BP23, 62330 Isbergues France*

In 1933, Norman Goss filled the first patent describing how to obtain a highly anisotropic electrical steel (GOES) which was to move upside-down the whole transformer world. Offering from the start much lower losses than the so far used electrical steels, this 86‘ material is still today the most valuable one to cope with the ever challenging situation of environmental concerns in the field of production, transport and distribution of electric energy. Although the metallurgical principle to achieve such performing steel is among the most complex ones, a very simple recipee did build its success and durability: a basic alloy composition of 97% iron and roughly 3% Silicon in shared weight combined with metallurgical routes of the classical, well experienced, reliable and productive tools of the steel industry. After decades of continuous improvement, two main events made recently GOES endeavour even further to show its capacity to stand the spot in energy saving environment, 1) Ecodesign directive enforced by European Commission since July 2015 driven by the need for a drastic reduction of CO2 emission and 2) the push forward of the power electronic industry. This latter one now offers components able to switch very high voltages and current in the medium frequency range for the manufacturing of efficient static converters. Those are dedicated at the growing needs of the renewable energy industry for the management of reversible energy flows. In this case DC grids are more and more thought of with converters working in the kHz range. Some development have been made by various institutes to integrate GOES inside Solid State Transformer (SST) cores even with using the ability of the steel to be operated a high temperatures. GOES industry faced all these changes by developing new grades of reduced thickness through accurate metallurgical processes leading to lower specific loss with excellent magnetising ability. Standards have, too, adapted to this evolution in terms of whether product performance or measurement technique of electrical steel properties. Although its basic structure is well known, some of its features need still to be better understood and described for utmost improvement of the end application. Transformer / converter industry may take advantage of it as well as e-mobility sector for some special motors of very high efficiency are built around GOES cores. This presentation intends to show the specifity of GOES and all the changes that occured in its properties leading to some successful use cases which will be shown.

Emerging Magnetoresistance Effects in Spin-Orbitronics

A. Dyrdał,[1] J. Barnaś,[1,2] and A. Fert[3]

[1]*Faculty of Physics, Adam Mickiewicz University, 61-614 Poznań, Poland*
[2]*Institute of Molecular Physics, Polish Academy of Sciences, 60-179 Poznań, Poland*
[3]*Unité Mixte de Physique, CNRS, Thales, Univ. Paris-Sud, Université Paris-Saclay, 91767, Palaiseau, France*

The main objective of spintronics is currently full electrical control of the spin degree of freedom via electrically-induced spin torques of various origins. In this context, the key role is played by spin-orbit coupling that allows for efficient charge-to-spin interconversion owing to the spin Hall effect (SHE) or current-induced spin polarization (Edelstein effect) [1].

In the past few years, the new concepts for the magnetoresistance phenomena mediated by spin-orbit coupling were reported. One of them explores the processes induced by the spin Hall effect at the interface between ferromagnet (insulating or metallic) and a material with strong spin-orbit coupling (e.g., heavy metal) [2]. Recently, the magnetoresistance which scales linearly with both external electric and magnetic fields has been reported, even in a single uniform layer of material with strong spin-orbit coupling [3]. The bi-linear character of spin-orbital magnetoresistance phenomena makes them undoubtedly attractive for applications.

During the lecture, we will summarize recent magnetoresistance experiments in materials used in spin-orbitronics (topological insulators (α-Sn, Bi_2Se_3), perovskite oxides (LAO/STO based systems, and thin films of Germanium). We will also discuss possible theoretical explanation of the bi-linear behavior of the magnetoresistance signal [3,4].

References:

[1] A. Soumyanarayanan, *et al.*, Nature 539, 509 (2016).
[2] H. Nakayama, *et al.*, Phys. Rev. Lett. 110, 206601 (2013); Y.-T. Chen, et al., Phys. Rev. B 87, 144411 (2013); J. Kim, et al., Phys. Rev. Lett. 116, 097201 (2016).
[3] Pan He, *et al.*, Nature Physics 14, 495 (2018); S.S. Zhang, G. Vignale, ArXiv 2018.
[4] A. Dyrdał, J. Barnaś, A. Fert, ArXiv2019; A. Dyrdał, J. Barnaś, A. Fert, to be published.

Energy losses in soft magnetic materials: an overview

Fausto Fiorillo

Advanced Materials and Life Science Division, Istituto Nazionale di Ricerca Metrologica (INRIM), 10135 Torino, Italy

Energy losses are the chief technical parameter by which the properties of a soft magnetic material are evaluated. The variety of available materials and the related physical properties, the wide range of frequencies and excitation regimes involved in applications, and the complex unfolding of the magnetization process with applied fieldstrength and frequency, make the accurate experimental measurement and the general assessment of magnetic losses an especially complex problem. After many decades of investigative efforts, loss modelling is still a subject of debate, with new challenges posed by progressively extended fields of application, enticing the development of competing and somewhat contrasting theoretical approaches. Empirical-phenomenological models are sometimes preferred in the engineering context, although the computing burden might be relevant. The simplest approach to the loss at given magnetizing frequency and induction level is the one offered by the popular Steinmetz's equation, with its trail of fitting constants, variously modified and adapted to specific experimental circumstances. It has since long recognized, however, that quasi-static W_h and dynamic W_{dyn} contributions to the energy loss are better treated as separate quantities. In doing this decomposition, by maintaining a phenomenological approach, one can focus on a quasi-static model for W_h and postulate a certain frequency and peak induction dependence for the dynamic eddy-current fields. While in this way one can better emulate the material response, a firm theoretical ground to the whole phenomenology is achievable only by detailed physical analysis of the magnetization process, accounting for its complex intrinsically stochastic nature. This goal is remarkably accomplished in Bertotti's Statistical Theory of Losses (STL), where the concept of loss decomposition, hysteresis plus classical and excess components, emerges in a natural way from the statistical approach to domain wall motion and magnetization reversal. By combining rigorous physical derivation with intrinsic flexibility, the STL permits one to deal with complex excitation regimes, while not being limited to conducting materials, that is, to the treatment of eddy current losses. It has been extended, for example, to the broadband analysis of losses in soft ferrites. Instigated by increasing use of soft magnetic cores in high-speed electrical machines and power electronics, recent investigations are especially focused on high-frequency losses and non-sinusoidal regimes, where challenges are posed by the treatment of the skin-effect and of the dissipative mechanisms by spin damping.

Magnetocaloric Effect: From Energy Efficient Refrigeration to Fundamental Studies of Phase Transitions

Victorino Franco

University of Seville, Seville, Spain

The magnetocaloric effect, that is, the reversible temperature change experienced by a magnetic material upon the application or removal of a magnetic field, has become a topic of increasing research interest due to its potential applications in refrigeration at ambient temperature that is energy efficient and environmentally friendly [1]. From a technological point of view, the improvement of magnetic refrigeration systems can have a notable impact on society: a large fraction of the electricity consumed in residential and commercial markets is used for temperature and climate control. From the point of view of magnetic materials, research on this topic mainly focuses on the discovery of new materials with lower cost and enhanced performance. In addition, the characterization of the magnetocaloric effect can be used for more fundamental studies of the characteristics of phase transitions.

I will cover an overview of the phenomenon and a classification of the most relevant families of alloys and compounds. I will analyze possible limitations for the optimal performance of the materials in magnetic refrigerators, including hysteretic response and cyclability. Regarding phase transitions, I will present a new method to quantitatively determine the order of thermomagnetic phase transitions using the field dependence of the magnetic entropy change [2]. For second-order phase transition materials, I will show that critical exponents can be determined using the magnetocaloric effect even in cases where the usual methods are not applicable [3]. In the case of first-order phase transitions, more details about their hysteretic response can be obtained using T-FORC [4].

References:

[1] V. Franco, J. S. Blázquez, J. J. Ipus, J. Y. Law, L. M. Moreno-Ramírez, and A. Conde, Prog. Mater. Sci., vol. 93, pp. 112-232, Apr. 2018.
[2] J. Y. Law, V. Franco, L. M. Moreno-Ramirez, A. Conde, D. Y. Karpenkov, I. Radulov, K. P. Skokov, and O. Gutfleisch, Nat. Commun., vol. 9, p. 2680, Jul. 2018.
[3] V. Franco and A. Conde, Int. J. Refrig., vol. 33, pp. 465-473, May 2010.
[4] V. Franco, T. Gottschall, K. P. Skokov, and O. Gutfleisch, IEEE Magn. Lett., vol. 7, 6602904, Mar. 2016.

Soft Magnetic nanostructures investigated by ^{57}Fe Mössbauer spectrometry

J.M. Greneche

Université du Maine, Institut des Molécules et Matériaux du Mans,
UMR CNRS 6283, 72085 Le Mans Cedex, France

During the last three decades, many soft magnetic nanostructures have been developed: their morphology remains a crucial point to understand the origin of their magnetic properties. The study of their structural and magnetic properties requires the complementarity of several techniques. In addition to conventional ones, ^{57}Fe Mössbauer spectrometry is an excellent tool, as this local probe technique must first discriminate surface and volume effects, grain boundaries and interfaces, in addition to oxidation states and spin Fe species, and then help to follow the hyperfine magnetic properties and their dynamics in correlation with superparamagnetic relaxation phenomena.

After reviewing the main structural and magnetic characteristics of different types of nanostructures, we illustrate from selected examples how the selectivity and local probe character of ^{57}Fe Mössbauer spectrometry contribute to investigate *in situ* local atomic order and magnetic properties. In addition, we report some numerical modeling results, showing how Mössbauer spectrometry and Monte Carlo and / or *ab initio* calculations are complementary approaches.

Recent progress in amorphous and nanocrystalline magnetic materials

N. Ito,[1,2] D. Azuma,[1] and M. Ohta[1]

[1]*Hitachi Metals, Ltd.*
[2]*Metglas, Inc.**

Soft magnetic materials play an important role to improve efficiency of energy conversion devices. Many efforts have been made in conventional materials such as grain-oriented and non-grain oriented silicon steels to reduce core loss. Their magnetic characteristics, however, are primarily governed by magneto-crystalline anisotropy which is related to hysteresis loss In addition, it is difficult to achieve large reduction of eddy current loss, considering the cost to produce thin gauge, less than 100 μm, materials.

In amorphous and nanocrystalline materials, magneto-crystalline anisotropy is vanished or tremendously reduced as explained by random anisotropy models [1],[2], and the typical thickness ranging from 20 - 30 μm due to unique production techniques of rapid solidification process and a relatively high electrical resistivity of 1.0 -1.3 μΩm result in lower eddy current loss. On the other hand, saturation magnetizations of amorphous and nanocrytalline materials are generally lower compared to silicon steels due to the presence of metalloids and/or other paramagnetic elements such as Cu, Nb etc. Another challenge in using these materials is to manage brittleness after heat treatments. To overcome these difficulties, rapid heating techniques whose heating rates are more than 10 times higher than those of conventional heat treatment are employed [3]-[6]. This paper reviews recent advances in amorphous and nanocrytalline soft magnetic materials in terms of improvement of brittleness of Fe-based amorphous materials and higher saturation magnetization.

References:

[1] R. Alben, J.J. Becker, and M.C. Chi, J. Appl. Phys., 49, 1653 (1978).
[2] G. Herzer, IEEE Trans. Magn., 25, 3327 (1989).
[3] B Francoeur and P. Couture, J. Appl. Phys. 111, 07A309 (2012).
[4] M. Ohta and R. Hasegawa, IEEE Trans. Mag. 53, 2000205 (2017).
[5] B. Zang, R. Parsons, K. Onodera, H. Kishimoto, A. Kato, A. C. Y. Liu and K. Suzuki, Scr. Mater. 132, 68 (2017).
[6] K. Suzuki, R. Parsons, B. Zang, K. Onodera, H. Kishimoto and A. Kato, Appl. Phys. Lett., 110, 012407 (2017).

* - *former affiliation*

Coupling between spin waves in planar ferromagnetic nanostructures toward exploitation in magnonic devices

K. Szulc,[1] P. Graczyk,[2] M. Mruczkiewicz,[3] S. Mamica,[1] M. Zelent,[1] P. Gruszecki,[1] J. Rychły,[1] J. W. Kłos,[1] and M. Krawczyk[1]

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Spin waves span a broad range of frequencies from hundreds of MHz up to tens of GHz with the respective wavelengths ranging from micrometers to nanometers. Moreover, their spectra can be tuned by the external fields and depend on the magnetization configuration. These properties are desirable in microwave and information processing technologies and are in focus of our investigations in magnonics. We show magnonic band structure formation and opening magnonic band gaps with different kinds of periodicity in thin ferromagnetic films introduced by etching holes, structural modifications, magnetic domain formation and dynamic dipolar coupling. We continue to demonstrate the effect of non-reciprocity in the spin wave spectra and to propose directional couplers, transduction between acoustic and spin waves, and the rout to control the spin wave propagation in the film plane and along the vertical direction.

References:

[1] M. Mruczkiewicz, et al., Phys. Rev. B 90, 174416 (2014).
[2] P. Graczyk and M. Krawczyk, Phys. Rev. B 96, 024407 (2017).
[3] C. Banerjee, et al., Phys. Rev. B 96, 024421 (2017).
[4] P. Graczyk, et al., New J. Phys. 20, 053021 (2018).
[5] M. Zelent, et al., ACS Nanoscale (2019).

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Industrialization and applications of high *B* FeSiBPCu nanocrystalline alloys with improved magnetic softness

A. Makino,[1] H. Men,[2,3] H. Guo,[2] and L.S. Huo[2]

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[2]*Ningbo Zhongke B Plus New Materials Technology Co., Ltd, Ningbo, China.*
[3]*Ningbo Institute of Industrial Technology, Chinese Academy of Sciences, Ningbo, China.*

In 2009 the present authors, A Makino and H Men, have reported that the Fe-rich Fe -Si-B-P-Cu nanocrystalline alloys exhibit high saturation magnetic flux density (B_s > 1.8 T), low coercivity (H_c < 10 A/m) and low core losses by crystallizing a melt-spun hetero-amorphous phase(1,2). Since the finding, in the last 10 years the development of the manufacturing process or method of the material with low cost and seeking of suitable applications have been made by industry-academia collaboration. After overcoming many issues, recently the mass production of the materials with optimized alloy compotitions has been successfully carried out, as shown in Figure1. The commercialized materials show high *Bs* >1.7T and extremely low *Hc* of 1A/m after optimumized crystallizing process, which is almost the same as that of Finemet type alloy. The prototype motor, the toroidal power transformer and many kinds of magnetic devices using cores made of the nano-crystallized material ribbon exhibit remarkable improvement in energy consumption in comparison to those of Si-steel and the other soft magnetic materials cores.

Figure1. Mass production of the material by a single-roller melt-spinning in B Plus Co.,Ltd.

References:

[1] Makino A, Men H. *et al.*, MATERIALS TRANSACTIONS. 50(1)p.204-209, (2009)
[2] Makino A. IEEE TRANSACTIONS ON MAGNETICS. 48(4)p.1331-1335, (2012)

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Imaging of Magnetic Domain Dynamics at Power Frequency

R. Schaefer,[1] and I. Soldatov[1]

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In spite extensive domain studies in grain oriented electrical steel [1], there is still a lag of knowledge about the domain dynamics and flux propagation on the grain size level under application-relevant conditions, owing to a lag of suitable imaging techniques. PMOIF- [2] and Neutron Dark-field Microscopy [3] open the path for such investigations as will be reviewed.

The core of a PMOIF is a transparent magnetic garnet film with up-and-down magnetized band domains. Placed on the surface of a magnetic specimen, the stray-field emerging from poles in the sample modifies those band domains by wall motion. Imaged under low-resolution conditions leads to an averaged polar Faraday contrast in an optical polarization microscope. The contrast pattern thus reflects the pole pattern of the specimen. Compared to conventional indicator films with in-plane anisotropy, which act on the sample stray-field by magnetization rotation, the PMOIFs offer much higher sensitivity as their susceptibility is governed by wall motion in the garnet film. So, domains can even be imaged in the presence of the insulation coating on the transformer sheets, and the contrast is strong enough to allow for single-shot imaging of dynamic processes up to the 500 Hz frequency regime by using a high-speed camera.

The dark-field image (DFI) of neutron grating interferometry (NGI) is a technique that enables the spatially resolved analysis of bulk magnetic domains deep in the volume of materials and thus provides unique information. The contrast is based on the small-angle scattering of neutrons at domain walls and the consequent disruption of a predefined interference pattern. By combining a standard NGI setup with a multi-channel-plate (MCP) detector, stroboscopic imaging of (repetitive) volume domain processes becomes directly possible with a spatial resolution of 100 μm.

[1] A. Hubert and R. Schäfer: Magnetic Domains. Springer (1998)
[2] R. Schäfer *et al.*, J. Magn. Magn. Mat. 474, 221 (2019)
[3] R. Harti *et al.*, Scientific Reports 8, 15754 (2018)

Neutron imaging was performed by Ralp Harti and Christian Grünzweig at Paul Scherrer Institute in Villigen, Switzerland

Comparison of FORC Analysis Methods for Ni Nanorods in a Hydrogel

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The First Order Reversal Curve (FORC) analysis method has been shown to be a good qualitative tool for detecting interactions and their distributions between magnetic spins in ferromagnetic materials. As a consequence it is becoming a common technique in the examination of collections of nanoparticles and of both hard and soft ferromagnets. However, since the technique relies upon determining the distribution function:

$$\rho(H_R, H) = -\frac{1}{2}\partial^2 M(H)/\partial H_R \partial H$$

where M is the magnetization, H is the applied field, and H_R is the reversal field, proper calculation of the numerical derivative when there is no analytic function expressing the M versus H relationship is necessary if the technique is to be made quantitative.

For illustration, in this study we have measured the magnetization as a function of applied magnetic field for a large number of reversal fields on a system of 200 nm long Ni nanorods (20 nm diameter) randomly dispersed and embedded in a hydrogel. We then performed FORC analyses on this data set using several of the different methods (running average, local regression, etc.) presently being used in the community, as well as a new method using cubic splines developed at NIST, to calculate the distribution function ρ. Here, we develop metrics to assess the quality of each of these methods for FORC analysis. These metrics include the residuals in the magnetic moment and the standard error in the moment calculated from the predicted behaviour relative to the measured behaviour, as determined by each analysis method. By presenting these metrics as a function of field for different reversal fields, we also highlight regions where each method becomes problematic.

The authors greatfully acknowledge the assistance of Professor Andreas Tschöpe and Dr. Christoph Schopphoven at the Universität des Saarlandes, Saarbrücken, Germany by their providing the Ni nanorod samples used in this study.

Evolution and recent developments of 80%Ni permalloys

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Facing the growing success of competing, cost reduced, high permeability and highly dynamic, amorphous or nanocrystalline ultra soft magnetic materials, how the old FeNi80 permalloys may survive ? Which properties, compromise, industrial advantages or innovation keep them in the race of enjoying performances, of interesting markets ? Which applications are going out or on the contrary are developed ? This presentation aims at reviewing the main recent tendencies influencing the development of FeNi80 alloys.

The remaining interest for these high nickel content alloys comes from the mixture of high level electromagnetic features (low and precisely controlled magnetocrystalline or magneto-elastic energies), from the mechanical ability to be easily machined into 3D shaped pieces, from the isotropic magnetic properties and from the medium Curie point: these features are recalled, with an emphasize of their relationships with precise chemical content, steelmaking routes or final heat treatments [1].

In the second part a set of applications are reviewed, aiming at understand what are the causes of death or creation of application-80 permalloy couple. A representative example of the former – the ground fault circuit breaker (GFCB) sensor– exhibits the ends of a rather important industrial market of FeNi80 alloys, despite remaining applications in very highly sensitive GFCB relay. On the opposite the growth of automotive torque sensor market, of room shielding and especially Rayleigh domain behavior for medical applications such as MagnetoEncephaloGraphy [2], of cryogenic shielding for large equipments devoted to fundamental physic research [3] or current transformers for medium voltage equipments ensure that such very soft magnetic materials remain very used.

It is shown that rather low permeability together with very low coercive field can be obtained with the help of final annealing under high fields (a few T) whereas the high frequency impedance behavior around the Curie point may be used as a contactless temperature sensor in any application requesting such function.

FeNi80 alloys appears to remain modern materials, associated with promising properties, behaviors and applications.

References:

[1] G. Couderchon, J.M.M.M. 96 (1991) 47-59
[2] A. Canova *et al*, IEEE Trans. Magn. 54, 3 (2018) 2000304
[3] M. Masuzawa *et al*, Proc. of SRF2013, Paris, France, WEIOD02, pp 1-4

Novel Techniques for Revealing Atomic-Scale Properties of Magnetic Materials

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The design of novel functional magnetic materials requires detailed knowledge about their atomic-scale properties, including atomic structure, competing spin-dependent interactions down to the atomic level as well as atomic-scale details of the resulting spin textures. In recent years, several spatially-, energy-, and spin-resolved techniques have been developed, such as spin-polarized scanning tunneling microscopy and spectroscopy [1,2], magnetic exchange force microscopy [3], single-atom magnetometry [4,5] or time-resolved spin-sensitive spectroscopy [6,7] allowing detailed investigations of magnetic materials down to the atomic level. We will present several outstanding examples, ranging from novel types of soft-magnetic surface alloys, to nanostructured thin films and atomic-scale clusters as well as artificially constructed nano-scale atomic arrangements on surfaces.

References:

[1] R. Wiesendanger *et al.*, Science 255, 583 (1992).
[2] R. Wiesendanger, Rev. Mod. Phys. 81, 1495 (2009).
[3] U. Kaiser, A. Schwarz, and R. Wiesendanger, Nature 446, 522 (2007).
[4] F. Meier *et al.*, Science 320, 82 (2008).
[5] A. A. Khajetoorians *et al.*, Nature 467, 1084 (2010).
[6] S. Krause *et al.*, Science 317, 1537 (2007).
[7] A. A. Khajetoorians *et al.*, Science 339, 55 (2013).

Soft Magnetic Wires for Sensor Applications

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Studies of amorphous magnetic wires have attracted great attention owing to excellent magnetic, mechanical and corrosion properties. Excellent magnetic properties such as magnetic bistability or Giant Magnetoimpedance (GMI) effect are suitable for magnetic sensors applications [1]. Recent tendency in devices miniaturization stimulated development of thin (few micrometers diameters) microwires.

Excellent soft magnetic properties and GMI effect have been reported for properly prepared and processed Co-rich microwires [1]. However, less expensive Fe-rich microwires are preferable for the applications. But amorphous Fe-rich materials exhibit rather high magnetostriction coefficient and consequently present quite low GMI effect [1].

The most common method for magnetic softness optimization is the annealing.

Consequently, the purpose of this paper is to present our recent experimental results on influence of preparation and processing conditions on magnetic properties of Fe- and Fe-Co based glass-coated microwires.

We observed that stress-annealed at appropriate conditions (time and temperature) microwires can present considerable magnetic softening and enhanced GMI effect.

For interpretation of observed changes of hysteresis loops after stress annealing we considered internal stresses relaxation and different mechanisms of stress-induced anisotropy.

Observed versatile properties of stress annealed glass-coated microwires with enhanced and tuneable soft magnetic properties make them suitable for magnetic sensors applications.

References:

[1] A. Zhukov, M. Ipatov and V. Zhukova, Advances in Giant Magnetoimpedance of Materials, Handbook of Magnetic Materials, ed. K.H.J. Buschow, 24: 2015 ch.2,pp.139-236.

[2]. V. Zhukova, J. M. Blanco, M. Ipatov, M.Churyukanova, S. Taskaev and A. Zhukov, Sci. Reports, 8, 3202 (2018)

ORAL CONTRIBUTIONS

Thin Band Sensors for Analyses of Rotational Magnetization in the Interior of Transformer Cores

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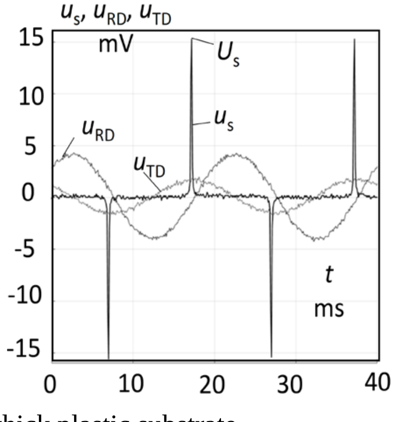
As well known, 3-phase transformer cores exhibit pronounced rotational magnetization (RM), in particular in their T-joint regions. The cores represent 3-dimensional systems which means that analyses of RM should be performed in the core interior. However, so far, not any sensor type was available in order to detect inner RM in non-destructive ways. Recently, we developed nano-crystalline sensor bands [1] which however where restricted to determine the peak induction component B_{RD} in rolling direction (RD). For the first time, this paper reports a methodology to determine also the peak component B_{TD} in transverse direction (TD). This allows the calculation of the RM axis ratio according to $a = B_{TD} / B_{RD}$.

For the RD, a nano-crystalline ribbon of e.g. 40 mm x 10 mm x 0.02 mm size as a nucleus is arranged inter-laminarely. By means of a transfer function that depends on the type of material, the induction B_S of the sensor is „translated“ into the induction B_{RD} of the core material.

Our first sensors for the TD exhibit a ribbon of 30 mm x 10 mm x 0.02 size with eight search coil turns that are printed by a 2D/3D assembler, as described in [2]. Corresponding to the induction of ribbon, the search coil yields a voltage signal $u_S(t)$.

As an example of result, Fig.1 shows sensor signals for two periods for RM of grain oriented SiFe, elliptically magnetized with B_{RD} = 1.5 T and a = 0.4. $u_{RD}(t)$ and $u_{TD}(t)$ are the corresponding voltages of search coil sensors through four small holes of the material. On the other hand, the signal $u_S(t)$ of the novel sensor exhibits sharp peaks of height U_S for instants of onset (and offset) of B_{RD} in TD. The peaks reflect switch-like starting (and ending) saturation of the extremely sensitive nano-crystalline ribbon. The switch dynamic rises with rising B_{TD}, and a, respectively, however, with non-linear slope.



For the first time, the novel sensor methodology allows for interior assessment of rotational magnetization in non-destructive ways. As significant features, the sensors can be manufactured in automatic ways, with a total sensor thickness of just 200 µm, including a 25 µm thick plastic substrate.

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References:

[1] H. Pfützner, G. Shilyashki, A.Windischhofer, *J. Appl. Electrom. Mech*. 56-4, pp. 585-594, 2018.

[2] G. Shilyashki, *et al.*, *Sensors* 17, 2953, pp.1-7, (2017).

Magnetic Properties of Grain-oriented 6.5%Si Steel with Fine-grained Structure

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It is well known that 6.5%Si steels possess excellent soft magnetic properties. Non-oriented 6.5%Si steels are now produced commercially by the CVD (chemical vapor deposition) siliconizing method, and are widely used for high-frequency reactors and motors to decrease high-frequency iron losses [1].

Texture control can improve the magnetic properties of these steels. However, the secondary recrystallization method causes a coarse grain size and increases anomalous eddy current losses and high-frequency iron losses [2]. In this investigation, we prepared grain-oriented 6.5%Si steels with {110}<001> grains (grain size: 0.1-1 mm) finer than the secondary recrystallization grains (10-100 mm). Specimens having a thickness of 0.1 mm were prepared by cold rolling conventional grain-oriented 3%Si steels and siliconizing in order to obtain fine {110}<001> grains [3]. The grain-oriented 6.5%Si steel shows low iron loss and high flux density compared to the non-oriented 6.5%Si steel with the same thickness (Fig. 1 and 2). The fine-grained structure results in a small magnetic domain size, low anomalous eddy current losses, and low iron losses at high frequency.

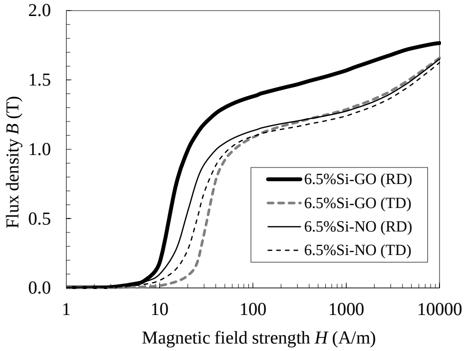

Fig. 1. DC magnetizing curves.

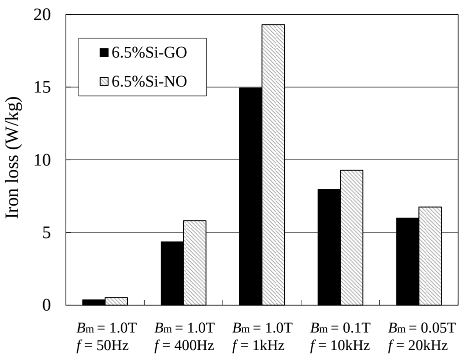

Fig. 2. Iron losses in rolling direction.

References:

[1] H. Haiji, *et al.*, J. Mag. Mag. Mater., 160, p109 (1996).
[2] H. Homma, *et al.*, J. Appl. Phys., Vol. 70, No. 10, p6259 (1991).
[3] C. G. Dunn, Acta Met., 2, p386 (1954).

Effect of Stress on Vector Magnetic Hysteresis Loop Characteristic of Electrical Steel Sheet

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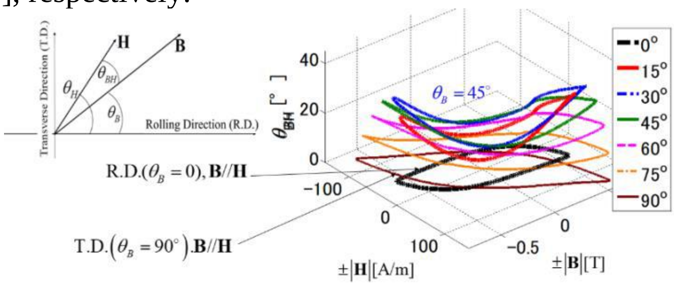
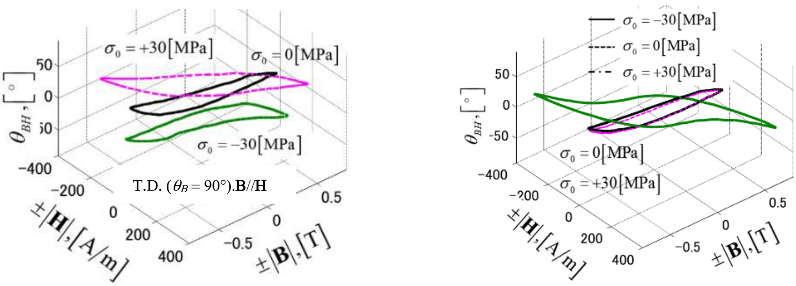
This paper describes the new expression of vector magnetic hysteresis loop characteristic of arbitrary direction. The conventional magnetic hysteresis loop characteristic was limited in the case of the magnetic flux density vector **B** parallel to magnetic field strength vector **H**, which can be named scalar magnetic hysteresis loop characteristic. The vector magnetic hysteresis can be expressed θ_{BH}-|**B**|-|**H**| hysteresis loop characteristic. The θ_{BH} is the spatial difference in phase angle between vector **B** and vector **H**.[1]

Figure 1 shows (a) the vector magnetic hysteresis loop and its (b) effect of tensile or compressive stress and (c) shearing stress of θ_B=45[°] of vector **B,** by ±30[MP], respectively.



(a) Vector magnetic hysteresis loop.



(b) Effect of tensile and compressive stress. (c) Effect of shearing stress.

Fig. 1 Effect of stress, ±30[MP] at arbitrary direction θB=45[°].

References:

[1] W. Brix, K. A. Hempel, F. J. Schulte, "Improved method for the investigation of the rotational magnetization process in electrical steel sheets", *IEEE Trans. Magn.*, vol. MAG-20, no. 5, pp. 1708-1710, 1984.

Influence of the $Li_{0.5}Fe_{2.5}O_4$ addition on magnetic properties of manganese ferrites at MHz frequencies

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Switching mode power supplies (SMPS), such as AC-DC converters and DC-DC converters, are widely used in almost all electronic equipment due to their portability and high efficiency. Ferrites with the low power loss (P_{cv}) and high saturation flux density (B_s) are the essential materials in SMPS. Currently, the working frequency of SMPS is up to 500 kHz. With the development of the third generation semiconductor, SMPS are required to work at higer frequencies. Therefore, it is urgent to develope the ferrites with the low P_{cv} and high B_s working at MHz frequencies.

In this work, the $Li_{0.5}Fe_{2.5}O_4$ added manganese ferrites with the low P_{cv} and high B_s at MHz frequencies were prepared by using conventional ceramic process. Influence of $Li_{0.5}Fe_{2.5}O_4$ content on the microstructure and magnetic properties were investigated. A moderate amount of $Li_{0.5}Fe_{2.5}O_4$ helps to form uniform fine grains and to reduce the Fe^{2+} content and consequently P_{cv}. For all samples, the cut-off frequency is above 9 MHz and B_s is above 500 mT at 30 °C. With the 1.20 mol% $Li_{0.5}Fe_{2.5}O_4$ content in manganese ferrite, the lowest P_{cv} is achieved to be 76 kW/m^3 at 25 °C and 82 kW/m^3 at 80 °C in the AC field magnitude of 10 mT at 2 MHz. Due to the high magnetic performances (high B_s and low P_{cv}) at high frequencies, the $Li_{0.5}Fe_{2.5}O_4$ added manganese ferrites could be the promising core materials for switching mode power supply applications at MHz frequencies

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Selective Magnetic Separation to concentrate bioactive compounds from microalgae

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Bioactive compounds from various natural sources (plants, fruits, fungi, bacteria, algae etc.) have been attracting more and more attention, owing to their broad diversity of functionalities and benefits to the human health. The extraction of bioactive compounds from plant materials is the first step in the utilization of phytochemicals in the preparation of dietary supplements or nutraceuticals, food ingredients, pharmaceutical, and cosmetic products. However, many of these compounds often exist at extremely low concentration in a mixture so that new extraction methods are required to obtain several high-quality bioactive compounds by lowering, at the same time, the cost production and the energy consumption. The innovative solution proposed to refine and enhance the purity of organic molecules extracted from natural sources (plants, fruits, fungi, bacteria etc.) is based on the use of small Magnetic Particles or beads (MPs) functionalized with surfactants and ligands able to specifically bind only one class of target molecule. The magnetic separation is mainly designed to increase the purity of enriched solutions (>80%). The main principle is based on non-covalent and/or ionic binding of a specific organic molecule to a short oligopeptide, antibodies, metal ions and other chemical groups. Herein, we present preliminary results for the extraction of astaxanthin. In the present work, different astaxanthin extracts preparations from heamatococcus pluvialis (microalgae) were used as target compounds to be bind on magnetic nanoparticles. Effects of time, concentrations and temperature on astaxanthin recovery were investigated. After an extraction time of 60 min, maximum recovery was reached at room temperature.

This paper is part of a project that has received funding from the Bio Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 745695. E. Hristoforou wishes to acknowledge financial support of the Ministry of Science and Higher Education of the Russian Federation in the framework of Increase Competitiveness Program of NUST «MISIS», contract № K2-2019-012.

Thermally Activated Processes and Wideband Magnetic Behavior of Ni-Zn Ferrites

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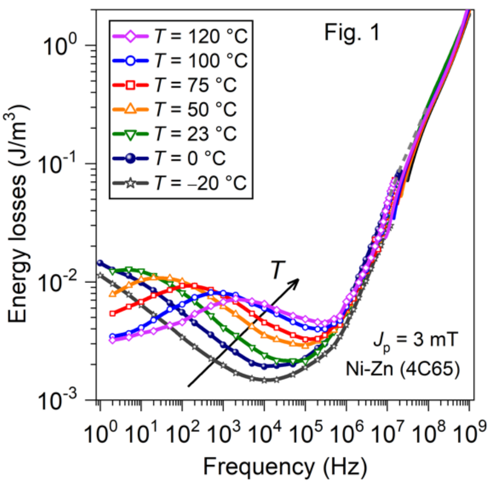
Extremely high broadband electrical resistivity, ensuring the absence of eddy currents, makes the sintered Ni-Zn ferrites a favorite material for efficient high-frequency applications. Despite ubiquitous use of this soft magnetic material, quantitative appraisal of their many-decade frequency response is conspicuously lacking in the literature. In this study we investigate the behavior of the energy losses and permeability in Ni-Zn ferrite ring samples (Ferroxcube 4C65, 4A11) upon a wide range of measuring conditions: (i) peak polarization $2\ \mathrm{mT} \leq J_p \leq 100\ \mathrm{mT}$, (ii) frequency $1\ \mathrm{Hz} \leq f \leq 1\ \mathrm{GHz}$, (iii) temperature $-20\ ^\circ\mathrm{C} \leq T \leq 120\ ^\circ\mathrm{C}$. The results reveal the presence of a large temperature-dependent extra-contribution to magnetic loss W and permeability in the 4C65 ferrite. Such a contribution covers the lower frequency range ($f < 1$ MHz), as illustrated in Fig. 1, where a broad maximum of W versus frequency is observed to occur and to move towards higher frequencies by increasing T ($J_p = 3$ mT). This phenomenology can be interpreted in terms of diffusion aftereffect, the process by which the motion of the domain walls (d.w.s) is affected by the thermally assisted magnetization-induced cation diffusion. The interpretative approach to the extra-loss governed by the aftereffect is worked out by postulating a distribution of activation energies E_a and an ensuing temperature dependent spectrum of time constants $\tau \propto \exp[E_a/(k_B T)]$, ($k_B$ Boltzmann constant). Permeability and loss behaviors in 4C65 are found, in particular, to be consistent with an average activation energy $\langle E_a \rangle \sim 0.60$ eV. Full loss versus frequency analysis, taking into account the separate contributions of d.w.s and rotations to the magnetization process, shows that the d.w.s remain active up to very high frequencies ($f \sim 10$ MHz), in both types of Ni-Zn ferrites. This limit is notably and justifiably higher than the one observed in Mn-Zn ferrites.



Multiscale Magneto-Mechanical Constitutive Laws in Finite Element Analysis through Thermodynamic Framework

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We present a new approach for efficiently implementing magneto-mechanical material models in finite element (FE) analysis of ferromagnetic cores, avoiding the need of performing complex characterization measurements. Following the approach of [1], a multiscale model is first applied to produce magnetization and magnetostriction data for different combinations of magnetic and mechanical excitations, starting from only three physical parameters: the saturation magnetization, saturation magnetostriction, and initial magnetic susceptibility. A Helmholtz free energy density $\psi(\boldsymbol{B}, \boldsymbol{\varepsilon})$, expressed as a function of the magnetic flux density $\boldsymbol{B}$ and strain $\boldsymbol{\varepsilon}$, is then fitted as a spline against this data, allowing the magnetic field strength and stress to be obtained as $\boldsymbol{H}(\boldsymbol{B}, \boldsymbol{\varepsilon})$ and $\boldsymbol{\sigma}(\boldsymbol{B}, \boldsymbol{\varepsilon})$ using simple interpolation techniques. In this paper, the spline-based thermodynamic model is implemented in a coupled magneto-mechanical FE method, solving the Ampere law (curl $\boldsymbol{H}(\boldsymbol{B}, \boldsymbol{\varepsilon}) = \boldsymbol{0}$) and the mechanical balance equations (div $\boldsymbol{\sigma}(\boldsymbol{B}, \boldsymbol{\varepsilon}) = \boldsymbol{0}$) in an EI transformer core. The model appears to converge well. Fig. 1 shows simulation results for the flux density, magnetoelastic stress $\frac{3}{2}\boldsymbol{H}^{\mathrm{T}}\left(\boldsymbol{\sigma}-\frac{1}{3}\operatorname{tr}\boldsymbol{\sigma}\right)\boldsymbol{H}/\|\boldsymbol{H}\|^2$, and magnetostrictive deformation (magnified by $6\cdot10^5$) in one quarter of the core.

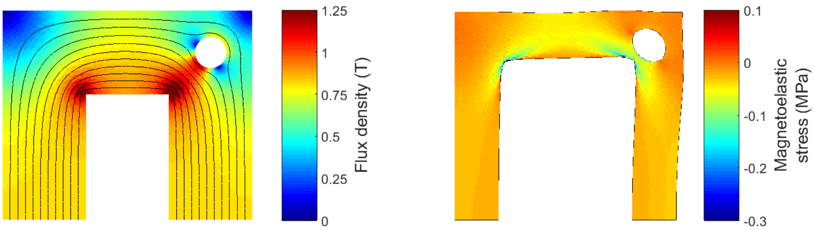

Fig. 1 Flux-density, magnetoelastic stress, and deformation of the EI-core.

References:

[1] P. Rasilo, D. Singh, J. Jeronen, U. Aydin, F. Martin, A. Belahcen, L. Daniel, R. Kouhia, "Flexible Identification Procedure for Thermodynamic Constitutive Models for Magnetostrictive Materials," *Proc. R. Soc. A*, Vol. 475, No. 2223, 2019.

Amorphous Metals on the Move: Making Amorphous Metal Ribbons Suitable for High-Frequency Applications

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The high-flux density (B_s >1.5 T), high-permeability ($\mu>10^5$), ultra-low coercivity (H_c<1 A/m), and high resistivity (>100 μΩ cm) of amorphous metals makes them a potential soft magnetic material for device miniaturization in high-frequency applications. The single largest example of commercially available amorphous alloys is melt-spun ribbons that have a thickness in the range of 20-30 µm and are used for low-frequency (50-60 Hz) power distribution transformers. However, as the operating frequency (f) of device approaches kHz range, the eddy-current loss ($W_e \propto f^2$) sharply increases as compared to the hysteresis loss ($W_h \propto f$) and the total core loss is dominated by W_e at f >100 kHz. The eddy current loss not only deteriorates the performance of magnetic materials but also generates a substantial amount of Joule heating that consequently complicates the design and engineering of the device. Magnetic cores with ultra-low loss and high permeability are highly-desirable for the miniaturisation of high-frequency drive applications.

Recently, we have demonstrated a rapid quenching approach to synthesise ultra-thin amorphous ribbons to show the cost-effective advantages of in-situ thinning of ribbons over existing commercial soft magnetic amorphous alloys [1]. In this work, we present the high-frequency material loss advantages of ultra-thin ribbons compared to existing state-of-the-art soft magnetic materials. The material loss performance and permeability of various Co-, Fe- and CoFe-based amorphous ribbons of different thickness (8-30µm) were investigated over 50 kHz-1 MHz frequency range at various excitation fields using a custom designed solenoid setup. The power loss density of the ultra-thin as-quenched ribbons was significantly lower than the best-known commercial amorphous materials. The ultra-low loss density of amorphous ribbons could be attributed to the ultra-low coercivity ($H_c \leq 10$ A/m) and significantly reduced eddy current losses at high frequencies. Besides, the ultra-high permeability of thin ribbons, as compared to best-in-class amorphous metal cores, makes them a superior material for device miniaturisation in high-frequency drive applications.

References:

[1] A. Masood, *et al.*, J. Mag. Mag. Mater, **483,** p.54-58 (2019).

Sheet thickness dependence of dynamic magnetization properties based on magnetic domains and walls within the diffusion-like equation for GO SiFe electrical steels

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The dynamic hysteresis of soft magnetic materials corresponds to excess iron losses, due to dynamic magnetization reversal processes within magnetic domains and especially to microscopic eddy currents around the magnetic walls in motion and inside rotating domains [1]. Whatever the magnetization mechanism (domain walls displacement, bowing, fusion, nucleation and multiplication), it is proposed to define a dynamic property Λ [2] involved in the magnetic field damping due to microcopic eddy currents (1):

$$\boldsymbol{H} = \mu^{-1}\boldsymbol{B} + \sigma\Lambda^2\partial_t\boldsymbol{B} \qquad (1)$$

Magnetization properties should be intrinsic to the materials, with its electrical resistivity $\rho = 48\ \mu\Omega.cm$, the saturation polarisation $Js = 2.1\ T$, the walls mobility influenced by the magnetic walls density and area, the grain boundaries and the defects. Changes usually occur due to experimental conditions (field magnitude frequency). Meanwhile, the geometry dependent behaviour is described by the field $\boldsymbol{H_M} = \mu^{-1}\boldsymbol{B}$ diffusion-like equation (2).

$$\boldsymbol{\nabla} \times \boldsymbol{\nabla} \times \left((1 + \sigma\Lambda^2\mu\partial_t)\boldsymbol{H_M}\right) + \sigma\mu\partial_t\boldsymbol{H_M} = \boldsymbol{0} \qquad (2)$$

In this paper, we analyze the thickness ζ dependence [3] of the dynamic magnetization property $\Lambda(\zeta)$. To this extend, we suggest carrying out and interpret magnetic measurements on GO SiFe samples with the Epstein frame for four different thicknesses (ζ = *0.23, 0.27, 0.30 and 0.35 mm*). Results will be discussed taking the magnetic texture and the manufacturing and coating residual stress into account.

References:

[1] R.H. Pry, C.P. Bean, *J. Appl. Phys.*, vol. 29 (1958), 532-533.
[2] O. Maloberti *et al.*, *JMMM*, vol. 304 (2006), pp. e507-e509.
[3] M-A. Raulet *et al.*, *IEEE Trans. on Mag.*, vol. 42, n°2 (2004), pp. 872–875.

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Magnetic Ageing in TiO_2-doped Mn-Zn Ferrites

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Application in sensing and power electronics calls for low magnetic loss materials, like Mn-Zn ferrites, whose soft magnetic properties can be suitably tailored by doping, exploiting the phenomenon of anisotropy compensation. Also thermal considerations are important for power electronic design, mainly in automotive applications, to ensure that the magnetic core will function safely at its maximum working temperature. In this work the effect of Ti-doping is investigated in connection with thermal ageing (exposure at 200°C/ 100 hours in air) in Co-doped Mn-Zn ferrite ring samples, prepared by conventional ceramic processing. The complex permeability and energy loss behaviors have been measured, in particular, in the broad DC-1 GHz frequency range for two TiO_2 doping levels: 1000 ppm and 5000 ppm and standard Co content. The measurements were carried out, for peak polarization values ranging between 2 mT and 200 mT at T = 23 °C and 100 °C. Fig. 1 shows the deterioration of the initial permeability due to ageing in the conventionally 1000 ppm TiO_2-doped ferrite. The detrimental role of ageing is restrained by addition of TiO_2 up to 5000 ppm, an advantage preserved at 100 °C.

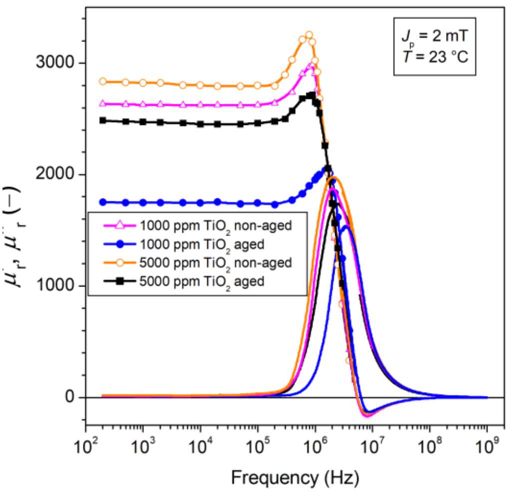

Fig. 1. Real μ' and imaginary μ'' components of the initial permeability, measured up to f = 1 GHz, before and after 100-hour ageing treatment at 200 °C . Increased TiO_2 contents mitigates the effect of magnetic ageing.

The limitation of the ageing effect, which is enhanced by the dissolution of Ti^{+4} cations, is explained on the basis of the theoretical analysis of losses and permeability and their frequency dependence. The shielding mechanism of TiO_2-doping against ageing is chiefly related to the role of the magnetocrystalline anisotropy, with ensuing effects on the magnetization process and the proportions of it shared by rotations and domain wall displacements.

Magneto-optical testing for domain observation of SiFe alloys

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For 15 years, the industry-oriented R&D institute INNOVENT, based in Jena, has been working in the field of magneto-optical (MO) sensors and systems. MO sensors use the Faraday effect for the direct visualization of magnetic stray fields on the sample surface. Magnetic domains of electrical steel sheets (SiFe alloys) have been investigated by MO imaging. Sensitive MO sensors are used for structural inspections with lateral resolutions up to 25 µm. The aim of this new developed method is observing the domain structure behavior of polycrystalline SiFe and to figure out their influence on the specific loss characteristics of this widely used soft magnetic material. Different properties of the silicon-iron alloys like grain size and orientation, inclusions, pinning effects, edge behavior of the domains, domain sizes, rolling direction and saturation effects can be analyzed from the MO images directly. It is possible to visualize certain material properties arising through the manufacturing process. For example, laser cutting creates different zones of influence depending on the parameters of the cutting process. In addition, this new MO method allows the local observation of domain refinement by laser treatment and its real effect on smaller domains in terms of reducing losses. High camera frame rate and power light source of the testing equipment now enable dynamic investigations of electrical steel sheets. Thus, important tests can be performed to understand losses in grain-oriented SiFe during magnetization reversal due to limitations of domain wall motion. In order to achieve dynamic observation with the AC field frequency of 50 Hz, the high speed imaging system enables 1,000 MO images per second at an image size of 18 x 13 mm^2. This provides the technical basis for using this non-destructive material testing method for quality control of SiFe sheets due to the fast and direct domain analysis. Sample preparation is not required. Therefore, the thin steel sheets simply have to be brought into contact to the MO sensor area.

References:

[1] Richert H., Schäfer R., Schmidt H., Lindner S., Lindner M., Wenzel B., Holzhey R.: “Dynamic Magneto-Optical Imaging Of Domains In Grain Oriented Electrical Steel”, Steel research international (2015), Wiley-VCH.

[2] Wenzel B., Lindner M.: „Magneto-Optical Domain Observation On Electrical Steels“, 8th International Electric Drives Production Conference (2018), Schweinfurt (Germany).

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Magnetocaloric effect in rare earth Ho_2O_3 nanoparticles at cryogenic temperature

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The magnetocaloric effect (MCE) refers to conversion of magnetic energy of a magnetic materials into the thermal energy under an application or removal of an external magnetic field [1-3]. A large value of MCE and broader working temperature range are considered to be the most important requirement for applications, therefore, it is desirable to find the new materials with large MCE at low magnetic fields and small magnetic hysteresis. In the development of new magnetic refrigerant materials, magnetic nanoparticles have been found very promissing. The working temperature, refrigeration capacity can be induced by nanoparticles size and shape [4, 5]. In the present study, we have fabricated Ho_2O_3 nanoparticles by oxidation of HoN prepared by plasma arc discharge. The Ho_2O_3 annealed at 1200°C followed by structural and MCE analysis. The XRD pattern confirms the amorphous nature of naturally oxidized HoN,which converted into crystalline after annealing. It has been discovered that Ho_2O_3 exhibits MCE at low temperature without magnetic hysteresis loss with the second-order antiferromagnetic phase transition with Néels temperature around 2 K. The maximum entropy change was found to be 15.1 J/kgK and 22.4 J/kgK at an applied magnetic field of 5 T for amorphous and crystalline Ho_2O_3 .

References:

[1] K. A. Gschneidner Jr., V. K. Pecharsky and A. O. Tsokol, Rep. Prog. Phys., 68, 1479 (2005).
[2] M. H. Phan and S. C. Yu, J. Magn. Magn. Mater., 308, 325 (2007).
[3] E. Warburg, Ann. Phys., 13, 141 (1881).
[4] P. Poddar, J. Gass, D. J. Rebar, S. Srinath, H. Srikanth, S. A. Morrison, and E. E. Carpenter, J. Magn. Magn. Mater. 307, 227 (2006).
[5] V. Franco and A. Conde, Scr. Mater. 67, 594 (2012).

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Softening of spin waves in Co-Py magnonic crystals

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In thin-film bicomponent magnonic crystals (MCs) an in-plane magnetization causes the demagnetizing field to occur around interfaces between constituent materials. The field has a great impact on the spin-wave spectrum at low external magnetic fields [1]. Here, by means of the plane wave method, we study cobalt-permalloy MCs based on a two-dimensional hexagonal lattice squeezed in the direction of the external filed. We found that at the low external field the lowest-frequency spin waves are excited in Co much more likely than in Py regardless the matrix or rods are made from Co (Fig. 1). This is a consequence of the mode-dependent softening of spin waves resulting from the growing influence of the demagnetizing field. We show this effect can be tuned by the squeezing of the MC.

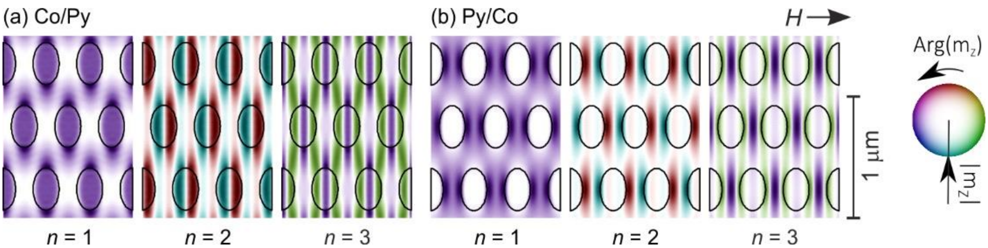

Fig. 1. Spin wave profiles of three lowest-frequency modes for the squeezed MC consists of (a) Co rods in Py matrix and (b) Py rods in Co matrix at the external field 50 mT. Ellipses mark rods borders. Colors represent argument (phase) and their intensity the modulus of the dynamic magnetization, as shown in the inset.

References:

[1] S. Mamica, M. Krawczyk, D. Grundler, Phys. Rev. Applied 11, 054011 (2019).

This study was partially supported by the EU's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie GA No. 644348 (MagIC) and from the Polish Ministry of Science and Higher Education resources for science in 2017-2019 granted for the realization of an international co-financed project (W28/H2020/2017).

Magnetic and magnetoelastic parameters affecting the magnetoelectric response in L-T mode working metallic glass/PVDF laminated composites

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Recent efforts in ME laminated composites have been focused mainly in improving the bonding between magnetostrictive and piezoelectric phases in order to implement them in a wide variety of high efficiency applications [1-3]. In order to develop new high performance ME laminates, it is essential to study the influence in the ME response of parameters such as the piezomagnetic coefficient or quality factor of the whole laminated composites [4].

In this work, we present a deep study of magnetic and magnetoelastic parameters affecting the magnetoelectric response of laminated composites working on longitudinal-transverse (L-T) mode. The piezomagnetic coefficient of the magnetostrictive ribbons and the quality factor of the laminates have been analyzed in 3, 2, 1 and 0.5 cm long $Fe_{64}Co_{21}B_{15}$/polyvinylidene fluoride (PVDF)/$Fe_{64}Co_{21}B_{15}$ magnetoelectric composites. The experimental results show that the product of piezomagnetic coefficient and the quality factor drives the magnetoelectric response in magnetoelectric laminates, as the theoretical equations predict, with a linear regression coefficient up to R=0,976 Furthermore, the magnetoelectric coupling factor has been deduced from the ratio between the experimental and the expected magnetoelectric coefficients, with maximum coupling values up to 0.89 obtained for the longest laminate.

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References:

[1] A. Lasheras, *et al.*, Sensors Actuators, A Phys., 263, 488–492 (2017)
[2] X. Zhuang, *et al.*, Appl. Phys. Lett., 111, 163902 (2017)
[3] A. Lasheras, *et al.*, Smart Mater. Struct., 24, 065024 (2015)
[4] P. Martins, *et al.*, Adv. Funct. Mater., 23, 3371–3385 (2013)

Power loss reduction of uncoated grain oriented electrical steel using annealing under stress treatment

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Power transformer magnetic core is made with thin sheets of grain oriented (GO) electrical steel and, for that reason, new procedures that could reduce its power loss are desired. It has been shown that the heat treatment under tensile stress could align solute atom pairs at stress direction [1], creating an elastic deformation on crystal lattice [2]. As a consequence, an extrinsic magnetic anisotropy is introduced, changing the magnetic domain structure [1–3] and reducing the power loss [2]. In this article, the effect of annealing under stress on hysteresis loops and other magnetic properties of uncoated GO electrical steel under 4 peak magnetic inductions (0.7, 1.0, 1.3, and 1.5 T) at 60 Hz is shown. Overall, two annealing temperatures (300°C and 400°C) were investigated, while the mechanical stress and annealing time were held constant at 35 MPa and 600 s, respectively. For the samples treated at 300°C, the hysteresis loops remain unchanged and the power loss stays barely constant. Instead, at 400°C, the stress annealing reduces the power loss by 18%, 16%, 10% and 4% at 0.7, 1.0, 1.3, and 1.5 T, respectively. These results are coherent with the directional order theory [1]. Under high temperature (400°C), the silicon atoms could diffuse across the crystal lattice and create Si-Si pairs that will introduce a magnetic anisotropy [1,2]. However, at 300°C, the atomic mobility is low and the silicon atoms do not diffuse. In summary, the stress annealing could be an important procedure to reduce the power loss of GO electrical steel, improving the transformer performance. Moreover, the annealing under stress parameters effects are not fully understood and future work is needed to reduce, even more, the power loss.

References:

[1]H.J. Birkenbeil, R.W. Cahn, Proc. Phys. Soc. 831–847 (1962).
[2]V.A. Lukshina, I.E. Startseva, ISSN 0031-8949, 386 (1989).
[3]N.J. Jones, M. Wun-Fogle, A.E. Clark, ISSN 0021-8979. 09A915 (2010).

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The influence of residual stress on flux-barriers of non-oriented electrical steel

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In rotating electrical machines, cutouts from the rotor laminations can guide the magnetic flux in the d- and q-axis. Such cutouts can lead to very narrow bridges of the electrical steel. This can limit the maximum speed of a rotor due to the maximum allowed mechanical stress. Therefore, the centrifugal forces can limit the achievable power density [1]. The aim of this study is the examination of the effect of flux-barriers fabricated by mechanical embossing on the magnetic properties. The imprinting process causes a static residual stress distribution and thereby a reduction of the permeability resulting from the Villari effect. In some preliminary experiments the desired interdependency has been shown [2]. The non-oriented electrical steel samples, punched with varying distances between the barriers and are measured at different angles to the barrier edges on a single-sheet tester. A comparison with respect to their directional and embossing geometry-dependent effectiveness as magnetic flux barriers is done. A correlation of the results with measurements of the local density, obtained by neutron-grating interferometry, is performed in order to enable a consideration of the mechanical embossing on the local magnetic flux density distribution.

References:

[1] Groschup, Benedikt, Franco Leonardi, IEEE International Electric Machines and Drives Conference (IEMDC), 1-6, (2017).

[1] Vogt, Simon, Neuwirth, Tobias, Schauerte, Benedikt, Weiss, Hannes Alois, Falger, Peter Markus, Gustschin, Alex, Schulz, Michael, Hameyer, Kay, Volk, Wolfram, Production Engineering 13(2), 211-217, (2019).

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On the Correlation of Texture and Magnetic Properties of FeSi Electrical Steels

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Electrical steels are one of the most important soft magnetic materials for the application in the core of electrical motors and transformers. FeSi electrical steels magnetic performance is dictated by an appropriate combination of chemical composition, final thickness, grain size, texture. Grain sizes are usually in the range of 0.1 and 10 mm for the non-oriented (NOES) and grain oriented electrical steels (GOES), respectively [1]. Further, the desired final texture is also dependent on the material: for NOES the θ-fibre is preferred whilst for the GOES this is the Goss texture component. Texture is a key factor that affects the magnetic performance of electrical steels. In order to correlate texture quality with magnetic properties, such as magnetic polarization and iron losses, the texture can be quantified by using angle parameter expressions, such as the A-, α-, γ-, β- or θ-parameters [2]. Additionally, with the help of a loss separation procedure, defined by Bertotti et al. [3], it is possible to correlate texture to the hysteretic and excess losses. In this work, several FeSi steels were characterized in terms of texture and magnetic properties, using conventional diffraction techniques, such as X-ray and EBSD, and texture parameters were determined. After separating the losses into the various loss components, it was found that the core losses do not show a strong variation with texture as Nozawa et al. [4] reported. Nevertheless, an excellent correlation could be observed between permeability and texture angle parameters, which could be confirmed from the data available in literature.

References:

[1] P. Rodriguez-Calvillo, *et al.*, AIP Advances 8, 047605 (2018).
[2] N. Bernier, *et al.*, Micron, 54-55 (2013).
[3] G. Bertotti, M. Pasquale, IEEE Transactions on Magnetics, 2787-2789 (1992).
[4] T. Nozawa, *et al.*, IEEE Transactions on Magnetics, 252-257 (1978).

Relaxation and Equilibrium Properties of Assembly of Interacting Superparamagnetic Nanoparticles

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Assemblies of superparamagnetic nanoparticles are very promising for various biomedical applications. In this report stochastic Landau-Lifshitz equation [1,2] has been used to study the relaxation and equilibrium properties of assembly of random clusters of interacting superparamagnetic nanoparticles as a function of particle diameter and cluster packing density $\eta = N_p V/V_{cl}$, where N_p is the average number of the particles in the cluster, V is the nanoparticle volume, and V_{cl} is the cluster volume. Considerable deviation of the equilibrium assembly magnetization as a function of applied magnetic field from the Langevin function is obtained by increasing the cluster packing density within the range $0 < \eta < 0.35$. The statistics of the demagnetizing field created by the neighboring particles in the center of Lorentz sphere is found to be Gaussian. Based on this result, self consistent mean field approximation for an assembly of interacting superparamagnetic nanoparticles has been developed. The mean field approximation for the equilibrium assembly magnetization and magnetic susceptibility is shown to deviate not more than 15% from the accurate numerical results obtained by means of stochastic Landau-Lifshitz equation. It is also found that at least two different relaxation times are necessary to characterize the relaxation process in assembly of interacting superparamagnetic nanoparticles.

References:

[1] N.A. Usov, O.N. Serebryakova, V.P. Tarasov, Nanoscale Res. Lett. 12, 489 (2017)
[2] N.A. Usov, *et al.*, Beilstein J. Nanotechnol. 10, 305 (2019).

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Pinning Field Model Using Play Hysterons for Stress-Dependent Domain-Structure Model

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The assembled domain structure model (ADSM) [1] is an energy-based multiscale model, which can predict stress-dependent magnetization property of silicon steel. The ADSM simulates the domain-wall motion to yield the hysteresis loss due to the pinning field of which the distribution is given by a Gaussian function [1] or an assembly of stop hysterons [2]. This study develops a direct identification method of pinning field distribution using the scalar and vector play models [3].

A 2D or 3D vector play model is constructed by the superposition of scalar play models. Its shape function f are determined from unidirectionally measured *BH* loops. After removing the anhysteretic property, the shape function f is used in the scalar play model to represent the pinning field accompanied with the domain-wall motion in the ADSM.

From *BH* loops of a non-oriented silicon steel under stress-free condition, the scalar (1D) and vector (2D, 3D) play models are identified. The computed hysteresis loss with and without compressive stress is shown in Fig. 1. The simulated *BH* loops are plotted in Fig. 2. The properties under the compressive stress of 40MPa are roughly predicted without any parameter fitting to the measured data under the stress.

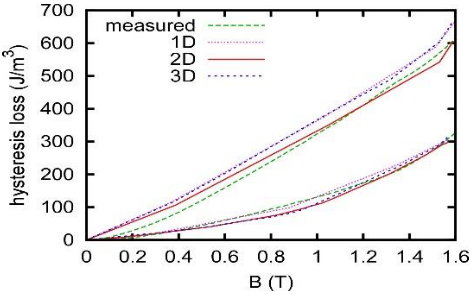

Fig. 1 Hysteresis losses per cycle.

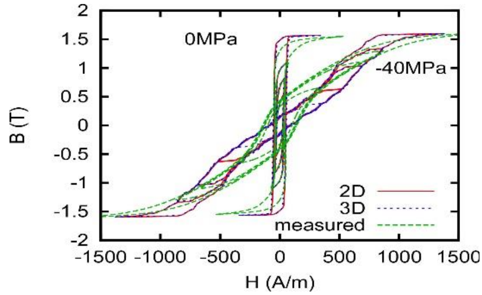

Fig. 2 Simulated *BH* loops.

References:

[1] S. Ito, *et al.*, AIP Advances, 8, 047501 (2018).
[2] T. Matsuo, *et al.*, COMPUMAG Paris, PA-M2 (to be presented).
[3] T. Matsuo, M. Shimasaki, IEEE Trans. Magn., 44, pp. 898-901 (2008).

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Impact of grain size distribution on the magnetic deterioration due to cutting of electrical steel sheets

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Efforts to increase the power density and continuous power of electric machines have intensified the wish for tailored non-oriented (NO) electrical steel grades. Possible measures are the use of thinner steel grades as well as grades with tailor-made microstructural properties [1,2]. However, these grades are developed mainly focusing on the magnetic and mechanical properties, thereby neglecting the detrimental and strongly material-dependent processing effect on the magnetic properties of NO, e.g., the cutting influence [3,4].
In this paper, the microstructure-dependence of the magnetic-material deterioration due to guillotine cutting is studied on twelve industrial NO grades with thicknesses between 0.1 and 0.5 mm. This allows to consider the interdependence of material thickness, microstructure, alloy content and residual stress effects. The magnetic deterioration is characterized on a single-sheet-tester with samples in rolling as well as transverse dirrection, according to [3]. For the first time the grain size distribution and homogeneity is evaluated and linked to magnetic-loss and magnetization-curve deterioration by means of statistical methods. As a result sheet-thickness-dependent microstructures are evaluated with respect to their cutting influence. This allows the motor designer to add further selection criteria to the material selection process.

References:

[1] A. Krings, A. Boglietti, A. Cavagnino, S. Sprague, IEEE Trans. Ind. Appl., 64(3), 2405-2414 (2017).
[2] M. F. de Campos, J. C. Teixeira, F. J. G. Landgraf, JMMM, 301(1), 94-99, (2006).
[3] A. Schoppa, J. Schneider, J.-O. Roth, JMMM, 215-216,100-102, (2000).
[4] H. A. Weiss, N. Leuning, S. Steentjes, K. Hameyer, T. Andorfer, S. Jenner, W. Volk, JMMM, 421, 250-259, (2017).

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Experimental and theoretical studies of Ti_2MnX (X=Al, Ga)

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We synthesized and investigated Ti_2MnX (X=Al, Ga) samples because these compounds were predicted by previous theoretical studies to exhibit very interesting electronic structure [1,2] and in particular a Spin-Gapless Semiconductor (SGS) state [3]. Ti_2MnGa was not studied experimentally before and for Ti_2MnAl only a very limited set of experimental studies was published [4,5]. Here we present crystal structure (obtained by XRD technique), microstructure (obtained from SEM, TOF-SIMS and XPS techniques), magnetic, thermodynamical and transport properties as well as detailed ab-initio calculations. Using these results we judge whether these compounds really exhibit SGS properties and why this may not be the case. Our Constrained Density Functional Theory calculations show, that lower energy of the unit cell is observed for a non-magnetic structure of Ti_2MnGa, and a non-magnetic ground state is in contradiction with SGS state. The nonmagnetic ground state for Ti_2MnGa is also confirmed by our experimental results.

References:

[1] Q.L. Fang, *et al.*, J. Magn. Magn. Mat. 349 104 (2014)
[2] J. Noky, *et al.* Phys. Rev. 97, 220405 (2018)
[3] H. Y. Jia, *et al.*, AIP Advances 4, 047113 (2014)
[4] W. Feng, *et al.*, Phys. Status Solidi RRL 9, No. 11, 641 (2015)
[5] J. Han, *et al.*, Phys. Lett. 113, 102402.(2018)

Static and dynamic energy losses along different directions in GO steel sheets

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Grain-oriented (GO) Fe-Si sheets are often preferred to non-oriented steels in high-power rotating machines, where the material response along directions different from the rolling one (RD) matters, both in terms of magnetization curve and energy losses. The experiments show, however, that the material properties depend in a complex fashion on the angle θ made by the applied field with respect to RD in the lamination plane. This effect can be quantitatively interpreted in terms of evolution of the domain wall processes, passing from the regular displacements of 180° domain walls for RD-directed field to the unfolding and combination of 90° and 180° domain wall displacements upon increasing θ. It has been shown that the pre-emptive knowledge of the material behavior along RD (θ = 0°) and TD (θ = 90°), allows one to predict, under quasi-static excitation, the normal magnetization curve, the hysteresis loop shape, and the energy loss dependence on θ in high-permeability GO sheets [1]. Such a prediction accounts, in particular, for the role of the sample geometry, making the measured quantity independent of sample shape only for θ = 0° and θ = 90°. The evolution of the quasi-static magnetic properties with θ has an obvious counterpart in the dynamic behavior. In this work we have therefore investigated, both from the experimental and theoretical viewpoint, the behavior of the magnetic energy loss W versus frequency (1 Hz ≤ f ≤ 1 kHz) and peak polarization (0.15 T ≤ J_p ≤ 1.7 T) in high-permeability 0.29 mm thick GO sheet and strip samples, cut at 15° steps between RD and TD. We show that the predicting method developed in [1] for the quasi-static energy loss can be made general through loss decomposition and applied, in particular, to the determination of the excess loss component. This permits one to achieve a general description of the magnetic loss versus frequency as a function of the sheet cutting angle, eventually allowing for the role of the skin effect and its dependence on θ at high frequencies.

References:

[1] Fiorillo *et al.*, *IEEE Trans. Magn.* 38, 1467-1476 (2002).

Universal FMR procedure to probe magnetic characteristics of ferromagnetic samples

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One of the main goals of performing ferromagnetic resonance (FMR) experiments is to find how the energy stored in a sample under investigation depends on magnetic field direction with respect to a sample crystalographical axes. This information is usually obtained by examining the experimental dependence of the resonance field value on the static field direction in space. The traditional analysis of experimental data is carried out using the well-known Kittel or Smit-Beljers equations describing the precessional motion of the sample magnetization. This work reports on a new interpretation of FMR measurements performed for finite samples of different geometries by having recourse into the geometrical interpretation of the Smit-Beljers equation: *the resonance frequency of the precessional motion of the magnetic moment is equal to the Gaussian curvature of the spatial distribution of the magnetic free energy*. The application of this interpretation makes it possible obtaining all the values of relevant physical quantities with high accuracy (the saturation magnetization *M*, *g*-factor, demagnetizing tensor $N_{\alpha\beta}$ and magnetocrystalline anisotropy constants K_{α}) and consequently the spatial distribution of the free energy from a single FMR experimental data set. We have tested this approach using the cross-validation procedure [1] for bulk magnetite, (Ga,Mn)As thin film and for YIG ultrathin film. Note, however, that it is necessary while doing the cross-validation, to use a proper form of the free energy dependence on all above mentioned magnetic parameters characterizing the sample of each ferromagnet under investigation. Therefore, the criterion of the correctness of the free energy formulas given in [1] was also applied in this work. Let us emphasize that none of the known methods of analysis of FMR experiments does not give such universal opportunities.

References:

[1] P. Tomczak and H. Puszkarski, Phys. Rev. B 98, 144415 (2018).

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Enhanced Magnetic Properties of Fe-Based Nanocrystalline Soft Magnetic Composites with Nano-Sized ZnO-B_2O_3-SiO_2 Glass-Silicone Resin Coating

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Magnetic flux density and high-frequency properties of soft magnetic composites (SMCs) are not only associated with the magnetic properties of magnetic particles, but also significantly influenced by the characteristics, contents and uniform distribution of insulating materials between magnetic particles [1–3]. Therefore, suitable insulating medium and its uniform coating on magnetic particles are the keys to improve the performances of SMCs. Herein, silicone resin (SR) and nano-sized ZnO-B_2O_3-SiO_2 (ZBS) glasses fabricated by a sol-gel method have been chosen as insulating materials to coat FeSiBNbCu nanocrystalline alloy powders to prepare SMCs using a transient liquid phase spark plasma sintering [4,5]. The results indicated that appropriate amount of nano-sized ZBS and SR coating are conducive to forming a compact and uniform microstructure and increasing electrical resistance for the SMCs, which remarkably enhanced soft magnetic properties, for example, magnetic flux density of ∼1.36 T, effectively permeability of ~221 (at 10 kHz), coercivity of ~1.0 A/m and core loss of ~432.3 kW/m^3 at 50 mT and 100 kHz were obtained for the SMCs with 0.5 wt. % ZBS and 1 wt. % SR. The correlating of phase evolution, microstructure and magnetic properties of the SMCs with the variation of insulating coating and sintering temperature has been investigated in detail.

References:

[1] J. M. Silveyra, *et al.*, Science 362, eaao0195 (2018).
[2] H. Shokrollahi, *et al.*, J. Mater. Process. Technol. 189, 1–12 (2007).
[3] E. A. Périgo, *et al.*, Appl. Phys. Rev. 5, 031301 (2018).
[4] R. Murugasami, *et al.*, Scripta Mater. 143, 35–39 (2016).
[5] T. Zhou, *et al.*, J. Alloys Compd. 731, 1138–1145 (2019).

Acknowledgments

This study was partially supported by "the Fundamental Research Funds for Central Universities" and the key technology and development program of PanXi Experimental Area (Grant 2016SFGW001).

Comparison of Room-Temperature Ferromagnetism in ZnO Single Crystals and Sputtered Films implanted by Xe^+ ions

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ZnO single crystals and 600 nm-thick sputtered ZnO films deposited on Si substrates were implanted by Xe^+ ions in the energy range of 100-500 keV with fluences between $5x10^{11}$ and 10^{16} ion/cm^2. The magnetic properties were measured by SQUID in the temperature and field range of 5-300 K and 0-5 T, respectively. We have shown that the measured room-temperature ferromagnetism (RTFM) of pure and implanted samples is burdened by artifacts originating from the measuring technique. We only obtain reliable results that can be compared with each other if the raw data points of the disordered sample are subtracted from those of the untreated sample under identical experimental circumstances (e.g. using the same sample-holder straw for both measurements).

The magnitude of the saturation magnetization induced by implantation is about three orders of magnitude smaller in ZnO single crystals compared to ZnO sputtered films if the magnetization is related to whole sample volume, as it is frequently observed in the literature. However, if it is related to the volume affected by ion implantation determined by the sample surface and the penetration depth of the ions calculated via TRIM (Transport of Ions in Matter) simulations, similar saturation-magnetization values are obtained for both types of ZnO. It suggests that the ferromagnetism induced by ion implantation originates from the deformed regions of the material created by the ions, irrespective of whether the host material is single crystal or polycrystal. These regions are intensively investigated by TEM, SEM and Raman spectroscopy.

The dependence of RTFM on the fluence and ion energy is also studied. The saturation magnetization seems to show a maximum around 10^{12} ion/cm^2 fluence- and 100 keV ion-energy values.

Synergetic effect of silicon content and grain size on the losses of non-oriented electrical steels

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The large demand for electric cars nowadays make the study of losses in steels very relevant. Even small improvements of electrical motors can save significant amount of energy. This motivates new investigations on commercially available materials. Electrical motors used in electric cars can work at very different frequencies, because the speed is usually controlled by the frequency. Thus, the gearbox of electric cars usually have only one gear [1]. However, this implies that the material should be suitable for working in a wide range of frequencies. For example, the maximum rpm of Tesla Model S is 18000 rpm (9.73:1 gear ratio). This indicates that the electrical steel has maximum working frequency of 300 Hz. Thus, new commercial materials need to be developed. In other words, the steel suitable for 60 Hz may not be the most adequate material for 300 Hz.

In the present study, 21 different samples of non-oriented silicon steel were evaluated. Three alloys with different resistivities were considered, with 2.0 %Si; 2.4 %Si and 3.3% Si. Seven different grain sizes were obtained by menas of grain growth. As the different grain sizes by grain growth, all samples have the same thickness of 0.65 mm. Losses were evaluated in several different frequencies: 0.005 Hz e 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 e 20, 30, 40, 50, 60, 100, 150 e 200 Hz. This also allowed the test of different methods for loss separation. It is found a synergy between the effects of grain size and silicon content: When the silicon content decreases, the resistivity increases and the ideal grain size for minimum losses also increases.

Reference:

[1] Benji Jerew. Do Electric Cars Have Gears? No. Here's Why. February 11, 2015. Available at:
https://www.greenoptimistic.com/electric-cars-gears/#.XNq3F45KiUk

This study was partially supported by FAPERJ and CNPq.

Modeling the Complex Behavior of a Fe-Ga Energy Harvester Fitted with Magnetic Closure Using Magneto-Mechanical Finite Element Model

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Energy harvesters based on giant magnetostrictive materials (Terfenol-D and galfenol etc.) allow conversion of ambient vibrational energy otherwise wasted into electrical energy to power up small-scale electronic devices. The amount of harvested power is influenced by the operating conditions and design characteristics, which involves the geometry of the harvester, the magnetic and mechanical bias and in some cases the magnetic closure circuit. The device performances have some constraints, like the amplitude and frequency of the available mechanical vibrations, whereas the other quantities can be used to optimize the performance [1] and [2].

Various researches have been carried out to study the effect of several design parameters, but there is a lack of knowledge related to the influence of the device design (geometry and the magnetic closure circuit) yielding maximum power density. Moreover, there is no unique model that addresses the overall behavior of the energy harvesters to determine the optimal device design. The proposed paper utilizes thermodynamic magneto-mechanical constitutive laws implemented in a 3-D finite element model using COMSOL Multiphysics software. Experimental results obtained from the prototype energy harvester concept device developed in [2] will be utilized to validate the modeling approach. The aim of this paper is to validate the proposed model in an energy harvester geometry that includes a magnetic flux closure constructed with soft magnetic material and analyze the influence of the design parameters on the device performances. A parametric study will also be presented on the device output as a function of the main geometric quantities.

References:

[1] Apicella, V., Clemente, C.S., Davino, D., Leone, D. and Visone, C., 2018, April. Magneto-mechanical Optimization and Analysis of a Magnetostrictive Cantilever Beam for Energy Harvesting. IEEE Transactions on Magnetics 53, no. 11 (2017): 1-4.

[2] Palumbo, S., Rasilo, P. and Zucca, M., 2019. Experimental investigation on a Fe-Ga close yoke vibrational harvester by matching magnetic and mechanical biases. Journal of Magnetism and Magnetic Materials, 469, pp.354-363.

Dynamic properties of the Barkhausen noise signal in soft ferromagnetic materials

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Barkhausen noise (BN) is a micro-scale magnetic signal, which originates from the abrupt irreversible motion of the magnetic domain walls. Intensity and peak position of the BN signal in soft electrical steels correlate with the corresponding hysteresis parameters: coercive field and losses [1]. This report sheds light on a scantily investigated problem of dynamic BN behaviour, which is more complex than that of the hysteresis loops. Recently we have found that total rms intensity of BN in soft magnetic materials (ribbon and electrical non/grain-oriented steels) rises as a square root of the magnetizing frequency, i.e. $\langle U_{rms} \rangle \propto \sqrt{f_{mag}}$ [2]. Dominating square root dependence was explained by stochastic overlapping of independent noise pulses with a partial compensation in the total intensity. Second important finding that rms profile (envelope) of BN is determined by the field rate of change, i.e. $U_{rms}(H) \propto dH/dt$, suggests an idea to reduce the BN envelope by $\sqrt{dH/dt}$. Such normalization fully compensates the envelope differences at low f_{mag} giving a stable quasi-static peak near coercive field H_c, which demonstrate a strong resemblance to the corresponding differential permeability curves (see Fig. 1) [3].

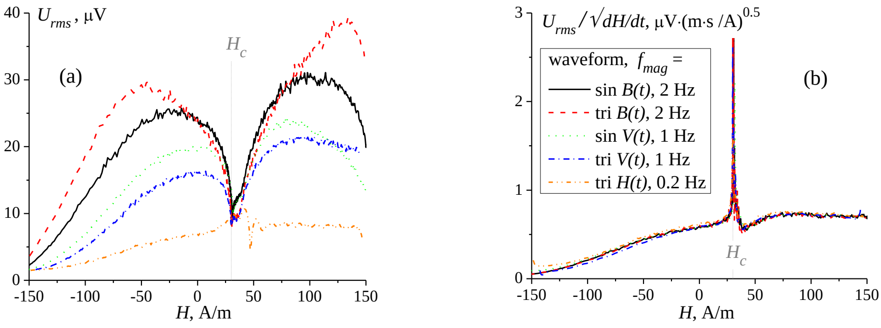

Fig. 1. (a) BN envelopes for a non-oriented steel measured at different magnetizing waveforms and frequencies specified in the graph label. (b) The corresponding BN envelopes normalized as $U_{rms}(H)/\sqrt{dH/dt}$ [3].

References:

[1] O. Stupakov, J. Nondestruct. Eval. 32, 405-12 (2013).
[2] A. Stupakov, A. Perevertov, J. Magn. Magn. Mater. 456, 390-9 (2018).
[3] A. Stupakov, J. Magn. Magn. Mater. 482, 135-47 (2019).

Sensitivity Enhancement in Geometrically Modified Magnetoelastic Resonance Based Sensors

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Magnetoelastic resonance based sensors for biological or chemical detection purposes provide an attractive alternative to conventional up to date used techniques. The detection on these materials is wireless and fast as it is based on the decrease of the magnetoelastic resonance frequency caused by the increase of the mass on the resonant system [1]. Many investigations have focused on the increase of this shift, and most of them are based on an increase of the sensitivity by a reduction of the magnetoelastic ribbon size [2]. Nevertheless and despite the interesting obtained results, it is necessary to work on high frequency values and with low intensity of the signal which requires a better detector. So, other alternatives to the reduction of the resonant platform size must be considered.

In this work, a commercial $Fe_{40}Ni_{38}Mo_4B_{18}$ metallic glass (Metglas 2826MB) has been used to study the effect of different geometries of the sensor and the percentage of the resonator surface functionalized on the sensitivity and other magnetic/magnetoelastic properties. Thus, by changing the geometry (triangular or arc shaped) of the resonator without change the size, results show an increase of more than a 1000% on its sensitivity which respect to one of the traditional rectangular shape. This is accompanied by low changes in the measured magnetoelastic properties of the different shaped magnetoelastic sensors.

References:

[1] C.A. Grimes, *et al.*, Sensors, 11(3), 2809-2844, (2011).
[2] A. Sagasti, *et al.*, IEEE Transactions on Magnetics, 53(4), 1-4, (2017)

Tailoring the magnetization linearity of Finemet type nanocrystalline cores by stress induced anisotropies

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Flat magnetization loops get more and more importance in the power electronics. Beside the shape anisotropy controlled flatness (cut cores and powder cores), for many applications, more advantageous is the linearity produced by induced transversal anisotropies obtained either by transversal magnetic field annealing or by stress annealing. The linearity of a flat hysteresis loop can be measured by the ratio $R = H_{lin}/H_K$, where H_{lin} is the limit of linearity and H_K is an effective anisotropy field defined by the saturation induction Bs and by the steepness of the linear magnetization, μ_{eff}, as $H_K = B_s/(\mu_o.\mu_{eff})$. This linearity will be investigated for toroidal cores from stress annealed Finemet type nanocrystalline ribbons as a function of the applied stress. The limit of linearity is determined by $H_{lin} = H_K - \Delta H$, where ΔH, is the half width at half amplitude of the anisotropy field distribution ($p(H_K)$) determined by the Barandiaran method. It will be demonstrated that the ratio R is almost independent of applied stress for a given technology.

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Magnetic relaxation and thermomagnetic properties of amorphous $(Fe_xCo_1)_{76}Mo_8Cu_1B_{15}$ (x = 3, 6 or 9) alloys

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Amorphous NANOPERM-type alloys with addition of Co atoms show good soft magnetic properties at elevated temperatures and offer the oportunity to apply these materials in electrical industry for a variety of practical applications [1]. In this paper I present high temperature investigations of magnetic properties, i.e. initial magnetic susceptibility, magnetic relaxations as disaccommodation [2], magnetization and coercive field for amorphous $(Fe_xCo_1)_{76}Mo_8Cu_1B_{15}$ (x = 3, 6 or 9) alloys. Fig. 1 shows magnetic susceptibility and thermal stability of amorphous ribbons. It is seen that Curie point changes with Co content. It was also confirmed from measurements of magnetization versus temperature. From decomposition of the isochronal disaccommodation curves the intensity of the individual processes, pre-exponential factor of the Arrhenius law and activation energies of relaxation processes were determined. Moreover, the investigations of disaccommodation amplitude versus magnetizing field for the as-quenched samples was also performed.

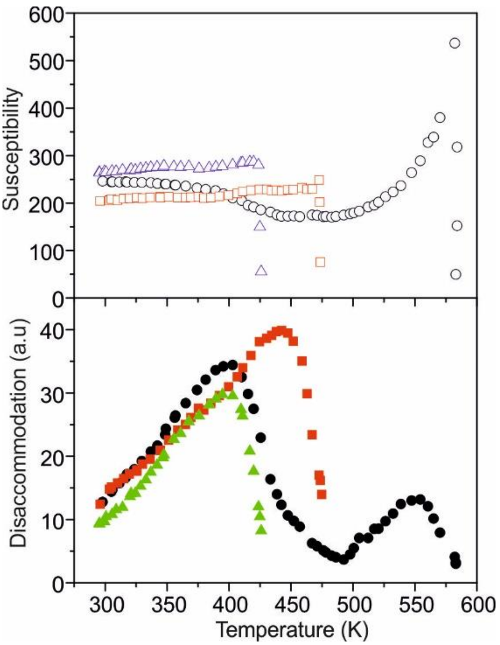

Fig. 1 Temperature dependence of initial magnetic susceptibility (top) and isochronal disaccommodation curves (bottom) for $(Fe_xCo_1)_{76}Mo_8Cu_1B_{15}$ where x = 3 (circle), 6 (square) and 9 (triangle).

References:

[1] M. Hasiak, M. Miglierini, M. Łukiewski, J. Kaleta, IEEE Trans. Magn. 50 (4), 2004104 (2014).

[2] W. Ciurzyńska, G. Haneczok, J. Zbroszczyk, J. Magn. Magn. Mater. 189, 384 (1998).

Standardization of the Method of Magnetostriction Measurement of Grain-oriented Electrical Steel Strip and Sheet

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Standardization of the method of measurement of AC magnetostriction characteristics of electrical steel strip and sheet by means of a single sheet tester equipped with an optical sensor, i.e. IEC 60404-17, has been promoted in IEC/TC68/WG2 to meet the demand of transformer industry. The relationship between the magnetostrcition characteristics of grain-oriented electrical steel and transformer noise is complicated and is as yet unsolved. One of basic problems has been the lack of a standard for the magnetostriction measurements. The measurement requires detection of slight vibration of the test specimen at a resolution of 0.01 μm/m or better. In order to ensure this resolution, not only magnetic aspects but also mechanical aspects of the test apparatus, e.g. the influence of friction and external vibrations, has to be specified. Figure 1 shows a schematic diagram of the test apparatus. The size of test specimen is 100 mm × 500 mm. In order to avoid the vibration of the test specimen, no mass is put on the test specimen and is connected to the its end except an optical target and a clamp to fix the test specimen to the test apparatus. The optical target of low mass and the clamp, which are made of non-magnetic and non-conductive materials, are installed between pole pieces of a single yoke. In order to reduce and to stabilize the influence of friction, an insertion sheet with a thin fluorine resin-impregnated glass cloth adhesive film on its upper surface is placed under the test specimen close to pole pieces. A round robin comparison using different test setups in accordance with the draft of standard is in progress and will be presented.

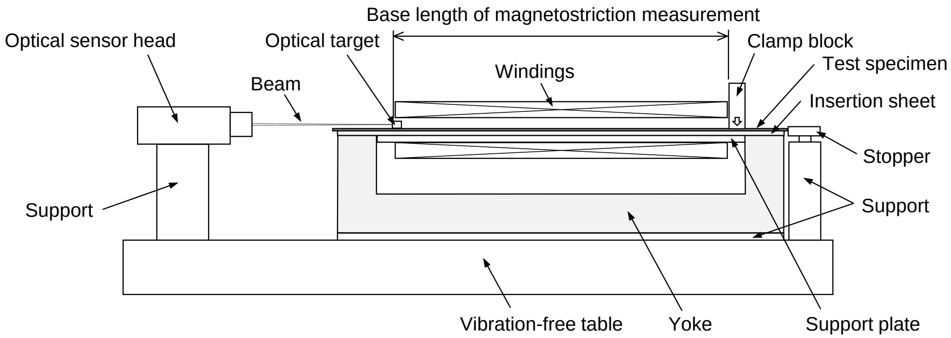

Figure 1 – Schematic diagram of test apparatus (cross-sectional).

Modelling the Characteristics of Ring-Shaped Magnetoelastic Force Sensor in Mohri Configuration

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Magnetoelastic stress and force sensors are promising solution for measurements in mechanical systems operating in hard industrial conditions. Due to its robustness and reliability magnetoelastic sensors are intensively developed for the most demanding applications [1].
Mohri configuration of ring-shaped sensor is one of the most common solution applied for magnetoelastic sensors. In such configuration, measured force is applied in the direction of diameter of ring-shaped core, as it is presented in figure 1.

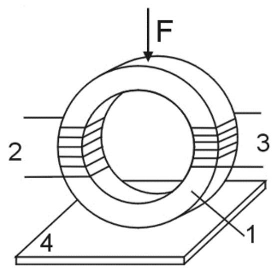

Fig. 1. Mohri configuration of ring-shaped sensor [2]: 1- magnetoelastic core, 2 – magnetizing winding, 3 – sensing winding, 4 – base plane

Due to the sophisticated mechanical stress distribution in magnetoelastic core, quantitative model of such sensor was still not presented. Considering the recent developments in the analyses of characteristics of magnetic materials with stress-induced uniaxial anisotropy [3], finite element model of magnetoelastic sensor in Mohri configuration is presented. Model in implemented in open-source ELEMER environment enabling verification of experimental characteristics and further optimisation of magnetoelastic sensors.

References:

[1] A. Bieńkowski, et al., Sensors and Actuators A113, 270 (2004).
[2] K. Mohri, E. Sudoh, IEEE Transactions on Magnetics 17, 1317, (1981),
[3] R. Szewczyk, Materials 7, 5109-511 (2014).

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High temperature ferromagnetic shape memory alloys based on Ni-Mn-Ga-(Co, Fe, Cu)

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Known Ferromagnetic Shape Memory Alloys (FSMA) have a relatively low actuation temperature that hinders their applications in many fields, as automotive or energy generation. With the aim to increase the magnetic actuation temperature of current FSMAs, we have studied the effect of Mn or Ga replacement by Cu in two series: $Ni_{43}Co_7Mn_{20-X}Fe_2Ga_{21}Cu_{7+X}$ (x = 0.25,0.5, 0.75, and 1.0) and $Ni_{43}Co_7Mn_{20}Fe_2Ga_{21-X}Cu_{7+X}$(x = 0.5, 1 and 1.5) with non-modulated tetragonal martensite structure [1]. Neutron diffraction experiments indicate that Cu occupies Mn positions in the structure; Co enters in Ni and Ga positions and Fe in Ni and Mn ones. A direct correlation between tetragonality ratio (c/a) and the martensitic (MT) and Curie (T_C) temperatures has been found in both alloys series. Some of the studied alloys show a combination of high MT temperature (>370 K) and T_C (>430 K), which extends the previous composition range of high temperature ferromagnetic shape memory alloys (HTFSMA). Three single crystals have been also produced, out of those alloys, by the Bridgman-Stockbarger method. Key parameters for the magnetic field induced twin boundary motion, such as magnetocrystalline anisotropy, twinning stress, magnetostress and tetragonality ratio, have been determined [2]. At least one of the crystals supports the feasibility of high temperature magnetic actuation.

References:

[1] A. Pérez-Checa, *et al.*, Scripta Materialia **154**, 131 (2018)
[2] A. Pérez-Checa, *et al.*, Scripta Materialia **158**, 16 (2019)

This work has been partially supported by the Spanish Ministry of Science under grant nº MAT2014-56116-C4-R

Switching-mode DC current transformer

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The current transformer (CT) is susceptible to measurement errors caused by DC magnetization. DC currents can be measured with 5 % accuracy by existing CTs using additional AC excitation [1]. The disadvantage of active DC current transformer is complicated electronics and large power consumption. The CTs can be demagnetized by momentarily increasing its burden by using pulse width modulation (PWM) switchable resistor [**2**]. In this paper we use similar technique to measure DC component of the primary by monitoring the second harmonic current in the secondary winding. The proposed circuit is shown in Fig. 1, where H-bridge with IGBT is added to the secondary winding of the CT. Transistors are controlled by PWM in two modes. In mode 1 transistors T1 and T4 are permanently on and T2, T3 off. This corresponds to conventional operation of CT. Mode 2 is used when the measured current is low. In this case the H bridge is switched to add AC component into the CT secondary winding. Amplitude of AC component is controlled by PWM. The DC component of the current I_1 can be measured from 2^{nd} harmonics of injected current (Fig. 2). Conventional bipolar switching results in high current peaks, we therefore selected unipolar switching strategy, where T1 and T2 are switched based on I_2 polarity and T3 and T4 are controlled by PWM (Fig. 3). In the full paper we will show the device performance using permalloy and nanocrystalline core.

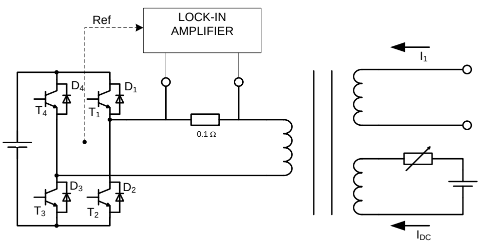

Fig. 1- Switched DC current transformer

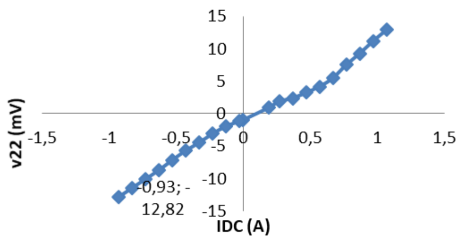

Fig. 2 – 2f ecx. current component vs DC primary current

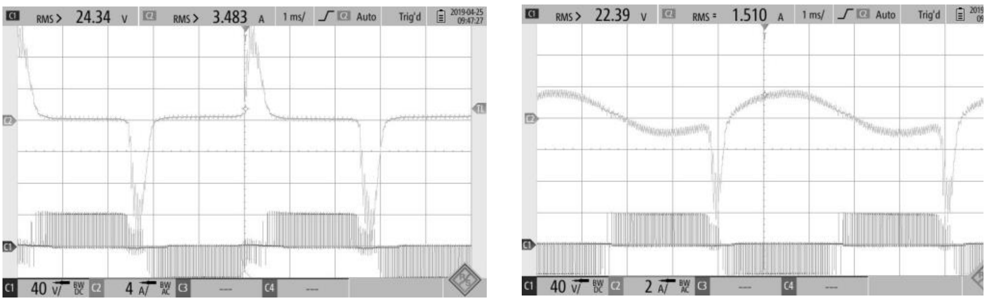

Figure 3 – Secondary current of ICT with injected voltage 200 Hz excitation current – unipolar switching a) with saturation, b) injected current detail

References:

[1] P.Ripka, K.Draxler, R.Styblikova: DC-compensated Current Transformer, Sensors 16 (2016), 114

[2] J.Bauer, P.Ripka, K.Draxler, R.Styblikova: Demagnetization of Current Transformers, IEEE Trans Magn 51 (2015), Article#: 4000604.

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Medium-frequency power transformer using GOES for a three-phase dual active bridge

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Medium-frequency transformers are used in high power electronic DC/DC converters. In the case of dual active bridge topology, a six-step PWM voltage is applied to the transformer. This study shows the efficiency of 0.18 mm thick high permeability **G**rain **O**riented **E**lectrical **S**teel (GOES) for such application. A 200 kVA three phase transformer has been designed and built in link with a transformer manufacturer. Aim is to operate at $f = 1$ kHz and $B = 1.5$ T. Attention have been brought to winding layout for at the same time leakage inductance purposes and insulation level. Cooling was taken into account in the design. This results into a very compact set-up (Table I ; Fig. 1.) [1]. At chosen frequency and working induction levels, a thin core material is mandatory for low eddy current core losses and magnetizing currents. A three-phase dual active test bench has been constituted to assess the transformer performances at varying frequency and flux density levels to get a full picture of the efficiency map. Measured loss data are then compared to single sheet tester ones and discussed on the basis of the IEM-5-Parameter loss formalism [2].

Fig. 1. 200 kVA transformer core.

TABLE I
CORE PROPERTIES

Dimension	Value
GOES thickness	0.18 mm
Height	290 mm
Width	360 mm
Depth	48.5 mm
Mass	19.3 kg

References:

[1] T. Kauder, T. Belgrand, K. Hameyer, IECON 2018 – IEEE Industrial Electronics Society, 4181–4186 (2018).
[2] D. Eggers, S. Steentjes, K. Hameyer, IEEE Transactions on Magnetics, 48 (11), 3021–3024 (2012).

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Impact of rapid annealing on the soft magnetic properties of Fe-Co-B-Cu melt-spun alloys

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The continuing interest in Fe(Co)-based nanocrystalline alloys is motivated mainly due to the combination of a high saturation magnetic flux density with good magnetic softness and their capability to operate at elevated temperatures. A further improvement of magnetic performance in these alloys is possible by using a careful compositional tuning as well as by employing special processing techniques resulting in optimal phase content and reduced grain sizes. Special attention of our work is focused on rapid annealing technique that utilizes a pair of pre-heated Cu blocks. Selected results will be presented on high Bs Fe-Co-B-Cu alloys with low amount of nonmagnetic elements. A part of our research interest is devoted also to the application of external magnetic field during the conventional furnace annealing in order to improve their soft magnetic characteristics. It is shown that the specimens of Fe-Co-B-Cu amorphous and nanocrystalline alloys annealed in conventional furnace without the presence of external magnetic field exhibit an unwanted increase of coercivity. In addition, the corresponding hysteresis loops show a presence of steps due to the depinnig of domain walls from the positions stabilized during annealing. After heat treatment in longitudinal or transverse magnetic field one can obtain smooth hysteresis loops with markedly reduced coercivity. We show that a similar improvement of the soft magnetic behaviour in these alloys can be achieved by employing of rapid annealing techniques leading to high heating rates and much lower processing time.

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Spins dynamics across metal-insulator transition in Fe_3O_4 films

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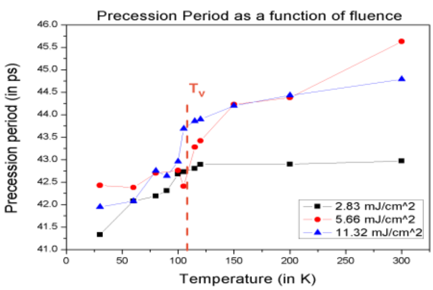
We show very first time-resolved magneto-optical study in thin Fe_3O_4 film as a function of temperature across the Verwey metal insulator transition. This MIT is hardly debated since many decades and to go deeper in the mechanisms underlying such transitions, out of equilibrium studies are well suited [1]. A recent picture of the insulating phase has been proposed based on the existence of trimerons network [2].

In this framework, we measure time-resolved (TR) magneto-optical signals in 120 nm Fe_3O_4 thin films, evaporated on a (100) MgO substrate, using visible pump-probe technique in the Faraday configuration in a systematic approach as a function of temperature and density of excitation. As observed in bulk magnetite[3], we see a drastic change in electrons dynamics behavior as we cross a laser fluency threshold which also depends on the initial temperature. The spins dynamics also demonstrates major changes as Verwey is crossed that is attributed to a non-trivial time dependent effective field reorientation due to structural change at the transition temperature. Moreover, our results demonstrate on both dynamics that their main temporal features undergo a step-like transition at the Verwey temperature showing that metal-insulator transition also impacts out of equilibrium behavior of the different degree of freedom (Figure). Finally, we will present two-temperature model simulations combined to Landau-Lifshitz equation using realistic Fe3O4 physical constants of TR magneto-optical dynamics where we can clearly identify Verwey transition.



References:

[1] M. S. Senn, J. P. Wright, and J. P. Attfield, Nature, **481**,173-176,(2011).
[2] S de Jong et al. Nat. Mater. **12**, 882-886, (2013).
[3] F. Randi et al. Phys. Rev. B **93,** 110 (2016).
[4] J. Panigrahi et al. , E-MRS spring meeting 2018 Strasbourg.

Correlating magnetic properties of ferritic NO electrical steel containing 2.4 m.%Si with hot strip microstructure

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Understanding the interdependencies of the processing steps of high silicon containing non-grain-oriented (NO) electrical steel is a key factor for improving its final magnetic properties. Moreover, every process step in the production has a significant impact on the properties. Steels with a high silicon content are ferritic (α-Fe). Accordingly, the microstructure and texture are inherited from one processing step to the next. The presented research relates the hot strip microstructure and texture to the magnetic properties of the final annealed material. To investigate the impact of hot strip microstructure and texture for a ferritic 2:4 m.% silicon containing steel, the material was hot rolled from an initial thickness of 64 mm down to a thickness of 1 mm whereby different microstructures and textures were achieved by varied hot rolling conditions. Subsequently, the material was cold rolled to 0:25 mm and annealed at 800 °C or 1000 °C for 3 min. Finally, samples of each processing step were analyzed by means of light microscopy and XRD texture measurements. Samples after hot rolling and final annealing were tested in a single sheet tester for specific losses and magnetic polarization. Findings show an influence of the initial hot strip microstructure on the microstructure and magnetic properties of the final annealed samples.

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Anisotropy of specific total loss components in Goss textured electrical steel

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Electrical steel sheets (ES) displays most favorable magnetic properties along rolling direction and in directions 55° and 90° appears poor magnetic properties. The amount of crystals oriented along RD in relation to whole amount of crystals decides about directional properties of ES. The anisotropy phenomenon play important role in construction of magnetic circuits. Cores made of grain oriented ES for construction of magnetic circuits of transformers, generators and large rotating machines are used taking into account the direction of sheet production. Taking into account the anisotropic magnetic properties of ES at the design stage, significant energy and material savings can be achieved and the technical parameters of the device can be improved.

In this paper an investigation of the specific power loss components of electrical steel sheets with Goss texture was performed. For this aim the measurements were carried out at ten different frequencies and for samples cut at different angles to rolling directions. Measurements were taken under axial examination on conventional five grades of grain-oriented (GO) ES. The ES grades varies by thickness form 0.27 mm to 0.35 mm and differs by specific total loss anisotropy from about 50% to 60%.

The loss separation of specific total loss into classical and additional eddy currents and hysteresis components was performed. Only classical eddy current specific total loss shows isotropic characters. This is due to the fact it is calculated for perfectly conducting infinite homogenous plate. The hysteresis and excess eddy current loss components display anisotropic character. Additionally, both components show similarity due to their common origin [1, 2].

An influence of magnetic anisotropy and frequency was on loss components was analyzed. The investigation of specific total loss components shows also applicability of three components specific total loss model [1] for analysis of anisotropy influence of specific total loss.

References:

[1] Bertotti G., “Hysteresis in magnetism”, Academic Press (1998).

[2] Pluta W.A., Angular properties of specific total loss components under axial magnetization in grain-oriented electrical steel. IEEE Trans. on Magnetics, Vol. 52, nr 4, s. 6300912 (2016).

The influence of complex technical parameters on magnetic and structural properties of ferromagnetic microwires

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Ferromagnetic microwires in glass coat manufactured by Taylor-Ulitovsky method possess specific magnetic properties depending on a metallic core composition, cross-section dimensions, and microstructure [1]. They have potential for applications in logic and coding devices, in various sensing devices including embedded sensors for technology control, and as magnetic tweezing in biomedicine [2,3]. To suit particular application, their magnetic and mechanical properties can be tuned by various annealing treatments and also by varying the technological regime of preparation. In this work, the influence of a number of technological parameters on the magnetic and structural properties of Fe, FeCo, and Co-based microwires was studied.

One of the critical parameters of microwire fabrication is the drawing velocity. In many cases it governs the dimensional parameters of microwires (diameter of a metallic nuclei and glass thickness) which affect the internal stress distribution and, hence, the magnetic anisotropic properties, coercivity and remanence magnetization. In Fe-rich microwires, the coercive field increases with increasing the drawing velocity. But in FeCo- and Co-based microwires a reversed tendency is observed. In general, a slower drawing velocity and air cooling make it possible to produce microwires in a mixed state (amorphous and nano/micro crystalline). For a number of compositions, the structural features vs. drawing velocity were studied by Mossbauer and XRD spectroscopy and HRTEM imaging. In Fe-based microwires the amorphous state prevails but for very low velocities crystalline micro regions were observed. In FeCo- and Co-based microwires the centers of crystallization appeared in an amorphous matrix and the size of crystalline grains increases with reducing the drawing velocity. Such microwire samples were investigated by FORC-analysis (First Order Reversal Curve) to detect the interaction between amorphous and crystalline parts and to trace its influence on the magnetization reversal process. This offered an opportunity to discuss the relationship between magnetoelastic and magnetostatic interactions.

The possible phase transformations were studied by DSC (Differential Scanning Calorimeter) technique. Two stages of the crystallization processes were detected and the activation energy of crystallization was calculated. Identifying the inflection point on the DSC curve, the Curie temperature was also deduced.

In summary, we have demonstrated that the change in critical parameters of microwire fabrication, namely, the drawing velocity, offers the opportunity to optimize the structural and magnetic properties of FeCo-based glass-coated microwires.

References:

[1] M. Vazquez, *et al*., Phys. Status Solidi A 207 (2010) 1.
[2] M. Hayashiet al, Science 320 (2008)209–211.
[3] V. Vega, *et al*., J. Appl. Phys. 112 (2012) 033905.

Influence of Co on Microstructure and Magnetic Properties of Nearly-Zero Magnetostrictive Fe-based Nanocrystalline Alloys

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The requirement for more efficient energy distribution systems or miniaturized sensors and related devices opened new opportunities for amorphous and/or nanocrystalline materials. In this work, we will present comparatively our latest results on the evolution of microstructure, magnetic and magnetoelastic properties of Co-substituted FINEMET^{TM}-type [$(Fe_{1-x}Co_x)_{73.5}Cu_1Nb_3Si_{13.5}B_9$] and VITROPERM 800^{TM}-type [$(Fe_{1-x}Co_x)_{73.5}Cu_1Nb_3Si_{15.5}B_7$] rapidly quenched ribbons (x = 0, 0.25, 0.5, 0.75 and 1), in the as-quenched state and after annealing at temperatures between 500 and 600°C. Our study focused mainly on the influence of Co on precipitation and anisotropies of the nanograins, as well as the temperature variation of magnetic and magnetoelastic properties of the 2 systems.

The as-quenched samples are fully amorphous, while the ones subjected to annealing are nanocrystalline, with grains of 15-30 nm, randomly dispersed within the amorphous matrix, depending on the annealing temperature and Co content. The substitution of Fe with Co, followed by optimum annealing, reduces drastically the saturation magnetostriction due to the more random distribution of internal micro-stresses in Co-substituted samples compared with the ones containing Fe only, but also due to the different orientation of the anisotropies of Fe(Co) grains relative to the matrix. The optimum magnetic properties are obtained for samples with Co contents ranging from 25 to 50 at.%, annealed at temperatures in the range of 530-540^{0}C, when the nanograins reach their optimum sizes (between 15 and 25 nm) and the percolation limit increases to 60-70%. In this case, the collective behavior of the nanograins reaches the maximum strength, this being also influenced by the presence of Co in the DO3 nanograins, which slightly shifts the nanograins structure from bcc towards fcc or even hcp. Such a specific behavior is also strongly dependent on Si and B contents, a larger content of Si in VITROPERM 800 playing a more significant role in the exchange interactions between the grains through the amorphous residual matrix.

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(Ga,Mn)As based ferromagnetic nanowires

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Over the last two decades (Ga,Mn)As has established its position of a canonical dilute ferromagnetic semiconductor (DFS) [1]. A moderate doping with Mn ions partially replacing Ga in the GaAs host lattice results in a soft ferromagnet with tuneable properties. The direct link between the semiconducting and magnetic properties provided by the valence band holes mediating interactions between Mn atomic spins resulted in observation of new physical phenomena and proposals for variety of prototypical spintronic devices [2].

Until recently (Ga,Mn)As has been investigated mostly in the form of epitaxial layers, where it crystalizes in cubic zinc-blende phase. We have shown that it can also be obtained in hexagonal wurtzite structure in the nanotube geometry, i.e. as the shells o wurtzite (In,Ga)As nanowires (NW) [3]. The properties of (Ga,Mn)As in this new phase will be discussed. We have also investigated the phase segregated system consisting of ferromagnetic MnAs nanocrystals embedded in GaAs NW shells. Such semiconductor-ferromagnet granular system can be obtained in an easy way, by thermal annealing of (Ga,Mn)As. The nanowire samples offer possibility of in-situ studies of the mechanisms of this phase segregation process (not much known, so far) with use of transmission electron microscopy techniques (TEM) without any TEM specimen preparation procedures. The tensely strained MnAs nanocrystals embedded in wurtzite GaAs matrix obtained in this way possess unique magnetic properties which do not occur in bulk MnAs.

References:

[1] T. Dietl and H. Ohno, Rev. Mod. Phys. 86, 187, (2014).
[2] T. Jungwirth, *et. al*., Rev. Mod. Phys. 86, 855 (2014).
[3] J. Sadowski, *et al.*, Nanoscale, 9, 2129 (2017).

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Microstructure and magnetic properties of nanocrystalline Fe-Pt - based ribbons

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The FePt-based nanocrystlline magnetic materials are widely studied over years due their potential applications as exchange spring magnets [1-3]. As it was proposed by E. Kneller and R. Hawig one of the important criteria to obtain exchange coupling between hard and soft magnetic phases is appropriate ratio between them [4]. Here we are focused on FePt - magnetic nanocomposites prepared by isothermal annealing of melt-spun $Fe_{52}Pt_{28}Nb_{2}B_{18}$ and $Fe_{51}Pt_{27}Nb_{2}B_{20}$ (at. %) ribbons. The relationship between crystal structure, microstructure and magnetic properties was determined by X-ray diffraction (XRD), transmission electron microscopy (TEM) and ^{57}Fe Mössbauer spectrometry (MS). Detailed analysis of magnetic properties was performed with the use of SQUID magnetometry and Faraday balance. As it was evidenced the as-cast samples consists of $L1_0$-FePt hard magnetic grains dispersed in a predominant soft magnetic matrix composed of A1 FePt, Fe_2B and boron-rich (FeB)PtNb residual phases. The applied annealing procedure reflects in temperature-induced structural and magnetic transition of dominated A1 FePt phase into $L1_0$-FePt dependent on Fe-Pt composition. As it was shown the $Fe_{52}Pt_{28}Nb_{2}B_{18}$ ribbon annealed at 700°C exhibit promising hard magnetic properties at room temperature manifested as resonably high remamance to saturation ratio (M_r/M_s=0.72); coercivity (H_c=835kA/m) and $(BH)_{max}$ = 83kJ/m3 parameter. Strong exchange coupling between both FePt – based hard and soft magnetic phases was demonstrated by a smooth demagnetizing curve.

References:

[1] W. Zhang, *et al.*, Appl. Phys. Lett. 85, 4998 (2004).
[2] O. Crisan, *et al.*, J. Alloys & Compd. 440, L3 (2007).
[3] A.D. Crisan, *et al.*, Mater. Sci. Eng. C 27, 1283 (2007).
[4] E.F. Kneller, R. Hawig, IEEE Transactions on Magnetics 27, 3588 (1991).

Losses and domain structure in highly mis-oriented Goss textured electrical steel.

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It has been shown previously that loss occurs in a strip of Goss oriented electrical steel due to a component of flux density which is set up in its transverse direction [1], [2]. This loss will not be detected when measuring losses using conventional sensors which detect the field and flux density just along the longitudinal direction of a strip so loss characterisation using the Epstein Square or Single Sheet testers will always give a low result.

The effect is small in well-oriented steel so in order to quantify the effect more clearly, components of longitudinal and transverse magnetic field and flux density have been measured using surface sensors in the single grains strips of 3% SiFe with intentionally produced poorly oriented Goss grains. Localised and overall loss due to each magnetic component were computed over a wide range of magnetisation conditions at 50 Hz magnetising frequency.

It is shown that large localised transverse components of flux density occur and they are responsible for up to 25% of the measured total loss which would not be registered if only components of field and flux density were used in computing the total loss.

The wider implications of this finding in magnetic testing of electrical steel are discussed in the full paper.

References:

[1] A.J. Moses, S. N. Konadu, S. Zurek, *J. Optoelectronics and Advanced Materials*, 10(5), 1110-1114, 2008

[2] X. T. Xu, J. P. Hall, A.J. Moses, Proc. of 5th Int. Conf. on Magnetism and Metallurgy (WMM'12). Ghent, Belgium, 319-323, 2012

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Investigation of phonons and magnons in $[Ni_{80}Fe_{20}/Au/Co/Au]_{10}$ multilayers

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The properties of surface acoustic waves and spin waves propagating in magnetic $[Ni_{80}Fe_{20}/Au/Co/Au]_{10}$ multilayers on silicon substrate have been investigated by high resolution Brillouin spectroscopy [1-2]]. The behavior of spin waves was studied in two experimental geometries: Backward Volume (BV) geometry and Damon-Eshbach (DE) geometry [3]. The thickness of cobalt (Co) layer was different for each sample and the influence of the layer's thickness on the dispersion relation has been tested. The samples were decorated with non-magnetic aluminum (Al)periodic structures. The crossing of phonon and magnon dispersion relations has also been examined. Additionally, the theoretical dispersion dependences have been obtained from simulations performed with finite element method.

References:

[1] A. Trzaskowska, S. Mielcarek, B. Graczykowski, F. Stobiecki, Journal of Alloys and Compounds 517, 132-138 (2012).
[2] M. Urbaniak, F. Stobiecki, B. Szymański, A. Ehresmann, A. Maziewski, M. Tekielak, Journal of Applied Physics101, 013905 (2007).
[3] P. Graczyk, A. Trzaskowska, K. Załęski, B. Mróz, Smart Materials and Structures 25(7), 075017 (2016).

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Magnetic Manipulation of iron oxide-Graphene Nanopletelets (GNPs) into polymer composites

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Several synthetic approaches have been proposed to obtain the well-ordered microstructures in platelet-reinforced composites, such as freeze casting, emulsion casting, templating and self-assembly [1-2]. Although, enhanced mechanical and electrical properties have been demonstrated, these approaches are not readily scalable and lack control or the ability to select a desired structure. Recently, an attractive strategy was proposed to control filler orientation or position in a matrix [3]. Coating the fillers with superparamagnetic nanoparticles (Fe_3O_4) enables possible manipulation by external low magnetic fields. In this work we present an approach for the decoration of graphene flakes with magnetite nanoparticles which significantly enhances their magnetic susceptibility and allows manipulation in very low magnetic fields (<100mT). A mathematical model was used in order to identify the key parameters in order to predict the minimum magnetic field H_{min}, considering the dimensions of the GNPs, the volume fraction of Fe_3O_4 and the viscosity of the epoxy solutions. The theoretical results were compared with experimental studies, using different filler loadings, magnetic field strengths and mixing methods. Anisotropic orientation of the magnetic GNPs was confirmed by SAXS analysis for a 1 wt% filled composite cured in a 100 mT field, giving the potential for fabrication of highly aligned graphene-based epoxy composites with controllable properties.

References:

[1] Ni, Na, *et al.* "Understanding mechanical response of elastomeric graphene networks." Scientific reports 5 (2015): 13712.
[2] Wu, Shuying, *et al.* "Aligning multilayer graphene flakes with an external electric field to improve multifunctional properties of epoxy nanocomposites." Carbon 94 (2015): 607-618.
[3] Erb, R. M.; Libanori, R.; Rothfuchs, N.; Studart, A. R. Composites Reinforced in Three Dimensions by Using Low Magnetic Fields. Science 2012, 335, 199−204.

Novel procedure for fabricating composite filaments with embedded magnetic particles for additive manufacturing

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Additive manufacturing (AM) is changing the way how 3D objects are designed and manufactured today. Through thin layer-by-layer deposition of material, usually a thermoplastic, 3D objects are built with virtually no limitation in shape. In fused deposition modeling (FDM), one of the most widely used AM methods, a filament feeds the extrusion head of a 3D printer, where it is fused for deposition. There is an increasing interest in fabricating customized composite filaments to add functionality to the printed parts. Common ways of doing so is by mechanical mixing of the polymer and the functional material (i.e. with a kneader, which requires large scale equipment) or purchasing pellets of composites, which limits the compositional possibilities to those provided by industrial suppliers. Production at laboratory scale was usually limited by the loss of powder in the hopper, causing inhomogeneities of the final filament. In this work, an original procedure to prepare composite filaments had been designed and developed. Customized polymer capsules filled with soft magnetic steel particles were used as the initial feedstock for the extrusion of the composite filaments. Results from both microstructural (X-ray tomography and scanning electron microscopy) and magnetic characterization reveal the actual distribution of the soft magnetic fillers in the composite, indicating a good agreement with the nominal content. This method, not only limited to the addition of metallic particles, does not require a sophisticated machinery, allows desired compositions at the laboratory scale with a good control of the amount of particles being added.

RF Noise Suppressor Embedded in IC Chip Interposer

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This work suggests a new application of FMR losses of hexaferrites to suppress RF electromagnetic noise emmition in a semiconductor IC chip. Each of Y- Z- and M-type hexaferrites, and a referencial NiCuZn spinel ferrite powder was mixted with epoxy resin to paste powder composite sheet, or sintered and cut into 50-80 μm-thick sheet, respectively, in order to fit narrow space between the test IC die and a small printed circuit board (interposer) enclosed in IC package. Diameter of magnetic powder was carefully selected as 1-3 μm to flatten the sheet surface.

Magnitude and ferquency range of the FMR losses were evaluated by relative complex permeability $\mu_r = \mu_r' - j\mu_r''$ up to 9 GHz. Then the input loss ratio, $P_{loss}/P_{in} = 1 - (|s_{11}|^2+|s_{21}|^2)$ was measured on an RF micro stripline as a figure of merit (FoM) of noise suppressor. This parameter means the ratio of power consumption at magnetic composite's portion to the input power [1]. Both μ_r'' and P_{loss}/P_{in} became more as the volume ratio of magnetic material in conposite was increased up to 50 vol.%, and as the density of sintered sheet became higher. The 50 vol.% Y-Type hexaferrite composite sheet exhibited P_{loss}/P_{in}=0.21, the highest value among the composite sheets.

The pasted composites and sintered sheets were embedded in between IC chip and interposer as a part of pre-assembly underfill. As shown in Fig. 1, the 55 μm thick and 50 vol.% of Y-Type hexaferrite composite sheet exhibited near field emission by 10 dB in a 5 GHz band, which offers a new noise suppression technology for sub-6GHz-range 5G telecomm-unication systems EMC aspect of this work will be reported separately [2]

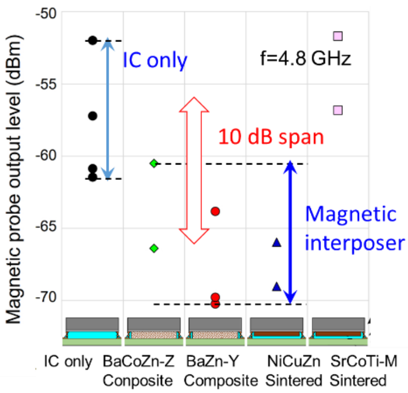

Fig. 1 Radiated noise suppression on IC chip

References:

[1] M. Yamaguchi *et al*, APEMC2015, SS10, 2015.
[2] M. Yamaguchi *et al*., EMC Sapporo & APEMC2019, MonPM2C.6, 2019.

This work was supported in part by Development of Technical Examination Services Concerning Frequency Crowding, MIC, Japan.

Spin Hall Magnetoresistance in Heavy-metal/Ferromagnetic-metal Systems

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Spin Hall Magnetoresistance (SMR) effect has been recently examined both theoretically and experimentally in heavy metal (H)/ferromagnet (F) heterostructures [1,2]. In the case of metallic H/F heterostructures proper estimation of SMR can be obscured by other possible magnetoresistance effects that occur simultaneously such as, for instance, anisotropic magnetoresistance (AMR). Here, we determine contributions to total multilayer magnetoresistance from SMR as well as AMR. For this aim we specifically consider AMR effect in diffusive transport in ferromagnet [3] and compare the theory to experimental results for H/F heterostructures where H:W, Pt and F:Co, CoFeB. We also consider magnetoresistance effects in H/F bilayers coupled to antiferromagnetic insulator (AF) NiO.

References:

[1] Y.-T. Chen *et al.*, Phys. Rev. B **87**, 144411 (2013).
[2] J. Kim *et al.*, Phys. Rev. Lett. **116**, 097201 (2016).
[3] T. Taniguchi *et al.*, Phys. Rev. Appl. **3**, 044001 (2015).

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Controlling magnetization direction of ferromagnets with antiferromagnetic to ferromagnetic phase transition of nearby FeRh alloy thin films

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We show flexibility of ferromagnet magnetization switching provided by an antiferromagnetic-ferromagnetic phase transition in the neighbouring FeRh alloy film. In case of Co/FeRh system grown on W(110) substrate the reversible 90-degree in-plane Co magnetization switching is observed as the FeRh layer undergoes temperature driven antiferromagnetic-ferromagnetic (AFM⇔FM) phase transition [1]. Switching of Co magnetization is characterized by a hysteretic behaviour owing to a temperature hysteresis of the AFM⇔FM transition in FeRh. Importantly, in-plane to out-of-plane magnetization switching of a ferromagnetic FeAu superlattices can be driven by antiferromagnetic-ferromagnetic phase transition [2]. For FeRh/Au/FeAu trilayers, the impact of the magnetic phase transition of FeRh onto the perpendicular magnetization of monoatomic FeAu superlattices is transferred across the Au spacer layer via interlayer exchange coupling. The polar spin reorientation process of the FeAu spins driven by the magnetic phase transition in the FeRh reveals its major features; namely it is reversible and displays hysteresis.

Our results provide a new method of writing information purely by a local temperature change.

References:

[1] P. Dróżdż, M. Ślęzak, K. Matlak, B. Matlak, K. Freindl, D. Wilgocka-Ślęzak, N. Spiridis, J. Korecki, and T. Ślęzak, Phys. Rev. Appl. 9, 034030 (2018).

[2] P. Dróżdż, M. Ślęzak, K. Matlak, A. Kozioł-Rachwał, J. Korecki, and T. Ślęzak, submitted to APL

This work was supported by the National Science Center of Poland under Project No. 2015/19/B/ST3/00543 and partially by the AGH University of Science and Technology statutory task No. 11.11.220.01/6 under a subsidy from the Ministry of Science and Higher Education. J. Korecki thanks the statutory research funds of ICSC PAS for their support.

Soft magnetic amorphous alloys in X-ray light: insights from ultrafast Joule heating experiments

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Metallic glasses prepared by rapid quenching method represent unique class of soft magnetic materials with excellent magnetic properties such as relatively high saturation of magnetic induction, high permeability combined with low magnetostriction, coercivity and magnetization loss [1]. In course of designing new materials with improved magnetic properties it is important to understand relationships between structural (atomic) modifications and their macroscopic (magnetic) characteristics. Time-resolved in-situ X-ray diffraction experiments performed at high-brilliance synchrotron radiation sources can detect tiny changes of the amorphous structure when exposed to a variety of temperature–pressure conditions [2,3]. In this contribution a novel setup for studying rapid crystallization of metallic glasses using a time resolved in-situ X-ray diffraction combined with a direct current fast Joule heating (flash-annealing) is presented. Its potential use is demonstrated by studying rapid crystallization of soft magnetic $Fe_{73.5}Cu_1Nb_3Si_{15.5}B_7$ (at. %) metallic glass prepared by melt spinning technique. Results show that a single rectangular current pulse with a fixed amplitude of 1.5 A and pulse duration of 50 ms causes temperature to rise to 1020 °C with an average heating rate of 5600 K/s.

References:

[1] R. Boll, Weichmagnetische Werkstoffe, VAC GmbH, Ed. Siemens AG, Berlin und München, Germany, (1990).
[2] J. Bednarcik, S. Michalik, and H. Franz, *J Alloys Compd*, 509, S92–S94, (2011).
[3] J. Bednarcik, S. Michalik, V. Kolesar, U. Ruett, and H. Franz, *Phys. Chem. Chem. Phys.*, **15**, 8470–8479, (2013).

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POSTER CONTRIBUTIONS

Manganese Ferrites for Wide Band Gap Semiconductor Driven Power

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As the spread of application of wide band gap power semiconductor (WBG), high frequency becomes the major trend of development in switching mode power supply (SMPS), which requires developing ferrites with low Pcv and high Bs at frequency of MHz for miniaturization and better energy efficiency. Manganese Zinc ferrite with less Zinc possesses high saturation magnetization and low power loss at high frequencies. In this work, some new Manganese ferrites were developed by the conventional ceramic processing technique. Fe2O3, Mn3O4 and ZnO were weighed and mixed by ball mill and calcined at 850 ℃ in air for 3 h. Same amounts of typical dopants (SiO2, CaCO3, etc.) were added all samples. Dried powders were granulated and pressed into toroidal shapes with the dimensions of outer diameter in 20 mm at 70 MPa and sintered at 1100-1200 ℃ in carefully controlled equivalent oxygen atmospheres. By investigating the composition and additives, together with the optimization of preparation conditions, the grain size was decreased to 2-3 micron meters. Magnetic properties at frequencies over 0.5MHz were improved to the level better than the newly high frequency MnZn ferrites published in the last 5 years, as promising candidate transformer cores for application in WBG driven SMPSs operating with MHz frequencies and high flux density excitation.

Effect of primary grain size and nitrogen content on the magnetic properties of a grain-oriented electrical steel

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Grain-oriented (GO) electrical steels are mainly used in transformer cores. The development of high efficient transformers includes the improvement of the magnetic flux density (B8) and lowering the core loss (W) of the GO electrical steels. For the GO steel produced by the acquired inhibitor technology, the primary grain size and nitrogen content play important effect on the final magnetic properties. The primary grain size must be controlled in order to optimize magnetic flux density, as else the control of the nitrogen content [1, 2].

GO steel samples produced by acquired inhibitor technology were submitted to variation in decarburization temperature and ammonia flow, in order to obtain variation on the primary grain size and nitrogen content. high temperature annealing was employed in all samples and magnetic properties were measured. Based on magnetic properties, an optimum grain size and a nitrogen content trend was identified. The samples have been investigated by SEM-FEG to evaluate the nitriding profile. EBSD and XRD were employed to discuss the effect of the primary grain size distribution and texture.

References:

[1] Chang, Sam Kyu e Hong, Byong Duk. ISIJ International. Vol. 44, pp. 1086-1092 (2004).
[2] Kumano, Tomoji, Haratani, Tsutomu e Fujii, Norikazu. ISIJ International. Vol. 45, pp. 95-100 (2005).

Characterisation of Grain Oriented Electrical Steels based on the Dynamic Hysteresis Loop (DHL)

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Mathematical methods based on the classical hysteresis models [1-3] and loss separation principle [4] are well recognised for physicist and engineers to characterise magnetic materials and power loss analysis. The main aim of this work is to develop an accurate analytical model to characterise Grain Oriented (GO) electrical steels for non-sinusoidal magnetisations. The modelling is based on the statistical energy loss separation principle proposed by Bertotti [4]. Using the dynamic models of classical eddy current and excess fields, loss separation can be interpreted as magnetic field separation which lead to the well-known thin sheet model [5]:

$$H(t) = H_h(B) + \frac{d^2}{12\rho}\frac{dB}{dt} + g(B)\delta\left|\frac{dB}{dt}\right|^{\alpha} \qquad (1)$$

where $H_h(B)$ is the hysteresis field, d is thickness of the material, $\delta = sign(dB/dt)$ is directional parameter, and α determines the frequency dependence of the model. DHLs of 0.3 mm thick GO 3 % *SiFe* were modelled using (1) for sinusoidal and non-sinusoidal excitations. The results at B_{pk}=1.5 T and fundamental frequency of 50 Hz are shown in Figs 1-a and 1-b, respectively. Non-sinusoidal induction was modelled by summation of a fundamental of 50 Hz, and its 3rd, 5th and 11th components at an amplitude of 10 % of the fundamental components. A close agreement with a maximum difference of less than 5 % was found between the measured and modelled energy losses.

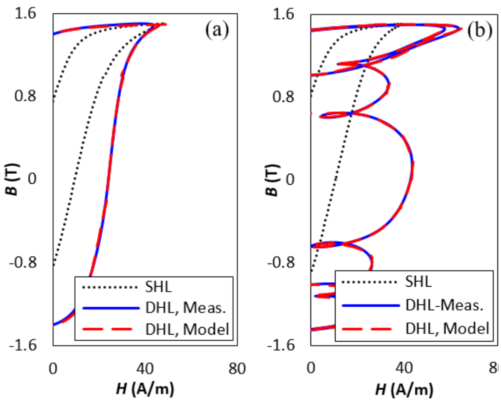

Figure 1 Modelling of DHL of GO 3 % SiFe under sinusoidal and non-sinusoidal inductions

References:

[1] C. Steinmetz, Trans. American Institute of Electrical Engineering, No. 9, 1892, pp. 3-51
[2] I. Mayergoyz, "*Mathematical Models of Hysteresis*", Academic Press, 2nd Ed., 2003
[3] D. Jiles and D. Atherton, JMMM, No. 61, 1986, pp. 48–60
[4] G. Bertotti, "*Hysteresis in Magnetism*", Academic Press, 1998
[5] S. Zirka, et. al., JMMM, Vol. 394, Nov. 2015, pp 229-236

Electrical steels were provided by Cogent Power Ltd, and the experimental work were performed at Wolfson center for magnetics at Cardiff University.

Bioinspired nacreSoft magnetic composite and a strategy of bioinspired nacre structural for high frequency structural soft magnetic composites with high permeability and low loss for high frequency

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Soft magnetic composite (SMC) is constructed by the insulating coated soft magnetic particles which shows low eddy current loss and high saturation. Hence, SMC is considered to be the most potential candidate for the future high frequency magnetic power device. However, to increase the working frequency, the nano magnetic particles have to be synthsized and insulated in large scale. Moreover, the dense nano bulk composite have to be prepared, all of which would lead to high cost. The bioinspired nacre structural soft magnetic composites fabricated by the highly planar arranged flaky-Sendust show the extremely high permeability and low loss which exhibit great potential in high frequency usage for the magnetic components. The novelty textured nacre structural soft magnetic composites exhibit the high permeability up to 600 at 1 MHz which is ten times of the common Sendust composites. The total loss is reduced to 470.82 and 1162.60 kW/m3 at 100 and 200 kHz stimulated at 100 mT, respectively, and the maximum magnetic induction is up to 714 mT at 8000 A/m which shows the special superiority to the ferrite. This outstanding comprehensive property roots in the anisotropic demagnetizing factor for the planar arrangement of the flaky particles which can be derived from the Aharoni’s formula. The minimum total loss generates from the balance of the hysteresis and the eddy current loss for the thin thickness which is less than the skin depth. In addition, three-dimensional loss separation characteristic was analyzed based on nonlinear regression method for theoretically exploring the influencing factors related to morphology of materials on magnetic property. Our approach would provide a new smaller, high frequency and high saturation magnetic device for switching regulator inductance, photovoltaic inverter boost inductor, noise filter, etc.

Influence of DC-Biased Magnetic Field on Power Losses Near the Magnetic Phase Transition in the $LaFe_{10.72}Co_{1.08}Si_{1.2}$ Alloy

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Magnetocaloric effect (MCE) observed in the $La(Fe,Si)_{13}$-type alloys [1-3] is comparable to MCE in Gd [4]. However, reasonable price, excellent physical properties and low environmental impact of $La(Fe,Si)_{13}$-alloys stimulate research on their applications in magnetic refrigeration. The experimental studies of LaFeCoSi-based alloys subject to DC-biased magnetic field offers a better insight into their performance under real-life operating conditions [5]. Biased excitation field corresponds to waveforms occurring frequently in practice, whereas the approach based on bipolar excitation field is recommended during tests of soft magnetic materials [6]. Therefore the main goal of the presented work was to study the power losses under DC-biased magnetic field in the $LaFe_{10.72}Co_{1.08}Si_{1.2}$ soft magnetic alloy. The experimental study of magnetic properties and power losses of a bulk ring sample was carried out at Curie temperature (292 K) and for the range of excitation frequency from 0.1 Hz to 10 Hz. The impact of biased excitation on the magnitude of magnetic loss density is best illustrated by the curves of specific power losses.

References:

[1] Pecharsky V. K., Gschneidner Jr. K. A., *Phys. Rev. Lett.*, 78, 4494-4498, 1997.
[2] Fujieda S., Fujita A., Fukamichi K., *Appl. Phys. Lett.*, 81, 1276–1278, 2002.
[3] Gębara P., *et al*, *J. Magn. Magn. Mater.***,** 442, 145-151, 2017.
[4] Bjørk R., *et al.*, *J. Magn. Magn. Mater.*, 322, 24, 3882–3888, 2010.
[5] Sandeman K. G., *Scr. Mater.*, 67, 6, 566–571, 2012.
[6] Gozdur R., *et al*, *Acta. Phys. Pol. A*, 128, 98–103, 2015.
This study was partially supported by Polish National Science Centre under the grant agreement No. 6370/B/T02/2011/40

Digital signal processing for conditions determination of Barkhausen noise response in soft magnetic amorphous ribbons

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We present a digital signal processing and analysis in Barkhausen noise response to establish the experimental conditions, which ensure the repeatability of this response in soft magnetic amorphous ribbons with different magnetostriction. For this objective, the measurements were performed on amorphous ribbons using different experimental conditions, such as: the magnetization frequencies, sampling rates, and using a single yoke magnet. The sample magnetization was controlled by means of inductor sensor. We use a discrete approximation of multiple magnetic states and which is necessary within the same measurement process, because the magnetization in material involves linear and non-linear stages and that are discussed in detail.

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Visualization of stray-field distribution by charged domain-walls in rare-earth substituted iron garnets

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Magnetic-optical methods are used to investigate the magnetic microstructure of an epitaxial film of (Lu,Bi) substituted iron garnet (REIG). In particular, we focused our study on a bi-dimensional domain configuration, the Néel spike [1], which is induced and pinned at defects inside the sample or at its edges. We analysed the magnetic microstructure by means of magneto-optical methods. Imaging of magnetic domains and domain-walls is obtained by direct magneto-optical interaction in the sample under study. The visualization of the stray-field distribution that is generated by single domain-walls is achieved by means of magneto-optical imaging with an indicator film (MOIF) [2]. Furthermore, magnetostatic calculations were performed in order to correlate the net magnetic charge of the Néel spike domain walls with the measured stray-field (fig. 1). It results that the measured magnetic field intensity nearby the Nèel spike tip is compatible with a Bloch-to-Néel wall transition.

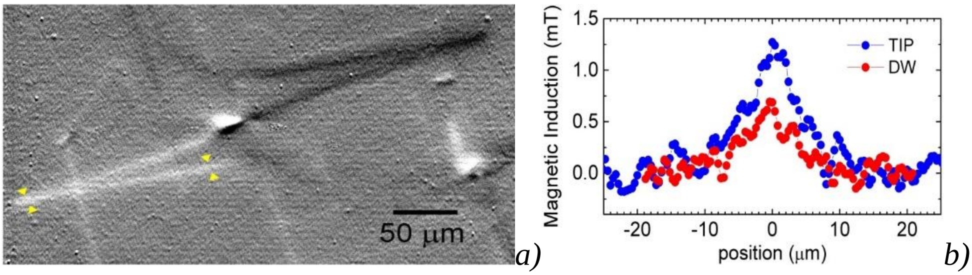

Figure 1. a) MOIF measurement of the magnetic field distribution of Neèl spikes above the REIG film. The bright light contrast corresponds to a magnetic field directed towards the reader, while a dark light contrast corresponds to the opposite direction. Yellow triangles mark the positions where linear profiles are extracted for b).

References:
[1] A. Hubert, and R Schäfer "Magnetic domains: the analysis of magnetic microstructures" Springer Science & Business Media, 2008.
[2] F. Laviano, R. Gerbaldo, G. Ghigo, L. Gozzelino, P. Przyslupski, and C. Ragusa, IEEE Trans Magn 52 (2016) 6500204.

Evaluation of local magnetic degradation by interlocking electrical steel sheets for an effective modelling of electrical machines

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To produce soft magnetic cores for electrical machines, electrical steel sheets are usually punched, stacked, vertically fixed by interlocking or welding and finally combined with a frame by shrink fitting. In the vertical fixing process, interlocking is a promising approach because it is suitable for mass production. This process, however, changes the soft magnetic properties of electrical steel sheets significantly. For the accurate modelling and simulation of electrical machines, it is thus important to know detailed information about such magnetic degradation.

In our previous work[1], BH and iron loss characteristics of laminated cores with interlocking have been studied by using interlocked ring cores. From the measurement results, averaged magnetic characteristics in the assumed damaged region have been calculated according to a simple magnetic circuit model. However, the size of the damaged region has not been clarified in the study.

The full paper will show measurement results of local magnetic properties in laminated cores with interlocking. Such local measurements have been performed for a test model core by using a sensor with needle probes and H-coils[2]. The size of the damaged region by interlocking is determined from the local magnetic measurement results. The modelling discussed in the paper will be useful for the simulation of local flux density and iron loss distributions in electrical machines.

References:

[1] S. Imamori, S. Steentjes, and K. Hameyer, IEEE Trans. Magn., Vol. 53 No. 11 8108704 (2017).
[2] S. Aihara, H. Shimoji, T. Todaka, and M. Enokizono, IEEE Trans. Magn., Vol. 48 No. 11 pp.4499-4502 (2012).

The influence of minor platinum additions (0.5 – 2.0 %) on the properties of ultrafast-cooled FeCoBW-based alloys in the shape of plates produced using two different methods

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This paper presents the results of investigations carried out on bulk, ultrafast-cooled FeCoBW-based alloy samples, with and without the addition of small quantities of platinum. The samples were created in the form of plates of 0.5 mm thickness using two production methods: injection- and suction-casting with in a cooled copper die. The respective platinum contents within the samples were: 0, 0.5, 1.0, 1.5 and 2.0 at.%. The resulting samples were subjected to structural investigations using: XRD, SEM. The magnetic properties were investigated using:VSM, and $\mu_0M_s(T_{20\text{-}850K})$. Based on the performed studies, it was found that the addition of even small quantities of Pt to the described base alloy influenced the resulting structure and magnetic properties of the alloy. Changes in the values of the saturation magnetisation and coercive field were observed. These changes are due to crystalline phases, created in the alloys with the addition of platinum. As a consequence of the presence of these crystalline phases, the value of the saturation magnetisation increased and the value of the coercive field decreased. The saturation magnetic polarisation curves, as a function of temperature, were found to be similar for all of the investigated samples. The presented results and associated discussion were based on a series of several samples.

The Influence of Severe Plastic Deformation on Magnetic Properties Fe-Ni-Al System With the L10 Phase

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The China is a practically complete monopolist in the market of rare-earth elements. There are no alternatives to China in the supply of rare earth elements. Growing in recent years, domestic demand for rare-earth elements in China has led to the restriction of their supplies to the international market, so there is an urgent need to develop alternative free rare-earth permanent magnets [1-6].

The proposed project is aimed at integrating the achievements of theoretical and experimental research which aimed at creating innovative directions for obtaining new functional materials, in particular, new types of free critical elements permanent magnets (including rare earth elements). High performance permanent magnets have become indispensable materials in many industries, ranging from data storage to small motors and clean energy devices. Thus, the reduction of the content of critical elements in the production of permanent magnets is an adequate response to the crisis of the supply of rare earth metals and their oxides and will make it possible to avoid the monopolistic dominance of China in the market of rare earth elements.

Along with rare-earth systems, some Fe-based alloys are some of the most promising candidates for rare-earth compounds for the production of permanent magnets.

In this work we report on the results of investigation of magnetic properties Fe-Ni-Al system with the L10 phase. For more L10 phases, Fe-Ni-Al alloys will be investigated by severe plastic deformation.

References:

[1] K. Kramer, Phys. Today, 63, 22-24 (2010).
[2] J. M. D. Coey, 67, 524-529 (2012).
[3] S Sugimoto, J. Phys. D: Appl. Phys. 44, 064001 (2011).
[4] R. Skomski, J.E. Shield, and D.J. Sellmyer, Magnetics Technology International, UKIP Media & Events, Ltd., p. 26-29 (2011).
[5] M.J. Kramer et al., JOM, 64, 752-763 (2012).
[6] B. Balamurugan et al., Scripta Materialia, 67, 542-547 (2012).

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Sm-Zr-Fe-V Compounds of $ThMn_{12}$-Type as a Perspective Permanent Magnets

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Rare-earth (RE) alloys are a backbone of permanent magnets. Recent increase in price of rare earths has pushed the industry to seek ways to reduce the RE-content in the hard magnetic materials. For this reason strong magnets with the $ThMn_{12}$ type of structure came into focus.
The important properties of the permanent magnets include their coercivity, remanence and energy product (see, e.g., the review [1]). There are essentially two ways how to achieve the large values of these properties necessary for today's applications. First, the microstructure of the material can be optimized (in our case with the help of severe plastic deformation) to prevent rotation of ferromagnetic domains. The second factor is the intrinsic spin–orbit coupling of electrons that forces the spins to align along a particular crystallographic direction, giving rise to the magnetocrystalline anisotropy energy of the material. As it shown in [2-4], severe plastic deformation has a great effect on magnetic properties of 4-f elements.
In this work we report on the results of investigation of magnetic properties Sm-Zr-Fe-V alloys, which will be investigated by severe plastic deformation with high torsion pressure technique. The measurements were performed in magnetic fields up to 3 T and in the temperature range from 50 to 350 K.

References:

[1] Oliver Gutfleisch, Matthew A. Willard, Ekkes Bruck, Christina H. Chen, S. G. Sankarand, J. Ping Liu, Advanced Materials, 23, 7, 821 (2011).
[2] S.V. Taskaev, M.D. Kuz'min, K.P. Skokov, D.Yu. Karpenkov, A.P. Pellenen, V.D. Buchelnikov and O. Gutfleisch, J. Magn. Magn. Mater., 331, 33 (2013).
[3] S. Taskaev, K. Skokov, V. Khovaylo, D. Karpenkov, M. Ulyanov, D. Bataev, A. Dyakonov, and O. Gutfleisch, AIP ADVANCES, 8, 048103 (2018).
[4] Sergey Taskaev, Konstantin Skokov, Dmitry Karpenkov, Vladimir Khovaylo, Maxim Ulyanov, Dmitriy Bataev, Alexander Dyakonov, Oliver Gutfleisch, Journal of Magnetism and Magnetic Materials, 479, 307-311 (2019).

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Structure and some magnetic properties of amorphous and partially crystallized Fe-(Co)-Mn-Mo-B alloys

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Microstructure, Curie temperature and isothermal magnetic entropy change of amorphous $Fe_{70-x}Co_xMn_{10}Mo_5B_{15}$ (x = 0, 0.25 and 0.5) alloys in the form of rapidly quenched ribbon in the as-cast state and after the accumulative annealing consequently at T_{a1} = 723 K, T_{a2} = 753 K, T_{a3} = 853 K and T_{a4} = 903 K for 0.5 h in vacuum of $1.33x10^{-2}$ Pa are investigated According to DSC curve the two former annealing temperature are within the amorphous state, whereas the two latter are above the onset of primary crystallization. The parent alloy, i.e., $Fe_{70}Mn_{10}Mo_5B_{15}$ is paramagnetic at the ambient temperature, and replacing of Fe atoms by small amount of Co ones makes them ferromagnetic. Beside amorphous phase the as-quenched alloys contain small fraction of medium range ordered (MRO) regions which are paramagnetic at room temperature [1]. The volume fraction of them increases only slightly on annealing at T_{a1} and T_{a2} and they become the nuclei of the crystalline grains during crystallization at T_{a3} and T_{a4}. X-ray diffraction and transmission Mössbauer spectroscopy confirm that the first crystalline phase presented in the specimens is the hexagonal ε-$Fe_{80}Mn_{20}$ phase with the lattice parameters; a=0.2530 nm and c=0.4079 nm. The phase α-Fe appears only after the annealing at T_{a4} in alloys containing Co. Curie temperature of the as-quenched alloys are equal to 298 K, 320 K and 370 K, after the annealing at T_{a1} 268 K, 330 K and 389 K, after the annealing at T_{a1} and then at T_{a2} 282 K, 345 K and 405 K for $Fe_{70}Mn_{10}Mo_5B_{15}$, $Fe_{69.75}Co_{0.25}Mn_{10}Mo_5B_{15}$ and $Fe_{69.5}Co_{0.5}Mn_{10}Mo_5B_{15}$ amorphous alloys, respectively. Such behavior results from invar effect in the parent alloy and its lack in alloys containnig Co. The isothermal magnetic entropy change, ΔS_M, is rather modest and shows the caret-like run on temperature with the maximum around the Curie point, T_C, of the amorphous phase. The peak value of ΔS_M are related to T_C. Elucidation of such behavior is undertaken.

References:

[1] A. Kupczyk, J. Świerczek, M. Hasiak, K. Prusik, J. Zbroszczyk, P. Gębara, J. Alloys Compd. 735, 253 – 260 (2018)

Effect of Partial Substitution of Manganese by Tungsten on Magnetocaloric Effect in MnCoGe Alloy

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In the present work, the structure and magnetic properties of the $Mn_{0.9}W_{0.1}CoGe$ alloy were investigated. The XRD studies of the sample in as-cast state carried out at room temperature revealed two orthorhombic structures with different lattice constants. The temperature dependence of magnetization and its first derivative exhibited two Curie points corresponding to recognized phases. Moreover, two overlapping peaks, corresponding to the detected Curie points were measured in the temperature dependence of the magnetic entropy change. The relatively high full width at half maximum of magnetic entropy change peaking at 90 K was detected. Such a high value gives the potential practical application of the alloy as an active magnetic regenerator in magnetic refrigerators.

This work was supported by the Rector of University of Technology, Professor Norbert Sczygiol.

A zero-field energy minimization principle to understand and control the magnetic domains refinement in GO SiFe – comparison between laser irradiation, scribing and ablation

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Surface treatments have appeared since the end of the 20th century to refine the magnetic structure of textured magnetic materials [1]. The theory called micro-magnetism can be used to describe the domain wall spacing but for very few domains and in a perfect crystal [2] or around small defects. In this paper, we look for the best laser mode and patterns to optimize the magnetic performances thanks to a pulsed laser irradiation, scribing or ablation process [3] (Fig. 1a). To do so, we investigate the impact of laser parameters onto the magnetic structure at zero external magnetic field. The domains wall spacing L will play the main role.

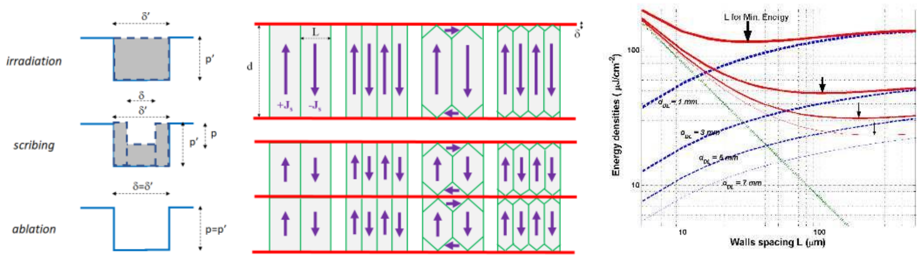

Figure 1: (a: left) laser modes, (b: middle): magnetic structures, (c: right): sensitivity analysis.

In Fig. 1b, we consider parallel laser lines with a line spacing d and a magnetic or/and a heat affected zone (width δ and δ' and depth p and p') depending on the laser mode (irradiation (δ,p), scribing and ablation (δ',p')). Calculation of the magnetic, magneto-elastic and demagnetizing energies in walls, closure domains and main domains due to magnetic poles can be performed as a function of material and laser process parameters (line spacing d, width and depth (δ,p) or (δ',p'), residual stress (s)). Then a sensitivity analysis (Fig. 1c) is carried out to analyze the impact of laser and magnetic parameters (L). This helps us choose the optimal laser parameters. Magnetic domains observation is carried out with the MFM and MOKE[1] imaging techniques. The magnetic behavior is characterized with the SST[2] frame.

References:

[1] T. Luchi, S. Yamaguchi, and T. Ichiyama, *Journal Appl. Phys.*, vol. 53 (3), March 1982.
[2] L. Landau, E. Lifshits, Reprinted *Phys. Zeitsch*. der Sow., vol. 8 (1935), pp. 153 – 169.
[3] S. Patri et al., *Journal of Material Science*, vol. 31 (1996), pp. 1693 – 1702

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[1] MFM : Magnetic Force Microscopy / MOKE : Magneto-Optical Kerr Effect.
[2] SST : Single Sheet Tester.

The tensor phase theory for volume magnetic structures of soft magnetic materials – Frequency dependent vector permeability and magnetic losses with time harmonics

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The tensor phase theory [1] can account for the sensitivity of the magnetic structure to the geometry, surface effects and induced stress at the mesoscopic scale. However, it must be developed to include dynamic magnetization reversal mechanisms. Magnetic objects have got properties described thanks to one tensor variable $[\Lambda^2]$, related to mean length of one pair of opposite neighbouring domains with tensors $[\Lambda_\uparrow{}^2]$ and $[\Lambda_\downarrow{}^2]$ such that $[\Lambda^2] = [\Lambda_\uparrow{}^2] + [\Lambda_\downarrow{}^2]$. We then define the magnetic polarization **J**(**x**,t) of a soft material with $[\Lambda^2]\,\vec{J} = \left([\Lambda_\uparrow{}^2] - [\Lambda_\downarrow{}^2]\right)\vec{J}_s$ ($\mathbf{J}_s=(J_s,J_s,J_s)$, J_s is the saturation polarization). When a time varying field is applied to the material, damping effects occur either in the bulk or at the surface. Eddy currents induced within domains lead to consider a volume dissipation energy. The surface magnetic field **H** is also damped by both the static hysteresis ($\mathbf{H}_s$(**J**,History)) mainly due to defects and the dynamic hysteresis ($\mathbf{H}_{dyn}(\mathbf{J},\partial_t\mathbf{J})=\sigma[\Lambda^2]\partial_t\mathbf{J}$) due to eddy currents around magnetic walls [2,3], added to the anhysteretic field $\mathbf{H}_M(\mathbf{J})$.
$\mathbf{H}_{surf}$, $[\Lambda^2]_{surf}$ and thus $\mathbf{J}_{surf}$ being known on the external surface, space and time variations of $[\Lambda^2]_{bulk}$ can be calculated within the bulk. Finally, finding the geometry and frequency dependent vector magnetic behaviour ($<\mathbf{J}>(\mathbf{H}_{surf})$ ($<.>_x$, space average)) and iron losses ($<\mathbf{H}_{surf}<\partial_t\mathbf{J}>_x>_t$) becomes possible. A sensitivity analysis to the grain, pattern and stress sensitive surface condition allows to orientate laser specifications for the domains refinement technique.
Two test cases for GO and NGO electrical steels are presented. Results will then be confronted to static measurements of GO SiFe materials.

References:

[1] O. Maloberti, G. Meunier, V. Mazauric, A. Kedous-Lebouc,, “How to Formulate Soft Materials Heterogeneity? *1. Quasi-Static Equilibrium and Structuring*”, *submitted to J.M.M.M.*, SMM’2007 conference.
[2] R.H. Pry, C.P. Bean, Journal of Applied Physics, March 1958, vol.29, n°3, pp. 532-533.
[3] T. Chevalier, A. Kedous-Lebouc, B. Cornut, C. Cester, Physica B, 2000, vol. 275, pp. 197-201.

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Effect on magnetic properties of inhomogeneous compressive stress in thickness direction of an electrical steel stack

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The manufacturing processes of electrical machines may lead to significant degradation of magnetic core properties and therefore of the machine performance [1]. Laminations are usually stacked and pressed which affects the magnetic properties and the iron losses [1]-[3]. However, the influence of this step must be still investigated when large generators are considered. Indeed, in that case, the stator and rotor stacking process consists in assembling several stacks of electrical steel sheets separated by airvents. The surface of the airvent spacers represents about ten percent of the lamination surface of the magnetic circuit, implying, during the compaction process, an inhomogeneous stress distribution with significant local stresses. The present work deals with the experimental characterization of a lamination stack, including airvents, under compressive stress in the thickness direction. A mock-up has been designed and built-up (Fig. 1) to study magnetic properties of lamination stacks under parameters corresponding to industrial conditions.

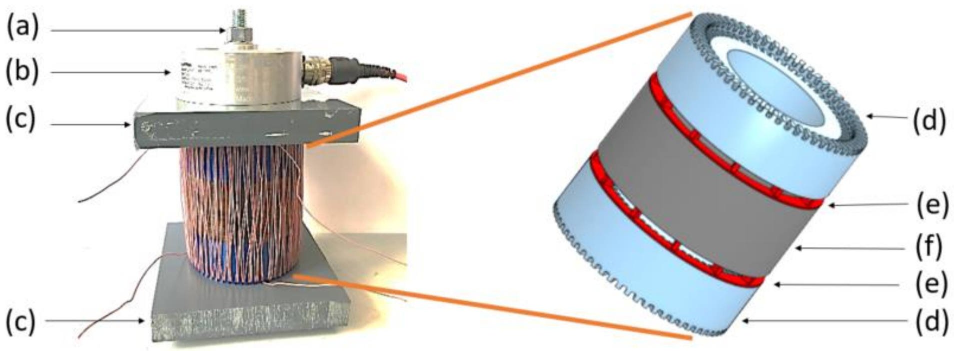

Fig.1 Experimental mock-up – (a) = Clamping screw, (b) = Force sensor, (c) = PVC plate, (d) = Winding frame, (e) = Airvents, (f) = Laminated circuit

References:

[1] W. Arshad, *et al.*, IEEE Industry Applications Annual Meeting, (2007).
[2] D, Miyagi, *et al.*, IEEE Transactions on magnetics, Vol.46, No.6, (2010).
[3] K. Yamamoto and S. Yanase, Przeglad Elektrotechniczny, (2011).

Effect of glass-removal on the magnetic properties and micromagnetic structure in amorphous FeSiB microwires

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Magnetic switching properties of amorphous microwires of Fe-based alloys with a positive magnetostriction coefficient are characterised by high velocity of the domain wall (DW) propagation [1] and, as a consequence, magnetic bi-stability [2]. This behaviour is of interest for the development of embedded sensors [3], high-speed mass storage devices with a high recording density [4] and logic elements [5]. To suit particular application it is important to tune the wire structural and magnetic properties which can be done by changing the technological parameters during fabrication and by applying specific annealing treatments [6].

In the present work, the influence of glass-removal on the magnetostriction, magnetization reversal and domain wall propagation in amorphous Fe77.5Si17.5B15 microwires is investigated. Glass removal releases high thermoelastic stresses originated by the difference in thermal expansion coefficients of glass and metal, which reduces the coercivity, increases the domain wall mobility and decreases the local nucleation fields and their distributions. As a result, the field range of a single domain wall propagation regime widens. It was also found that the saturation magnetostriction coefficient significantly changes after glass removal and extent of this change depends on the initial magnetoelastic energy. TEM, SEM, XRD analyses were used to study the structural properties. Micromagnetic structure and wall mobility were simulated via finding a particular solution of 3D Landau-Lifsshitz-Gilbert equation. It was shown that the overall magnetic anisotropy constant and its radial dependence affect the domain wall structure and velocity.

References:

[1] M. Vazquez, A.P. Zhukov, J. Magn. Magn. Mater. 160 (1996) 223,
[2] A. Zhukov, J.M. Blanco, M. Ipatov, A. Chizhik, V. Zhukova, Nanoscale Res. Lett. 7 (2012) 223,
[3] A. Zhukov, V. Zhukova, Int. Freq. Sens. Assoc. Brussels 154 (2014),
[4] S.D. Bader, S.S.P. Parkin, Spintronics, Annu. Rev. Condens. Matter Phys. 1 (2010) 71–88,
[5] C.K. Lim, T. Devolder, C. Chappert, Appl. Phys. Lett. 84 (2004) 2820,
[6] V.V. Rodionova, I.A. Baraban, L.V. Panina, A.I. Bazlov, N.S. Perov, IEEETrans. Magn. 54 (11) (2018) 8438530.

Re-entrant Spin glass Behavior in Fe doped $La_{0.85}Ca_{0.15}MnO_3$

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The effects of partially replacing Mn with Fe ions in the $La_{0.85}Ca_{0.15}MnO_3$ system are reported. On replacing 5% of the Mn with Fe ions the system changes from a ferromagnetic metal (T_c=210 K) to a re-entrant spin glass with a ferromagnetic T_c of 170K and spin glass transition T_f~100 K. The system remains insulating throughout both the ferromagnetic and spin glass phases with a sharp resistivity increase as the spin glass transition is approached from the ferromagnetic phase. The shift in the spin glass transition temperature T_f with increasing frequency is describable within the critical slowing down picture. The development of the spin glass phase is attributed to the frustration of the Mn spins caused mainly by their antiferromagnetic interactions with the Fe and the ferromagnetic double exchange between them.

Cube + Goss Textured Electrical Steels

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Electrical steels(ESs) are used on the core materials for motors and transformers. It has been known that the ideal texture for non-oriented ESs is {001}<uv0>, also (110)[001] orientation is main texture for grain-oriented ESs. That's because, <001> orientations are easist magentization directions in BCC iron.

The ideal texture for non-oriented ESs and the Goss texture can be controlled and achieved using conventional cold-rolling and annealing processes[1,2]. The cube + Goss texture evolution occurs with selective grain growth by surface energy diffrence.

The surface energy of close packed {110} plane shows lowest value in BCC crystals. However, {100} plane can be the stable plane with weakly segregated sulfur. Highly segreagated sulfur and Al_2O_3 at grain boundary is harmful to selective growth of cube and Goss grains[1,2].

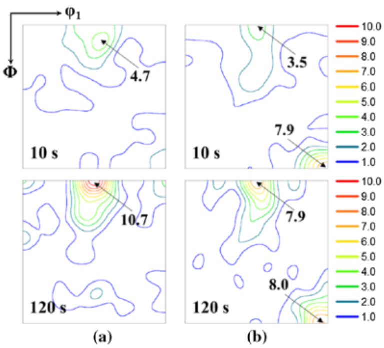

Fig 1. Changes in ODF of the low sulfur ES with final annealing time under mixed-gas atmosphere of 3L N_2/min + 1L H_2/min: (a) 25pct and (b) 50pct final reduction. $\varphi_2 = 45^{\circ}$[1].

References:

[1] H. Mun et al., METALL MATER TRANS A., 1465-1469 (2018).

[2] H. Mun et al., ISIJ International, 765-768 (2018).

Effect of chemical cutting on the magnetic properties of thin Non-Grain-Oriented FeSi electrical steel

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It is well known that manufacturing processes, e.g. cutting or welding, influence the magnetic properties of electrical steel (ES) significantly. In various scientific publications, the influence of mechanical cutting, e.g. punching as well as laser or waterjet cutting, on the magnetic properties of ES is studied [1, 2]. It is ascertained that particularly in the vicinity of cut edges, the magnetic properties are deteriorated as a result of plastic deformation and residual stress which is induced during the cutting process. Mechanical cutting of ES has a technical limit for thin ES grades [3]. Due to efforts to further decrease the thickness of ES and thereby reduce frequency dependent iron losses, new cutting techniques have to be studied to evaluate their degrading influence. In this contribution, thin ES of 0.1 mm is cut by chemical etching procedure and examined regarding its influence on the magnetic properties. Guilottine cut samples of the material are used as a reference. For the measurement single-sheet-tester samples are sub-divided into strips of different width to increase the proportion of cut surface per sample as in [2]. As a result, it can be noted that the conventional punching procedure leads to a dependency of the specific losses on the strip width, whereas chemical cutting shows hardly a cut edge effect. This behaviour can be noticed for a large set of samples. The cut edge effect of chemical etching is studied at elevated frequencies up to 2 kHz.

References:

[1] R. Siebert, J. Schneider, E. Beyer, IEEE Trans. Mag., 50, C2-09 (2013).
[2] H.A. Weiss, N. Leuning, S. Steentjes, K. Hameyer, S. Jenner, W. Volk, JMMM, 421, 250–259 (2017).
[3] K.U. Preissig, D. Petring, G. Herziger, Symposium on Laser Materials Processing: Industrial and Microelectronics applications, Vienna (1994).

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Analysis of losses in soft magnetic nanocrystalline alloys as a function of induction and frequency

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Magnetic losses are an important integral characteristic of soft magnetic materials operating on alternating current. For efficient use in power electronics, the mode of operation with the highest value of magnetic induction B_m is usually used. For this reason, the dependence of the magnetic losses on the magnetic induction in the region of more than 0.1 T is usually investigated [1–2]. It is known that the magnetization mechanism depends on the magnitude of the magnetic field and the type of magnetic anisotropy [3–5]. Therefore, the contribution of different mechanisms to magnetic losses will depend on the magnetic induction B_m.

In this work in the $Fe_{72,5}Cu_1Nb_2Mo_{1,5}Si_{14}B_9$ nanocrystalline alloy, we investigated the dependences of magnetic losses on the induction B_m in the interval of 0.003 to 1.0 T in the static mode and in an alternating magnetic field with a frequency from 50 Hz to 100 kHz. It is shown that hysteresis losses prevail in a weak magnetic field, and the exponent s in the Steinmetz formula $P_{tot} = r \cdot (B_m)^s$ approaches 3. The number 3 corresponds to the exponent in the hysteresis losses formula derived from Rayleigh equations. The dependences of losses on magnetic induction and frequency are taking into account the nature of the domain wall motion.

References:

[1] M.A. Willard, T. Francavilla, V.G.Harris, J. Appl. Phys **97**, 10F502 (2005).
[2] F.J.G. Landgraf, M. Emura, M.F. de Campos, J. Magn. Magn. Mater. **320**, e531–e534 (2008).
[3] C. Appino, C. Beatrice, E. Ferrara, F. Fiorillo, J. Optoelctron. Adv. Mater. **6**, 511–521 (2004).
[4] S. Flohrer, R. Schäfer, J. McCord, S. Roth, C. Schultz, G. Herzer, Acta Mater. **54**, 3253–3259 (2006).
[5] Yu.N. Starodubtsev, V.A. Kataev, K.O. Bessonova, V.S. Tsepelev, J. Magn. Magn. Mater. **479**, 19–26 (2019).

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The Effect of Initial Textures on the Goss and Cube Textures Evolution in Electrical Steel

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Electrical steel is a soft magnetic material and has high Si contents for reducing the eddy current loss. Grain-oriented electrical steel (GO) has excellent magnetic properties in the rolling direction (RD) and is usually used for the transformer. Because the <100> direction is the easiest magnetization direction in BCC iron, GO must have the strong Goss {110}<001> or Cube {010}<100> texture.

In this study, the effect of initial textures on the Goss and Cube textures evolution in electrical steel was investigated. The 2 mm-thick hot-rolled Fe-3%Si alloy sheets were cold-rolled by 60, 65, 70, 80, and 90% reductions in thickness and annealed at 800°C. The 65 and 70% cold-rolled sheets were recrystallized and subsequently cold-rolled by 65% reduction in thickness and again annealed at 800°C. The results were discussed based on the visco-plastic self-consistent (VPSC) deformation model and the strain-energy-release-maximization (SERM) model which was proposed by Lee [1]. The <110>//RD fiber strongly developed after the first stage cold rolling and the Goss orientation developed after the intermediate annealing. However, the Goss orientation did not evolve in the heavily rolled sheets in which the Goss crystallites were not situated inside shear bands. After the second stage cold rolling and annealing, the Goss and Cube orientation strongly developed, even though the initial textures are different. These orientations originated from the Goss and {554}<225> components.

References:

[1] D. N. Lee, Scripta metallurgica et materialia 32, 1689-1694 (1995)

Influence of Mechanical and Water-Jet Cutting on Static and Dynamic Properties of Magnetic Steels

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In the manufacture of the electrical machine cores by fully processed electrical steel laminations, the cutting operations introduce degradation of the soft magnetic properties of the material and contribute to the building factor of the core loss. We have investigated the dependence of magnetization curve and energy losses in non-oriented Fe-Si strips of thickness 0.20 mm - 0.35 mm on cutting type (guillotine punching versus water jet cutting) and strip width (5 mm – 60 mm). The measurements have been made by means of a digitally controlled single strip tester from DC to 1.5 kHz at different induction values. It is shown that the evolution of the magnetization curve and of the quasi-static W_h and excess W_{exc} loss components can be assessed using a simple phenomenological model, by which the width $2L_c$ of the damaged area at the strip edges is determined and a hyperbolic dependence of W_h and W_{exc} on the strip width is predicted. It is shown, in particular, that the limiting magnetization curves and hysteresis (quasi-static) losses for the fully damaged and the pristine sheets can be retrieved from knowledge of the behavior of these quantities at two generic strip widths.

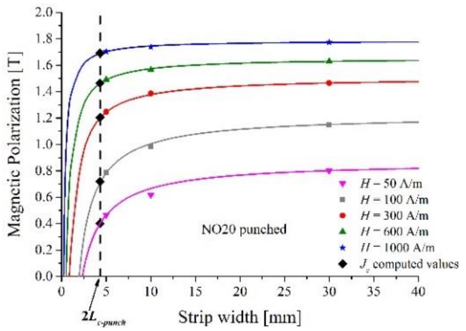

Fig. 1. Polarization value J_P on the initial magnetization curve for defined values of the applied DC magnetic field H as a function of the width of guillotine-punched 0.20 mm thick NO steel strips. Symbols: experiments. Lines: theoretical prediction. The vertical dashed line identifies the width $2L_c$ of the fully damaged area at the strip edeges.

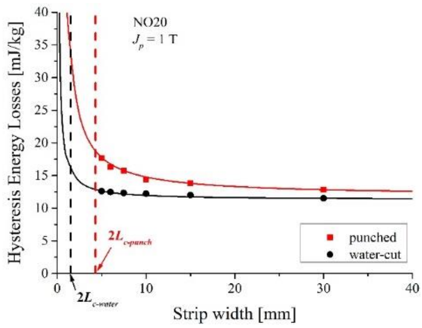

Fig. 2. Measured hysteresis losses (symbols) as a function of the strip width in the NO 0.20 mm thick steel sheets and predicted behaviors (solid lines).

Alteration of the magnetic properties and thermal stability of Fe-substituted $Hf_2Co_{11}B$ alloys

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$Hf_2Co_{11}B$ compound are considered as a candidate for rare earth free permanent magnet material. Exchange coupling between FeCo and HfCo nanoparticles was exploited to develop saturation magnetization but resulted in the reduction of coercive field due to the propagation of domain walls [1]. The iron substitution in place of Co atoms causes increase of saturation magnetization in bulk materials. However, the coercive field decreases significantly [2]. Crystallization of the ferromagnetic $HfFe_2$ phase, instead of $HfCo_2$, is regarded as another opportunity for the improvement of magnetic properties in Hf-Co-Fe-B system [3].

Amorphous ribbons of $Hf_2(Fe_{0.2}Co_{0.8})_{11}B$ and $Hf_2(Fe_{0.4}Co_{0.6})_{11}B$ were obtained by rapid quenching process. Investigated compounds exhibit two overlapping crystallization peaks in isochronal calorimetric curves. Thermal stability of the alloys increased with increasing Fe content, with T_{onset} = 611ºC for $Hf_2(Fe_{0.4}Co_{0.6})_{11}B$. Two additional phases appeared after isothermal annealing at T_a = 610ºC and 665ºC in comparison to annealed $Hf_2Co_{11}B$ alloy, namely α-Fe, instead of fcc-Co, and $FeCo_2B$. Saturation magnetization reached the highest value of 986 emu/cm^3 for $Hf_2(Fe_{0.4}Co_{0.6})_{11}B$ in as-quenched state. Moreover, the coercive field decreased from 0.83 kOe for $Hf_2(Fe_{0.2}Co_{0.8})_{11}B$ to about 0.04 kOe for the alloy with higher Fe content.

References:

[1] B. Balamurugan, B. Das, V.R. Shah, R. Skomski, X.Z. Li, D.J. Sellmyer, Appl. Phys. Lett. **101** (2012) 122407.

[2] B. Das, B. Balamurugan, P. Kumar, R. Skomski, V.R. Shah, J.E. Shield, A. Kashyap, D.J. Sellmyer, IEEE Trans. Magn. **49** (2013) 3330–3333.

[3] T. Sakakibara, T. Goto, Y. Nishihara, J. Phys. **49** (1988) C8-263-C8-264.

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A thermographic camera method for measuring the core loss distribution

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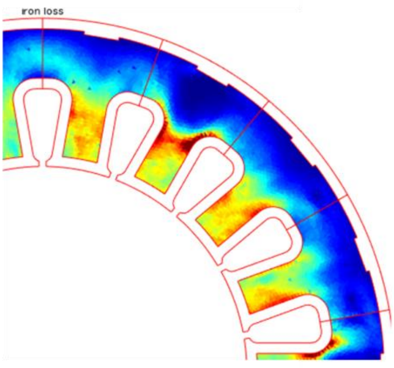
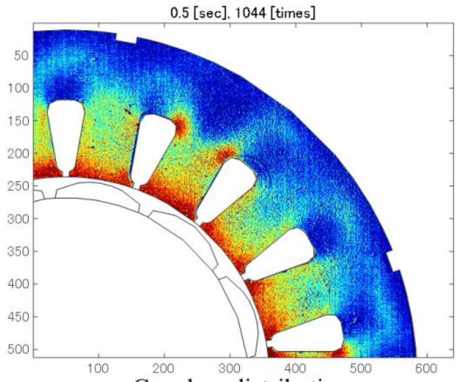
The motor core loss is evaluated as the total loss minus the known losses, including the copper loss and the mechanical loss. It is considered to be difficult to identify the main cause of core loss based on this evaluation method. In our previous study, we have proposed a method for measuring the core loss distribution by heat measurement using a thermographic camera for direct evaluation of the core loss [1]. Further, the ability to directly measure the core loss distribution of the motor core makes detailed analysis possible. Herein, we propose a method for identifying the correction coefficients by comparing the core loss distributions obtained by magnetic and heat measurements. The following figures show the core loss distributions of the permanent magnet motor obtained using magnetic and heat measurements. The correction coefficients give us an important information about the iron loss value from the thermal gradient value.



Core loss distribution
by magnetic measurement



Core loss distribution
by heat measurement

References:

[1] H. Shimoji, Bartosz E. Borkowski, T. Todaka, and M. Enokizono, IEEE Transactions on Magnetics, Vol. 47, No. 10, 4372-4375 (2011)

This research is partly supported by "Kyushu Bureau of Economy, Trade and Industry (METI-kyushu)" in Japan

Magnetic Performance of a Si-Fe Transformer Core under Sinusoidal and PWM Excitations

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Majority of power transformers are usually energised by sinüsoidal excitation. When transformers are subjected to non-sinüsoidal energization, additional harmonics would exist. In this study, localised losses and localised magnetostriction of a 20kVA 3-phase 3-limb T-joint transformer core under PWM excitation were investigated at different switching frequencies and modulation indices. These results were compared with those obtained under sinusoidal excitation. When PWM excitation is implemented, it is expected that there will be an increase in losses and magnetostriction due to the distortion of the magnetic flux waveform. At peak flux densities of 0.3T, 0.5T and 0.8T, the losses and strains at different locations of yoke, limb and central part of transformer core were obtained experimentally. Results, show that losses in some regions have increased by 20%. Overall losses under sinusoidal excitation at 0.3T was calculated as 0.15W/kg while under PWM excitation it increased to 0.3W/kg. Higher losses were observed at lower switching frequencies. Losses vary according to the location at the core. More than 20% increase in power losses is observed especially at the joint areas. It is estimated that the localised strain values could be increased by 15% under PWM excitation. Near the corner and T-joint, higher values of localised strain have been obtained taking into consideration the effect of lamination bending. This is because flux deviation occurred at the core joints.

This study is partially supported by Wolfson Center for Magnetics

The influence of surface shot peening laser processing on the magnetic properties of GO iron silicon steel

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Grain-oriented (GO) silicon steel represents conventional soft magnetic material having high permeability and low core losses along the rolling direction and is commonly used for cores of electric transformers. Its magnetic properties are closely related to the sharpness of {110}<001> crystallographic texture, i.e. the Goss texture. The improvement of core losses in grain-oriented steels is very important for the industry and could be carried out by using the refinement of their magnetic domains. It is already known that the desired effects can be achieved by laser scribing techniques.
In this paper, the unconventional shot peening laser treatment was used to study its effect on the resulting changes in magnetic domains structures, magnetic properties and mechanical stresses values in the area of interaction of high pressure plasma with surface of investigated GO steel. The conventional laser scribing process allow to effective to improve the final magnetic properties of electrical steels but on the other hand induce the damages of surface isolation layer. In our approach we cover the samples by inertial tamping layer which interaction with laser beam. During this interaction the high pressure plasma achieved which induce the pressure wave into the material under the laser interaction area. The conventional GO steel with silicon content 3% wt., taken from industrial line after final heat treatment, was chosen as an experimental material. The final domain structures were optimized in relation to the minimization of magnetic losses of the experimental material and to the optimization of mechanical stresses application on the surface. Also, the samples were subjected to magnetic measurements as well as nano-hardness and EBSD analysis of pressure affected zone before and after laser processing. The magnetic losses of experimental samples before and after individual shot peening laser scribing regimes were tested in DC magnetic field. These result show that the most significant coercitive reduction of 18% was obtained at optimized conditions of unconventional laser scribing technique.

This work was supported by Slovak Scientific Grant Agency VEGA, grant No. 2/0066/18 and No. 2/0073/19

Relationships Between Crystal and Magnetic Structures in $Bi_{1-x}AE_xFe_{1-x}Ti_xO_3$

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Perovskite-like compounds are widely known as model systems for studying the relationships between crystal structure and physical properties. Among them, magnetically-ordered ferroelectric oxides have attracted much attention in recent years. Such materials combine spin and electric dipole ordering in the same phase, thus providing the technologically important possibility to control magnetism with an electric field. While $BiFeO_3$ is the most thoroughly studied magnetic ferroelectric compound, the properties of its solid solutions remain a matter of intensive debate. In this work we show how variation in the chemical composition of $Bi_{1-x}AE_xFe_{1-x}Ti_xO_3$ (*AE*= Ca, Sr, Ba) multiferroics affects their crystal structure and magnetic behavior. The polycrystalline samples have been studied by X-ray diffraction, neutron powder diffraction, VSM-magnetometry, electron microscopy, and scanning probe microscopy techniques. It has been found that Ca/Ti and Sr/Ti substitutions suppress the cycloidal antiferromagnetic structure specific to the parent compound, thus stabilizing a weak ferromagnetic and ferroelectric state. The Ba/Ti-doped solid solutions retain the magnetic behavior characteristic of the pure $BiFeO_3$. The composition-driven changes in the magnetic properties of the $Bi_{1-x}AE_xFe_{1-x}Ti_xO_3$ perovskites correlate with the structural evolution, confirming the existence of tight coupling between the type of magnetic ordering and electric polarization / magnitude of oxygen octahedra tilting in these materials. It is assumed that the magnetostructural correlations reflect the pattern of chemical substitution-induced changes in the polarization- and octahedra rotation-related components of the Dzyaloshinskii-Moriya interaction.

This work was supported by the RSF (project 18-19-00307). Experimental investigations done at the CFisUC were supported by the FCT (projects UID/FIS/04564/2016 and IF/00819/2014/CP1223/CT0011).

Magnetization Study of the Low-Temperature Anomaly in some Terbium-Yttrium Iron Garnets

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The anomalous magnetic properties of the mixed terbium-yttrium iron garnet system ($Tb_xY_{3-x}Fe_5O_{12}$ (Tb_xY_{3-x}IG) in which the magnetic cations Tb^{3+} were partly replaced by nonmagnetic cations Y^{3+} ($0 < x < 3$) have not received considerable attention during the last decades. Furthermore, little attention has been paid to the study the influence of the Y^{3+} substitution on the low-temperature paraprocess phenomenon together with some concomitant effects which should cause sign anomalies near the so-called 'low-temperature Belov point' (T_B) [1] such those observed in the pure TbIG [2, 3] near T_B = 58 K [1]. In this work, magnetization measurements are performed in the 4.2-300 K range on two spherical single crystals with x = 0.37, and 2 in the case where each sample is allowed to rotate freely on itself under an high external magnetic field (H_{ex}) up to 20 T. Anomalies are observed in the range of T_B ~ 58 K in the temperature dependencies of some pertinent parameters in agreement with Belov'prediction for ferrimagnets with and without compensation point [1]. The effects of the magnetic anisotropy when H_{ex} is applied along the main directions in low and high magnetic fields are analyzed for the case of TbIG. All results are discussed in connection with the observed magnetodielectric effects for $H_{ex} \leq 0.2$ T [4] and with the significant hybridization between exchange magnon and ligand-field excitations of the Tb^{3+} ions around T_B [5].

References:

[1] K. P. Belov, Phys. Usp. 39, 623 (1996).
[2] M. Lahoubi, W. Wang, V. Varazashvili, J. Phys.: Conf. Ser. 827, 012014 (2017).
[3] M. Lahoubi, Physica B 536, 96 (2018).
[4] N. Hur, *et al.*, Appl. Phys. Lett. 87, 042901 (2005).
[5] T. D. Kang, *et al*., Phys. Rev. B 82, 014414 (2010).

Linking the differential permeability and loss coefficients

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Among all currently existing models, the core-losse decomposition as proposed by Bertotti[1] and coworkers is one of the most widespread and used to describe the iron losses in soft magnetic materials. In this work, we study the core-losses of non-oriented FeSi Epstein laminations with thicknesses spanning from 200µm to 650µm. This was carried out under sinusoidal induction waveform condition, frequencies from 5Hz to 2kHz and up to 1.8T.

Starting from physical considerations[1][2], we used the separation loss description with dynamical losses coefficients varying as function of the maximal flux density. As previously reported in [3], we observe a significant improvement of the loss description in all the studied frequency range. In the present work, the same loss coefficients variations is observed for all studied materials and directly correlated with the differential permeability defined from the normal curve. We interpret these variations as an image of the magnetic structure dynamic evolving with the magnetization process.

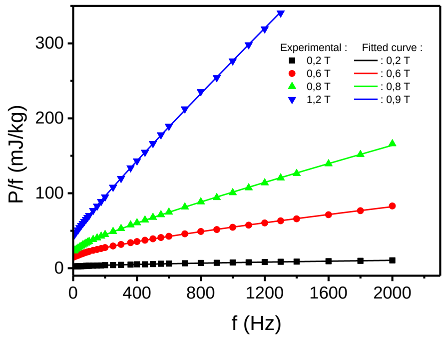

Fig 1 : Core-losses energy at a given Bmax as a function of the frequency. Points represents the experimental data obtained on 12 M800-50 Epstein sample cutted along the rolling direction. Solid lines is the result using:

$$\frac{P}{f} = K_h(B_{max}) + kcl(B_{max})\, f^2 B_{max}^2 + k_{exc}(B_{max})\, f^{0.5}\, B_{max}^{1.5}$$

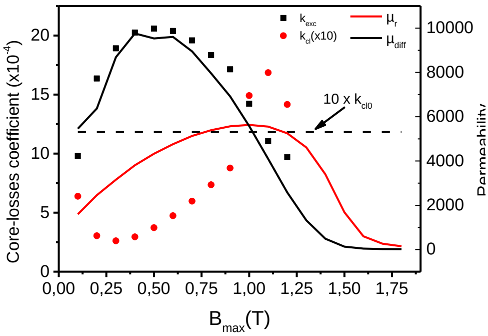

Figure 2 : Excess loss, k_{cl} coefficient, μ_r and μ_{diff} as a function of the maximal flux density in a M400-50A Epstein lamination. Points represents the measured coefficients, lines the permeability and dashed lines the theoretical classical coefficients : $k_{cl0} = \pi^2 d^2 \sigma / 6\rho$ with σ=2.2 MS/m the electrical conductivity, ρ the volume mass and d the lamination thickness.

References:

[1] G. Bertotti, IEEE Trans Magn, Vol. 24, No I (1988).
[2] R.H. Pry and C.P. Bean., Journal of applied physics, Vol 29, 532 (1958).
[3] D.M. Ionel, M. Popescu *et al.*, IEEE Trans. Industry Applications, Vol 42, 658 (2006)

Influence of Thickness of Electrical Steel Sheet on Magnetic Properties of Stator Core in Manufacturing Process

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In order to improve the efficiency of motors, it is important to suppress the deterioration of magnetic properties of electrical steel sheets imposed at the manufacturing processes and to reduce the iron loss due to it [1]. In this paper, we separately considered the effect of each manufacturing process such as stacking and welding on the deterioration of magnetic properties with attention to the difference in thickness of electrical steel sheet.

Table 1 shows the specifications of specimens. Two kinds of electrical steel sheets with the same assumed density and resistivity are compared because it is expected that their hysteresis losses are almost the same. The measurements were carried out by the magnetizing current method at 50 and 100 Hz for the iron loss separation and the measuring range of magnetic flux density is from 0.05 T to about 1.65 T at intervals of 0.05 T.

Fig. 1 shows the results of iron loss separation. W_h and W_e denote the hysteresis loss and eddy-current loss, respectively. W_hs for single sheet cases (specimen (s-1) and (s-2)) are almost the same. However, for the stacked specimens, W_h of specimen (a-1) is larger than that of specimen (a-2). It is considered that W_h is increased by the residual stress due to punching and adhesive impregnation. A similar tendency can be observed as the effect of welding (specimen (w-1) and (w-2)). It is experimentally confirmed that the difference of sheet thickness affects an increasing tendency in W_h at each manufacturing process. More detailed discussion will be reported in the full paper.

Table 1. Specifications of specimens.

Specimen	(s-1)	(a-1)	(w-1)	(s-2)	(a-2)	(w-2)
Shape	Single sheet	Stator		Single sheet	Stator	
Thickness [mm]	0.35	25	25	0.50	25	25
Number of welding points	0	0	8	0	0	8
Grade	M250-35A5			M290-50A5		
Assumed density [kg/dm^3]	7.60					
Resistivity [μΩcm]	54					

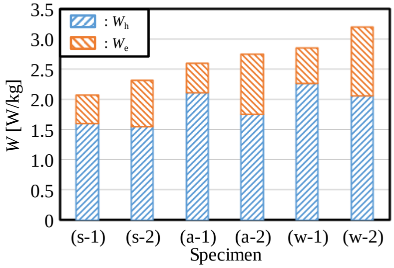

Fig. 1. Iron loss separation (1.5 T, 50 Hz).

Reference:

[1] K. Jeong, Z. Ren, H. Yoon, and C. S. Koh, "Measurement of Stator Core Loss of an Induction Motor at Each Manufacturing Process," *Journal of Electrical Engineering and Technology*, vol. 9, no. 4, pp. 1309-1314 (2014).

Iron Loss Calculation for Fe-Si Steels Based on Modified Steinmetz Equations under SPWM Excitations

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Iron loss prediction is an essential role to optimize the design of modern electrical devices. There are two ways to predict the amount of iron loss, use empirical method and build mathematical hysteresis model. Steinmetz equation, the well-known empirical equation, is widely used and valid only for sinusoidal flux. For non-sinusoidal flux, modified Steinmetz equations have been used to calculate the iron loss. This paper illustrates the comparative of iron loss calculation for soft magnetic materials under sinusoidal flux waveform and sinusoidal pulse width modulated (SPWM) excitation. Digital signal processing (DSP) is used to control the SPWM waveform and their characteristics (modulation index, switching frequency, etc.) in high frequency as experimental verification. Epstein Frame method, the standardized measurement method, is used to testing the various motor steels and the prediction of iron loss is calculated by the modified Steinmetz equations. In addition, results show that the iron loss prediction under SPWM excitations are quite different from the sinusoidal flux and the effect of harmonics are also taken into account. Improved Steinmetz equation gives the significant results of iron loss prediction rather than other Steinmetz based equation.

References:

[1] Amar, M., Kaczmarek, R. and Protat, F. (1994), “Prediction of power losses in silicon iron sheets under PWM voltage supply”, Journal of Magnetism and Magnetic Materials, Vol. 133 Nos 1/3, pp. 140-143.
[2] Barbisio, E., Fiorillo, F. and Ragusa, C. (2004), “Predicting loss in magnetic steels under arbitrary induction waveform and with minor hysteresis loops”, IEEE Transactions on Magnetics, Vol. 40 No. 4, pp. 1810-1819.
[3] Kaczmarek, R., Amar, M. and Protat, F. (1996), “Iron loss under PWM voltage supply on Epstein frame and in induction motor core”, IEEE Transactions on Magnetics, Vol. 32 No. 1, pp. 189-194.

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Influence of microstructure on the magnetic properties of Fe-P based soft magnetic alloy

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The advent of electric vehicles, has resulted in a demand to develop better soft magnetic materials with superior properties for high performance and energy saving. Currently non-oriented Si steel with a magnetic induction typically 1.7 – 2.0 T is the widely used material.[1]. In this context, we explore the Fe-P based soft magnetic material as an alternative to Si steel. Fe-0.4 wt.% P alloy was prepared adopting the conventional wrought metallurgical process of melting, forging, rolling with a subsequent aging treatment was compared with commercial Si-steel for its magnetic properties (M700-50A). The Fe-P alloy exhibited a high saturation magnetization (M_s ~ 2.0 T) and low coercivity (H_c ~ 43 A/m) which was better than M700-50A steel (M_s ~ 2.0 T, H_c ~ 77 A/m). The lower H_c value is attributed to the coarser grain structure of Fe-P (~330 μm) (Fig. 1a) compared to the finer grains of M700-50A (~30 μm). Transmission electron microscopic (TEM) revealed the presence of Fe_3P nanoprecipitates (2-4 nm) (Fig. 1b). The fine precipitates enhanced the resistivity of the alloy but not the H_c owing to the fine nature of precipitates much lower than the domain wall thickness. The texture study of Fe-P alloy shows the formation of {001}<100> cube and <100> α-fiber texture which improves the magnetic properties of the alloy. The role of P in obtaining these magnetically favourable features will be discussed understood through detailed microstructural analysis and fitting it to existing theoretical models.

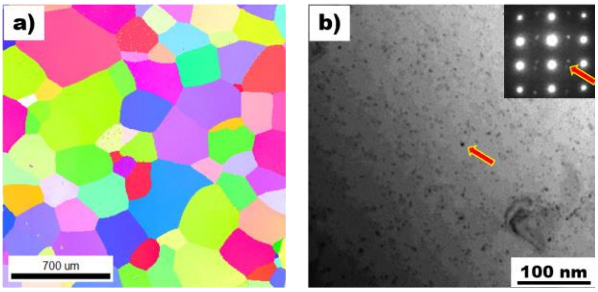

Fig.1(a) The Electron backscattered diffraction micrograph of Fe-0.4P aged sample showing the coarser equiaxed grain structure, (b) TEM image shows the presence of Fe_3P nanoprecipitates (marked by arrows) in α-Fe matrix and its SAED pattern (inset).

References:

[1] A. Krings *et al.*, IEEE Trans. Ind. Electron., 64, 2405-2414 (2017).

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Spin-wave diode

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Diode is an electronic device which is widely used in semiconductor technology. It has analogies in many branches of physics and in magnonics it was invented in 2015 [1].
We propose another model of spin-wave diode which is based on the effect of unidirectional wide-frequency-range coupling of spin waves in bilayered ferromagnetic system. This effect bases on Dzyaloshinskii-Moriya interaction and magnetostatic coupling and allows to propagate spin waves of given frequency in both layers in one direction but only in single layer in the opposite direction. Our spin-wave diode consists of two magnetic layers overlaping in determined length. Unidirectional coupling permits spin waves to transfer signal to the second layer when propagating in coupling direction (Fig. 1a), while in no-coupling direction the spin-wave transfer is strongly damped (Fig. 1b). The wide-frequency-range effect enables to use the device in a wide range of frequency and external magnetic field with high efficiency.

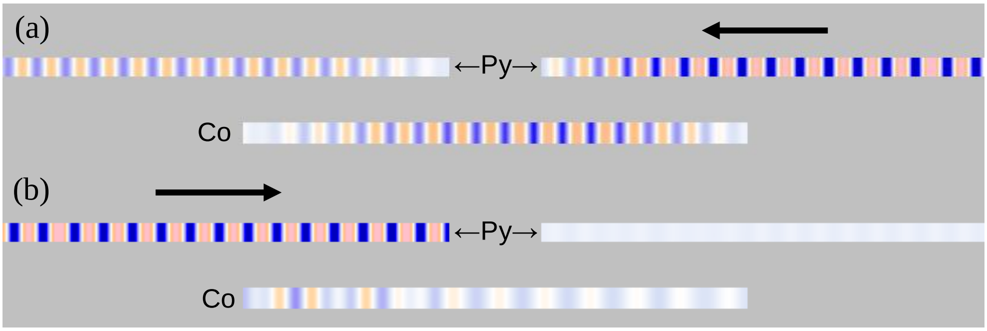

Fig. 1. Spin wave propagation in a diode along (a) the forward and (b) the reverse direction.

References:

[1] J. Lan, W. Yu, R. Wu, and J. Xiao, Phys. Rev. X 5, 041049 (2015).

This study was partially supported by National Science Center of Poland project Metasel UMO-2015/17/B/ST3/00118.

Effect of the HMTA Inhibitor on the Pickling Process of Non-Oriented Electrical Steel Sheet

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The study reproduces the industrial pickling of the 2%Si non-oriented electrical steel after hot rolling. Samples taken from the tail of a coil hot rolled by Steckel Mill were shot blasted and then pickled in HCl using different concentrations of the HMTA inhibitor. The steel surface was characterized by X-Ray and SEM. The inhibitor was characterized in pure state and in a commercial solution by FTIR. The hot band samples has showed an external oxidation of iron oxides besides an internal oxidation of silica and fayalite. The shot blasting remove mainly the iron oxides and the acid pickling remove the silica and fayalite. The addition of HMTA significantly reduces the attack on the base metal and is effective even in very small concentration. The best concentration was about 0,05% and this concentration leads to mass loss of 1,28% vs. 2,38% for pickling without inhibitor.

Developments on Soft Magnetic Composites with Double Layer Insulating Coating: Synergy between ZnO and B2O3

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This work presents the study and development of an iron based soft magnetic composite containing double layer insulating coating constituted of zinc oxide nanoparticles and vitreous boron oxide. The combination of these two insulating compounds improves significantly the electrical and magnetic behavior of SMCs due to a synergistic effect between the layers during processing. Dynamic losses were reduced nearly 78% and electrical resistivity was increased in almost 10 times for the double layered SMC compared to an SMC containing only vitreous boron oxide coating.
Moreover, the permeability was at least 10% higher in the double layered SMC than in the one coated only by ZnO nanoparticles. A mechanism responsible for the observed synergy is proposed in this paper based on the results of electrical resistivity, power losses and relative magnetic permeability of produced SMC samples.

References:

[1] J.M. Silveyra, *et al.*, Science. 362 (2018).
[2] H. Shokrollahi, K. Janghorban, J. Mater. Process. Technol. 189 (2007) 1–12.
[3] E.A. Périgo, *et al.*, Appl. Phys. Rev. 5 (2018).
[4] G. Tontini, *et al.,* J. Magn. Magn. Mater., in press.
[5] A. Watanabe, *et al.*, US20130181802A1, 2013.
[6] W. Ding, *et al.*, J. Magn. Magn. Mater. 378 (2015) 232–238.
[7] W. Ding, *et al.*, J. Supercond. Nov. Magn. 27 (2014) 239–245.
[8] T. Gheiratmand, *et al.*, J. Supercond. Nov. Magn. (2017) 1–6.
[9] M.V.F. da Luz, *et al.*, WO2018035595A1, 2018.
[10] L. Liya, *et al.*, CN 103177838 B, 2016.
[11] G. Vachon, C. Gelinas, US8911663B2, 2014.
[12] P. Kollár, *et al.*, J. Magn. Magn. Mater. 327 (2013) 146–150.

New Barkhausen Noise Probe for Measuring Stress of Ferromagnetic Materials

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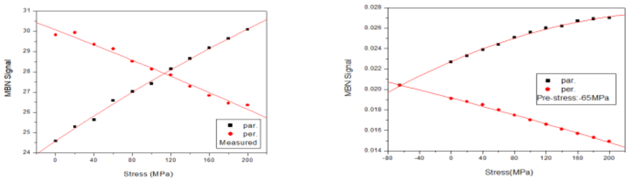
Barkhausen effect is the noise due to the abrupt changes in magnetization when a ferromagnetic material is being magnetized on application of a continuously time-varying magnetic field [1]. Through magnetoelastic coupling, the Barkhausen Noise (BN) changes with the mechanical stress state in the material [2]. BN is using for nondestructively measuring the structual defects, such as grain boundaries, dislocations, local mechanical stresses, inclusions, and precipitates of steel material [3].

In this study, we develped the new BN probe for measuring the stress type applied to the ferromagnetic material without the previously constructed database.

The photograph of fabricated probe is shown in Fig. 1. The probe is composed two perpendicular yokes wound the primary coils and sensing coils. The signals measuring by the two sensing coils is shown in Fig. 2. Fig 2-(a) and (b) are the measuring signals from the pre-compressive and pre-tensile stressed specimens, respectively. The point of intersection is the right of the origin when the compressive pre-stess is applied, it is the left as the tensile pre-stress is applied.

Fig. 1. Photograph of Probe.



(a) (b)

Fig. 2. Measured BN signals. Under (a) pre- compressive, and (b) tensile stress.

References:

[1] D. Jile, Introduction to Magnetism and Magnetic Materials, Chapman and Hall, London, 1991, pp. 97-98.

[2] K. Kwun, G. L. Burkhardt, NDT International, 20(3), 167 (1987).

[3] R. Ranjan, *et al.*, J. Appl. Phys. 61(8), 3196 (1987).

Acceleration technique of flux waveform control with FPGA

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In AC magnetic property measurement of ferromagnetic materials, the magnetic flux density waveform should be controlled to be a sinusoidal waveform for quantitative evaluation, because the ferromagnetic materials have usually nonlinear magnetic characteristics. Feedback control is often employed [1], but in the non-linear region that the magnetic flux density is very large, the convergence of the waveform control deteriorates due to the strong non-linearity and then measurement time increases.

In this research, we employed the FPGA (Field-Programmable Gate Array) in the magnetic flux density waveform control to obtain the criterion of measurement, in order to reduce measurement time. In this paper, we demonstrate the effectiveness of the proposed magnetic flux waveform control method with the FPGA in shortening the control time.

In the waveform control method, the various initial conditions necessary to the measurement set in a PC are sent to the FPGA together with the target voltage waveform, and then the FPGA starts feedback control from the data. This method is applied to the magnetic property measurement of an electrical steels sheet (50A470) with a single sheet tester. The maximum magnetic flux density was changed from 0.1 T to 1.9 T and those amplitude and strain ratio for the targeted sinusoidal waveform were set to be 0.5% or less. The result shows that the total measurement time of the proposed method with FPGA can be considerably reduced in comparison with one with the conventional software-based method.

References:

[1] K. Matubara, N. Takahashi, K. Fujiwara, T. Nakata, M. Nakano and H. Aoki, IEEE Trans. Magn., Vol. 31, No. 6 pp. 3400-3402 (1995).

The role of spin-flip assisted or orbital mixing tunneling on transport through strongly correlated multilevel quantum dot

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Using the slave boson Koliar-Ruckenstein approach (SBMFA) for N level Anderson model, we compare fully symmetric SU(N) Kondo resonances occurring for spin and orbital conserving tunneling with many-body resonances for the dot with broken symmetry caused by spin, orbital or full spin-orbital mixing. As a result of interorbital or spin flip processes new interference paths emerge what manifests by the appearance of antibonding Dicke like and bonding Kondo like resonances. Positions and widths of these resonances depend on degeneracy, types of mixing and their strengths. In the limit of maximal mixing i.e. when direct and indirect hopping integrals take the same values the antibonding states decouple from the leads and they do not participate in transport. In this case the analytical expressions for the characteristic resonance SBMFA temperatures and linear conductances for arbitrary N are found. Small deviations from the maximal mixing results in dramatic changes of nonlinear conductance and thermopower.

A Comparison between Core Losses in Particular Type of Wound Core Called Octagonal Wound Core and Iron Losses of GOES after Tensile Test

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Wound cores are widely used as magnetic cores for transformers, reactors. In order to realize energy-saving society, it is important to decrease both energy losses of wound cores and energy for core manufacturing processes. In the mid-1990's AEM Cores Pty, Ltd. started producing new type of wound core[1]. This type of wound cores is called octagonal wound core(OWC)[2]. According to the manufacturing method, since the grain-oriented electrical steel sheet(GOES) is bent, the shape is retained and the annealing step is not an essential step. But local strain is applied to GOES, which is one of the influences of core loss deterioration. In order to decrease energy losses of OWC, it is important to find out the influences of local strain. However, this influence of itself has not been evaluated yet. Our approach is based on tensile test of GOES. Iron losses were also measured after tensile test of GOES. We compared iron losses after conducted tensile test of GOES and core losses of OWC.

References:

[1] AEM Unicore-Innovation in Transformer Cores and Manufacturing Data catalog. Gillman, Australia: AEM cores PTY, LTD.,Oct. 2008.

[2] I. Hernandez, J. C. Olivares-Galvan, P. S. Georgilakis, and J. M. Canedo "A Novel Octagonal Wound Core for Distribution Transformers Validated by Electromagnetic Field Analysis and Comparison With Conventional Wound Core," IEEE Trans. Magn., vol. 46, no. 5, pp. 1251-1258, May. 2010.

Loss decomposition in plastically deformed and partially annealed steel sheets

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The effect of applied and residual stresses on the magnetic properties of steel sheets has been largely investigated in the literature, with main interest focused on the quasi-static properties, namely the coercive field and permeability. To predict the actual behavior of the magnetic devices at their working frequencies, the dynamics properties of the laminations, in particular the excess loss should be assessed. The increase of the hysteresis loss component in plastically deformed non-oriented Fe-Si alloys can be counterbalanced by a decrease of the excess loss [1]. In this work we discuss, in particular, the energy loss versus frequency behavior in 0.50 mm thick Fe-Si 3wt % sheets under the following conditions: finished product (Material 1, reference); *plastically deformed sheets* by an additional pass with 2% thickness reduction (Material 2); *annealed* at 600°C or 660°C for 2 hours after plastic deformation (Materials 3 and 4). Recovery Annealing, without recrystallization, leads to rearrangement and removal of crystallographic defects introduced by the plastic deformation. Fig. 1 shows the measured loss in the four materials, at frequencies sufficiently low to neglect the skin effect. The differences between the loss figures are therefore due to the hysteresis and excess loss components. The increase of excess loss with frequency is weaker in the plastically deformed sheets, in spite of higher hysteresis loss. According to the Statistical Theory of Losses, this effect descends from an increased number of active magnetic objects, due to plastic straining. It is concluded that the homogenizing effect of the plastic deformation on the magnetization process can overcome the detrimental effect of increased material coercivity and lead to decrease of the loss at sufficiently high frequencies.

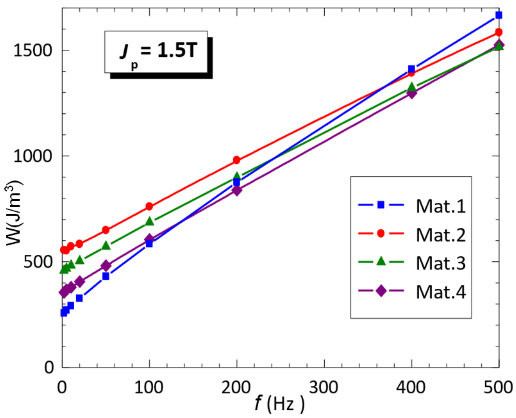

Figure 1: Measured loss for J_p =1.5 T

References:
[1] D.L. Rodrigues *et al.*, IEEE Trans. Magn. v. 50, no 4, 2002204 (2014).

Hysteretic properties of the magnetic linear birefringence and magnetization in the antiferromagnetic crystal of $LCoPO_4$

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Lithium orthophosphates of 3d-transition elements with an olivine structure are known as crystals, in which the antiferromagnetic ordering of spins is accompanied by a loss of the centre of symmetry, and spontaneously ordered $LiMPO_4$ crystals are linear magnetoelectrics. LiCo-orthophosphate is distinguished by the fact that it has a number of physical properties that do not correspond to the symmetries of ionic and spin structures, which were repeatedly determined in diffraction studies of X-rays and neutrons. The main ones are: weak ferromagnetism, a hysteresis of the magnetic field induced birefringence of linearly polarized light and the very weak piezoelectric polarization revealed by a acoustic method recently.
In the report the results of research of the magnetic hysteretic properties of magnetic birefringence in Faraday geometry (**k**||**H**||b) and magnetization (**M**||**H**||b) of $LiCoPO_4$ at different temperatures presented. The existence of magnetic hysteretic properties does not coincide with the view on the magnetic structure of olivine as a homogeneous one, and absence of the centre of symmetry in the crystal that is necessary for existence of the piezoelectric effect was not revealed in diffraction experiments.
In our opinion, the results presented in the report allow us to associate the observed birefringence magnetic hysteresis with the irreversible magnetization of the anisotropic spin clusters of Co^{3+} existing in the nominally pure $LiCoPO_4$ crystal. The crystal does not contain impurities, but as a result of auto-doping, it can contain a sufficient number of nonstoichiometric pairs of antisite defects (Co^{3+}_{Li} / Li^{0}_{Co}). There is experimental evidence that the antisite defects and their aggregates are created at high-temperature conditions of the growth of LiFe-, LiCo- and LiNi-olivine single crystals and at their heat treatment [1-3]. These results raise the question whether or not the observable unexplained properties of $LiCoPO_4$ can be caused by distortions of the ion crystal lattice created by its own nonstoichiometric defects.

References:

[1] A. Craig, J. Fisher, et al., Chem. Mater., 20, 5907–5915 (2008).
[2] Q.D. Truong, et al., Chem. Mater., 26, 2770–2773 (2014).
[3] M.K. Devaraju, et al., Scientific Reports, 11041-11048 (2015).

Experimental Evidence of Non-Negligible Imaginary Part of Spin Mixing Conductance

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The paper concerns experimental verification of the magnitude of imaginary part of spin mixing conductance in bilayers comprising heavy metals. We present results of broadband ferromagnetic resonance studies on heterostructures consisting of Finemet soft magnetic films covered by Pt and Ta wedge layers with the aim to observe spin pumping effects and to evaluate both the real and imaginary parts of the spin mixing conductance. The experimental results are analyzed in the framework of a recent microscopic theory and confirm the important role of spin-orbit interactions at the interface. In particular, we show that the imaginary part of spin mixing conductance cannot be regarded as negligible and we discuss its influence on magnetization dynamics. For Finemet|Ta bilayers, the ratio $\mathrm{Re}\left[g_{eff}^{\uparrow\downarrow}\right]/\mathrm{Im}\left[g_{eff}^{\uparrow\downarrow}\right] = 0.38$. In accordance with the underlying theory, we propose an experimental method for the estimation of the interface spin-orbit interaction. Our result may shed light on the magnetization switching mechanism in spin orbit torque MRAMs.

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Interest of square voltages for Solid State Transformer operation with Grain Oriented Electrical Steel wound core

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Solid-state transformers (SST) are becoming key elements of electrical grids when it comes to integration of intermittent renewable large energy sources such as wind farms and solar power plants [1]. The SST cell basic topology consists of two power electronic converters connected via a medium frequency transformer. Wound core transformers manufactured with thin Grain Oriented Electrical Steel (GOES) are interesting solutions for designing high power SST cells with a good technological and economic compromise [2]. The nowadays technology in power electronics and controllers make it possible to generate voltage waveforms close sinus but this is at the expense of complicated topologies and complex monitoring. We chose to go for simple rectangular waveforms to propose a simple compact one phase transformer set up.
The main focus of the paper consists in comparing the losses in the GOES wound-core medium frequency transformer under square and sine voltage wave excitations. For that purpose, a finite element model methodology is proposed to compute eddy current losses within one single sheet and extrapolate the result for the whole wound core. This model is completed by an analytical one valid for linear applications. The results show that, at the same frequency and peak flux density, the Eddy core losses are lower for square voltage than for sine one. Measurements performed on several GOES wound core show the same trend between the losses induced by the two cases. The paper brings explanation about the observed behavior based on the magnetic field and eddy currents density distributions within one lamination at the same operating conditions. This result is supported by the work presented in the reference [3].

References:

[1] B. Liu, Y. Zha, T. Zhang and S. Chen, ”Solid state transformer application to grid connected photovoltaic inverters,” International Conference on Smart Grid and Clean Energy Technologies (ICSGCE), Chengdu, 2016.
[2] S. Hamdinou, D. Roger,, M. Rossi, Th. Belgrand, “Medium Frequency Power Transformer Built With Grain-Oriented Rolled Cores,” Conference CPE-Powereng, Sonderborg (DK), April 2019.
[3] D. Y. Chen, “Comparisons of high frequency magnetic core losses under two different driving conditions: A sinusoidal voltage and a square-wave voltage,” *1978 IEEE Power Electronics Specialists Conference*, Syracuse, NY, 1978, pp. 237-241.

Soft magnetic composites based on Fe fibers

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This paper present the preparation and characterization of a new type of soft magnetic composites (SMC) which is based on long Fe fibers. Generally, the SMC are obtained via powder metallurgy route from ferromagnetic powders that are coated with an insulating layer and compacted to the desired shape [1, 2]. Our approach consist in the replacement of the ferromagnetic particles with long Fe fibers (the length of the fibers is in the order of meters) with a diameter of about 100 µm. The surface of the fibers was covered with different amount of Araldite polymer (ranging from 0.25 to 1.5 wt.%) witch will serve as insulating material. The as prepared fibers were subjected to compaction by cold pressing at the pressures of 500, 600 and 700 MPa and then polymerized at 180 °C for 1 h in air. The AC magnetic properties of the toroidal compacts were determined at a maximum flux density (B max) of 0.1 T in the frequency range of 50 Hz–10 kHz. For comparison reasons, SMC compacts based on pure Fe and Ni_3Fe powders were prepared in identical conditions. The obtained results clearly indicate that the fiber based soft magnetic composites can be a promising candidate to fill the gap between magnetic cores based on Fe-Si laminates and magnetic cores based on soft magnetic ferrites.

References:

[1] H. Shokrollahi, K. Janghorban, , J.Mater. Process. Technol., 189, 1-12 (2007).
[2] B.V. Neamţu, M. Nasui, T.F. Marinca, F. Popa, I. Chicinaş, Surf. Coat. Technol. 330, 219 – 227 (2017).

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Temperature sensor based on magnetocaloric materials

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Nowadays the temperature measurements [1, 2] of thin films of soft magnetic materials is a crucial issue e.g. in spincaloritronics [3]. In this paper the realization of a temperature sensor based on soft magnetic materials containing lantanium is given. In the developed sensor the temperature gradient was obtained contactless due to the laser illumination. Deterioration of magnetic properties due to temperature rise was measured in a closed magnetic circuit with pick-up coils. Curie temperature of presented sensor was close to the room temperature and therefore there is a wide variety of potential applications. The developed sensor can be useful during the investigation of thin films magnetic properties since the small size of tested materials frequently does not allow for thermal imaging.

References:

[1] M. Ghahremani, *et al*., IEEE Transactions on Magnetics, 48, 3999-4002, (2012).
[2] A. P. Kamantsev, *et al*, Journal of Magnetism and Magnetic Materials, 440, 70-73, (2017).
[3] B. Guzowski, *et al.*, Acta Physica Polonica A, 133, 541-543, (2018).

Localised Flux Density Distribution around Holes on Electrical Steel: Prediction and Calculation

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Localised flux density orientations are closely related the degraded area around the cut edge or a hole. Artificial neural networks (ANN) and MATLAB® Curve Fitting Toolbox™ are useful tools in prediction and calculation of magnetic properties of electrical steels [1, 2]. A 4-node input layer and 1-node output layer model with three hidden layers, and full connectivity between nodes was developed (Fig. 1). The input parameters were hole size, cutting method, induction frequency and bulk flux density while the output parameter was localised flux density due to the search coil located at the angles 0°, 25°, 45° and 65° corresponding to the centre of hole and rolling direction. The previous data obtained was used for training the proposed ANN model. Minimum correlation coefficients and RMS error for the localised flux density were found to be 0.99 and 0.09 respectively after the network was trained. After the network was tested using untrained data minimum correlation coefficient and RMS error for localised flux density was found to be 0.98 and 0.04 respectively. A simple analytical equation as depending on experimental results has been determined by using MATLAB® Curve Fitting Toolbox™ for localised flux distributions around the hole (Fig. 2). The results obtained by using the proposed ANN model and analytical equations are in good agreement with experimental results previously reported.

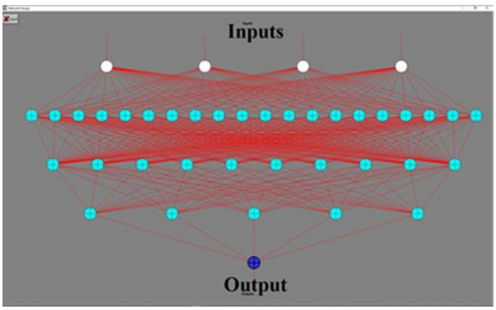

Fig. 1. Developed ANN model

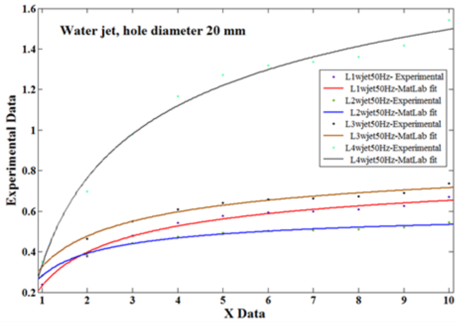

Fig. 2. Variation of localized peak B_m.

References:

[1] G. K. Miti, A. J. Moses, N. Derebasi, D. Fox, "A neural network-based tool for magnetic performance prediction of toroidal cores", J. Magn. Magn. Mat. vol. 254, pp. 262-264, 2003.

[2] N. Derebasi, "Effect of geometrical factors on magnetic induction distribution of toroidal cores using numerical methods", J. Supercond. Nov. Magn. vol. 28, no. 3, pp. 767-771, 2015.

Defects Classification in the Pulsed Eddy Current Signal using Machine Learning

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Local wall thinning is a point of concern in almost all steel structures such as pipe lines covered with a thermal insulator made up of materials with low thermal conductivity (fiberglass or mineral wool). Pulsed eddy current (PEC) is promising technology to monitor the local wall thinning such as corrosion under insulation (CUI) and flaw accelerated corrosion (FAC) [1]. The purpose of this study is to develop the new technology which identify these defects without removing the insulation. The actual thickness of the test piece was measured using an Olympus ultrasonic equipment. The specimens were machined with A106 Gr-B pipe length of 1500 mm and a thickness of 12.85 mm, with step. To identify the step difference from PEC signal machine learning methods such as principle component analysis (PCA), independent component analysis (ICA), and support vector machine (SVM) technology were applied [2]. PCA and ICA are investigated for feature extraction and compared for classification results using SVM. The wall thinned pipe covered with insulation are used for classification. The experimental results show that the proposed methods have great potential for in-situ defect inspection of pipeline covered with insulation.

References:

[1] B. Lebrun, Y. Jayet, J.C. Baboux, Materials Evaluation 53 1296–1300 (1995).
[2] L.J. Cao, K.S. Chua, W.K. Chong, H.P. Lee, Q.M. Gu, Neurocomputing 55 321–336. (2003)

Modelling Hysteresis in Soft Magnetic Materials Using LSTM

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Quasi-static and dynamic hysteresis behavior in soft magnetic materials is directly related to the energy losses in electrical machines. This time-dependent nonlinear relation between the magnetic induction B and magnetic field strength H has been studied for decades using several modelling techniques, one of which being neural networks. Feed-forward neural networks have been used as function approximators to model static, dynamic, unidirectional, bidirectional magnetization loops and corresponding iron losses [1] – [3]. These traditional neural networks achieve reasonable accuracy but are subject to the well-known vanishing gradient problem. LSTM neural networks, which were developed in 1997 but only recently gained popularity, provide a solution to this problem as their architecture allows for the memorization of specific values over arbitrary time intervals. This is specifically interesting for application in hysteresis modelling, because static magnetic hysteresis behavior is defined by the extreme values of the magnetic field strength H. This paper explores the capabilities of LSTM neural networks for modelling static and dynamic hysteresis. A dataset containing hysteresis loops is obtained using magnetic measurements on NO27 electrical steel. This dataset is used for training and testing the model using the Keras library. The performance of LSTM neural networks is tested using a validation set of BH loops. Also, the possibilities of LSTM in predicting iron losses for arbitrary excitation waveforms is tested and compared to realistic waveforms occurring in switched reluctance machines. The results show that LSTM neural networks perform well for static and dynamic hysteresis, and that accurate magnetic material behavior can be estimated for arbitrary excitation waveforms.

References:

[1] F. Sixdenier, *et al.*, JMMM 320.20, e992-e996 (2008).
[2] D. Makaveev, *et al.*, IEEE Trans. on magnetics 38.5, 3189-3191 (2002).
[3] D. Makaveev, *et al.*, JMMM 254, 256-258 (2003).

Magneto thermic characterization of forged steel used in claw pole machine

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During the operation of claw pole (CP) machine, the magnetic core temperature increases. In some hot spots, it exceeds 150°C. As a consequence the core electromagnetic properties considerably change, impacting the machine performances [1]. In such a case, a deep knowledge of the electromagnetic behavior in function of the temperature is required.

In our work, the CP rotor made of a forged bulk material needs a specific study. The CP magnetic properties heterogeneity and the claw shape made it necessary to extract bulk parallelepiped samples and use a miniaturized SST to characterize them [2]. Moreover, the chemical composition of the CP material is different from usual electrical steel, which makes it more sensitive to magnetic aging (%Si<1%)[3], as shown in Figure 1. To that end, this work proposes a specific methodology to characterize the electromagnetic properties of CP as a function of the temperature in order to better predict the machine electrical performances.

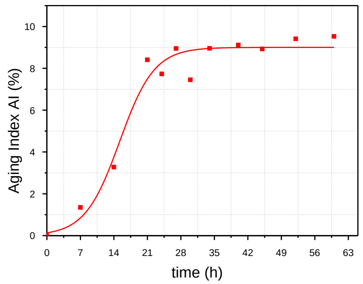

Figure 1: Behavior of the ageing index as a function of time for CP sample aged at 180°C, (AI=$\frac{W_{after\ aging}-W_{before\ aging}}{W_{before\ aging}}$).

References:

[1] M. Nakaoka, *et al.*, *IEEJ Trans. Fundam. Mater.*, vol. 125, no. 1, pp. 63–68 (2005).
[2] M. Jamil, *et al.*, 2dm 2018, Grenoble, France, (2018).
[3] S. K. Ray and O. N. Mohanty, *J. Magn. Magn. Mater.*, vol. 28, no. 1, pp. 44–50, Jul. 1982.

Design and assessment of a Solid-State Transformer built around a thin grain oriented electrical steel wound core

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The complexity of the electric grid has increased due to the growth of renewable energy sources (wind farms, photovoltaic plants, etc.). New technologies are needed to ensure proper monitoring of energy flows and flexible operation of the grid [1]. Solid-State Transformer (SST) is one of these. It can also be used in transportation systems as railway, more electric aircrafts or marine equipment [2]. SST offers the benefit of being able to be combined together as modular structures. Each of a so called elementary cell is composed of two static converters connected via a medium frequency transformer (MFT). The MFT is a critical part to the SST cell ensuring voltage adaptation and galvanic insulation. To transfer the highest possible power and having the lesser module to combine to avoid a complexity in monitoring the whole structure, the challenge is to be able to manufacture elementary cell as powerful as possible.

The paper deals with the design of a high-power SST cell using proven reliable technologies: standard medium voltage IGBTs with simple control strategies, medium frequency (MF) transformer built with Grain-Oriented Electrical Steel wound cores and high temperature organic coils. Previous measurements show that, at same peak flux density and operating frequency, core losses can be lower for square wave voltages than for sine ones [3;4]. This paper describes the process used for the design of such SST cell. The compact MF transformer operates at 1.6T and 2kHz with a core warmer than the windings. The design is very compact and the specific power ratio is 2.2 kW/kg with an efficiency of 96% for a 30kW SST cell. Based on the first results, it appears some room for further improvement.

References:

[1] Huber, Jonas E. and Johann W. Kolar. "Volume/weight/cost comparison of a 1MVA 10kV / 400 V solid-state against a conventional low-frequency distribution transformer. "2014 IEEE Energy Conversion Congress and Exposition (ECCE). IEEE, 2014.

[2] She, Xu, and Alex Huang. "Solid state transformer in the future smart electrical system." 2013 IEEE Power & Energy Society General Meeting. IEEE, 2013

[3] Hilal, Alaa, et al. "A Single-Phase Two-Winding Transformer Dynamic Model for Circuit Simulators." Soft Magnetic Materials Conference-MM22. 2015.

[4] Chen, D. Y. "Comparisons of high frequency magnetic core losses under two different driving conditions: A sinusoidal voltage and a square-wave voltage." IEEE PESC, 1978.

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Use of Low-Loss Electrical Steels in a High-Speed Machine

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The application of high-speed rotating machines, with significant impacts in specific engineering fields, has rapidly grown in recent years thanks to the development of electronics, digital processing, and control technologies [1]. However, these machines generally come with relatively low power because of the heat dissipation drawback. Although losses increase as frequency increases, particularly magnetic losses, the diameter is maintained small so that the machine can withstand mechanical stresses. Higher power can be obtained by improving machine efficiency. At extremely high speed, one can consider the replacement of classical electrical steel in the magnetic circuit with the low-loss grade as a promising solution. In this research, we propose an analysis that reports the potential of studied materials including SiFe 6.5% silicon, SiFe thin-gauge NO20 and amorphous ribbon. Their intrinsic magnetic properties are characterized and then used for FE simulations. A simplified mockup [2] was developed for the pre-design phase giving preliminary ideas about the accuracy of power losses estimation performed in simulations. Finally, a PM machine prototype with an interchangeable stator is developed which provides a complete analysis taking into account the influencing factors of the manufacturing process on losses.

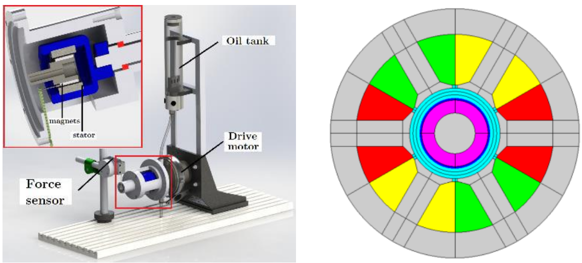

Figure 1 The mockup and the machine prototype

References:

[1] D. Gerada et al.« High-Speed Electrical Machines: Technologies, Trends, and Developments », *IEEE Trans. Ind. Electron.*, vol. 61, no 6, p. 2946-2959, juin 2014.

[2] A. T. Vo et al. , « An analysis of power losses in nanocrystalline and thin-gauge non-oriented SiFe materials for application to high-speed electrical machines », *The European Physical Journal Applied Physics*, 2019.

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Analysis and Dynamic Modeling of Magnetic Properties for SiFe Steel Under DC-Biased Magnetization

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Extensive reports point out that the magnetic components in electrical equipment could suffer from DC-Biased excitations, which leads to the degradation of material properties and increase of core loss. A dynamic hysteresis model, which combines the Tellinen model and Thin Sheet Model[1-2], is proposed in this paper in order to characterize the magnetic properties of grain-oriented SiFe sample 30Q120 under DC-Biased magnetization. This model adopts a B-dependent function instead of a constant coefficient when considering the excess field component. Only static major hysteresis loops and hysteresis loops under sinusoidal magnetization obtained by Epstein frame are demanded for parameter identification. The DC flux B_{dc}, which can't be measured directly is calculated using modified iterative method[3] to acquire the real hysteresis loops under DC-Biased magnetization of different B_m (maximal value of AC flux density), as shown in Fig. 1. Finally, modeling results are compared with experimental results as shown in Fig. 2. It can be seen that the model matches the experimental results well, accuracy of this dynamic model has been verified.

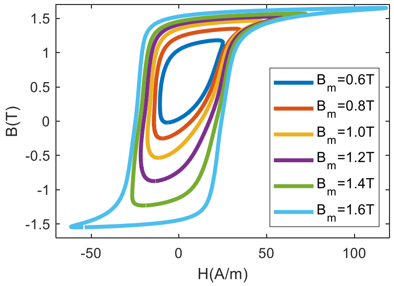

Fig. 1. Hysteresis loops under DC-Biased magnetization (f = 50Hz, H_{dc} = 5A/m).

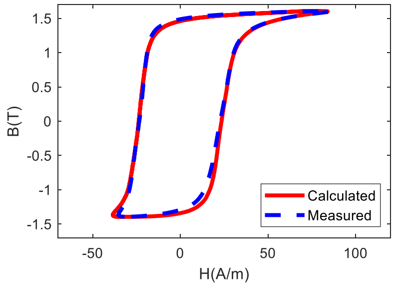

Fig. 2. Calculated and measured hysteresis loops under DC-Biased magnetization (f = 50Hz, H_{dc} = 5A/m, B_m = 1.5T).

References:

[1] J. Tellinen, *IEEE Trans. Magn.* 34 (1998) 2200.
[2] Zirka, S. E., et al., *IEEE Trans. Magn.*, 42 (2006) 3177.
[3] Xiaojun Zhao, et al., *IEEE Trans. Power Del.* 26 (2011) 475.

Highly Resistive Co-Sputtered Soft Magnetic Thin Films for High-Frequency Applications

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Conventional power converters use bulky ferrite magnetic cores for energy storage and are not suitable for miniaturisation through integration. The greatest level of miniaturisation will be achieved by the complete integration of the power supply onto silicon, i.e. Power Supply on Chip (PwrSoC). This level of integration requires operation at very high switching frequencies (>20 MHz), and hence there is a demand for high-performance magnetic materials that can operate with very low magnetic core losses at these frequencies. As a result of their ultra-soft properties, amorphous magnetic thin films serve as excellent candidates for these applications. The high-flux density (B_s >1.5 T), ultra-low coercivity (H_c<1 Oe), and high resistivity (ρ >100 μΩ cm) of amorphous materials are critical in reducing core losses and increasing device performance. However, when the frequency of these devices approaches the MHz range, the eddy current losses, W_e, significantly outstrip the hysteresis losses *as* $W_e \alpha f^2$, hence suggesting a need to develop novel materials with high resistivity.

With this in mind, the present study is focused on developing a soft magnetic amorphous material of high resistivity while maintaining ultra-soft magnetic properties along with uniaxial magnetic anisotropy for high-frequency applications. We have demonstrated how the co-sputtering of an amorphous Co-Zr-Ta-B alloy with a suitable non-ferromagnetic oxide (SiO_2) can produce a further amorphous alloy with a higher resistivity (ρ > 225 μΩ cm) compared to its amorphous source [1]. The significant improvement in resistivity was largely attributed to the greater atomic percentage of non-metallic elements and increasingly denser amorphous atomic structure. The resulting material retains its high flux density (B_s > 1 T), low coercivity (H_c <1 Oe) and in-plane uniaxial anisotropy. Further, the sputtering powers of Co-Zr-Ta-B (250-500 Watts) and SiO_2 (100-250 Watts) were varied to tune the permeability (μ=200-500) and ferromagnetic resonance (f_{FMR}=1-2GHz) of the materials to be used for a broad range of high-frequency drive applications.

References:

[1] Masood A, McCloskey P, Mathuna CO, Kulkarni S. Co-based amorphous thin films on silicon with soft magnetic properties. AIP Adv. 2018;8(5).

Magnetic response of the La(Fe,Mn,Si)$_{13}$H$_x$ alloys with multiple phase transitions

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At present, La(Fe,Mn,Si)$_{13}$H$_x$ alloys belong to the group with the most prospective applicative potential as far as active magnetic regenerators (AMR) are concerned [1]. In these alloys a strong MCE is observed in the field region below 1.5 T and for a wide temperature range above the room temperature [2]. The broadening of the range for AMR working temperature requires that La(Fe,Mn,Si)$_{13}$H$_x$-based components tailored for different Curie points be connected [3]. The outcome thermo-magnetic properties of such composite AMRs are nonlinear and depend significantly on temperature as well as on ferromagnetic interactions between components [3]. The present work contains the results of study on magnetic properties caused by temperature variations in magnetocaloric AMR components based on La(Fe,Mn,Si)$_{13}$H$_x$ alloys. An experimental study of transient magnetic states caused by temperature variations has been carried out for a sandwich sample made of three different layers, thus exhibiting three phase transitions at temperatures from the range 298-318 K.
The presented approach allows one to develop a behavioral model and to optimize the magnetic excitation systems of the MCE effect in AMRs featuring multiple phase transitions.

References:

[1] Gutfleisch O., *et al.*, Adv. Mater., vol. 23, no. 7, pp. 821-842, 2011.
[2] Krautz M., *et al.*, J. Alloy Compd., vol. 598, pp. 27–32, 2014.
[3] Radulov I.A., *et al.*, IEEE Trans. Magn., vol. 53, no. 11, 2502907, 2017.

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Scaling analysis of phase transitions in magnetocaloric alloys

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LaFeCoSi alloys are representatives of soft magnetic materials that exhibit a magnetocaloric effect at room temperature and thereby can be used in magnetic cooling systems [1]. In La-based magnetocaloric alloys, structural or ferro–paramagnetic phase transitions can be observed at temperatures close to the room temperature [2,3]. The phase transitions can be described analytically using the scaling theory, which allows one to determine critical exponents and their relationships in the form of scaling laws [3,4].
Recently, the scaling exponents α and β, related to energy dissipation in magnetocaloric alloys, were determined at three temperatures (293.5, 296.5 and 299.5 K), using the scaling approach based on the homogenous function in general sense [5,6]. It was found that the scaling exponents revealed a strong dependence on temperature, which changed its trajectory in the neighbourhood of the temperature close to structural phase transition (296.5 K). It indicated the existence of universality classes, characterized by different temperature dependences of the scaling exponents.
In the present paper, the scaling exponents α and β will be calculated using loss measurements, carried out at intermediate temperatures in the range from 293.5 up to 299.5 K. It should allow us to precisely determine the temperature dependences of scaling exponents in the mentioned universality classes as well as to empirically calculate their critical values.

References:

[1] M. Katter, *at al.*, IEEE Trans. Magn., 44, 3044-3047 (2008).
[2] V. Franco, A. Conte, Int. J. Refrig., 22, 465-473 (2010).
[3] R. Gozdur, *at al.*, Acta Phys. Pol., 131 (4), 801-803 (2017).
[4] H.G. Stanley, Rew. Mod. Phys., 71, S358-366 (1999).
[5] M. Najgebauer, Acta Phys. Pol. A, 128 (1), 107-110 (2015).
[6] R. Gozdur, M. Najgebauer, J. Electr. Eng., 66 (7/s), 37-40 (2015).

The project financed under the program of the Minister of Science and Higher Education under the name "Regional Initiative of Excellence" in the years 2019 - 2022 project number 020/RID/2018/19, the amount of financing 12,0000,00 PLN.

Temperature dependence of magnetic anisotropy in amorphous $Fe_{76}Mo_8Cu_1B_{15}$ alloy

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NANOPERM-type metallic glasses are still atrractive candidate for variety practical applications in electrotechnical industry because their good soft magnetic properties. In this paper we studied temperature dependence of magnetic anisotropy and magnetization in amorphous $Fe_{76}Mo_8Cu_1B_{15}$ ribbons produced by rapid quenching technique. Fig. 1 (top figure) shows magnetization versus temperature for the investigated as-quenched alloy. It is seen that for the external DC magnetic field up to 10 mT magnetization increases with temperature to its maximum and then drop down. This behavior is related to different temperature dependence of magnetic anisotropy and magnetization. Results obtained from analysis of the normal magnetization curves [1, 2] recorded in ferromagnetic region are presented in Fig. 1 (bottom figure). Moreover, the investigations of magnetization processes from the law of approach to saturation of magnetization [3] were also performed.

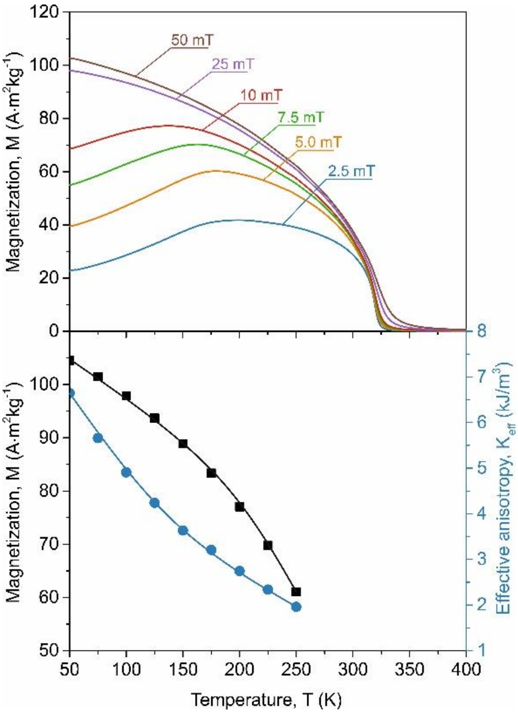

Fig. 1 Temperature dependence of magnetization measured in zero field cooled mode for the as-quenched $Fe_{76}Mo_8Cu_1B_{15}$ alloy.

References:

[1] M. Vázquez, W. Fernengel, H. Kronmüller, Phys. Stat. Sol. (a) 80, 195 (1983)
[2] T. Egami, and P. J. Flanders, AIP Conference Proceedings 29, 220 (1976)
[3] M. Vázquez, W. Fernengel, H. Kronmüller, Phys. Stat. Sol. (a) 115, 547 (1989)

New improved static iron losses model for electrical machines using Stop hysteron

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This paper presents an evolution of the Stop model [2] to reconstruct quasi-static magnetic hysteresis cycles. It is to be combined with the dynamic Loss Surface approach to estimate all the iron losses in electrical machines.

The improvement of the model accuracy has been obtained by adjusting the characterization measurements methodology [3] and the subsequent discretization. The overall method for hysteron's identification has been changed to accurately model various hysteresis behavior from very low flux density to highly saturated materials with different harmonic content.

The model was validated by comparison with several experimental results on the Epstein frame showing errors less than 5% for the iron loss calculation. Furthermore, some limitations of the model are *intentionally* highlighted, decreasing the accuracy up to 20% for a high harmonic content and low amplitude flux cycles.

The performance of the model can be used during a post-treatment of finite element analyses of an electrical machine in order to validate the model for typical motor flux density waveforms.

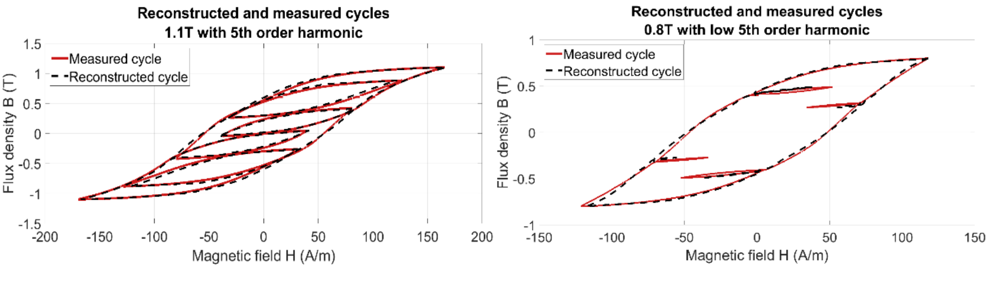

Fig 1: Example of model reconstitution results

References:

[1] G. Bertotti, "*General Properties of Power Losses in Soft Ferromagnetic Materials*", *IEEE Transactions on Magnetics*, vol. 24, 1988.
[2] S. Bobbio, M. de Magistris, G. Mho, C. Visone, E. Zamparelli, "*A New Model of Scalar Magnetic Hysteresis*", *IEEE Transactions on magnetics*, vol. 30, no. 5, pp. 3367-3370, Sep. 1994.
[3] A. Giraud, A. Bernot, Y. Lefèvre and J. F. Llibre, "*Modeling quasi-static magnetic hysteresis: A new implementation of the play model based on experimental asymmetrical B(H) loops*", *(ICEM)*, Lausanne, 2016, pp. 1895-1901.

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Quasi-static magnetic hysteresis model: Interpolation model based on first-order experimental BH curves

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In this paper, an original nonlinear model of scalar quasi-static magnetic hysteresis for iron losses computations is proposed. Despite many publications presented on this subject, there are still uncertainties and notable errors. The limitations of scalar quasi-static magnetic hysteresis models can be revealed by varying input signals amplitudes and their harmonic content. Therefore, these models have to be validated with a wide range of different experimental results. The new model establishes the relation between the magnetic field *H* and the magnetic field density *B* by interpolating several experimental first-order reversal curves obtained with an Epstein frame. These first-order reversal curves are used to create the magnetic field mapping, which is a function of the magnetic field induction and the history of the magnetic field induction, to reconstruct any first-order curves. Higher order curves are obtained from the mapping by taking into account Madelung's rule. This method is simple to apply and allows to obtain accurate results. The proposed model is validated by experimental data.

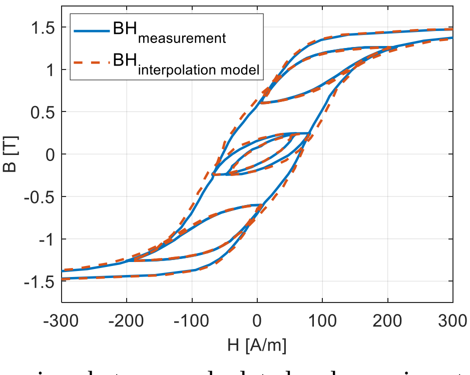

Figure 1: Comparison between calculated and experimental hysteresis loop

References:

[1] G. Bertotti, "*General Properties of Power Losses in Soft Ferromagnetic Materials*", *IEEE Transactions on Magnetics*, vol. 24, 1988.

[2] S. Bobbio, M. de Magistris, G. Mho, C. Visone, E. Zamparelli, "*A New Model of Scalar Magnetic Hysteresis*", *IEEE Transactions on magnetics*, vol. 30, no. 5, pp. 3367-3370, Sep. 1994.

[3] A. Giraud, A. Bernot, Y. Lefèvre and J. F. Llibre, "*Modeling quasi-static magnetic hysteresis: A new implementation of the play model based on experimental asymmetrical B(H) loops*", *(ICEM)*, Lausanne, 2016, pp. 1895-1901.

Influence of Heat Treatment on Magnetization Reversal in Rayleigh Region in Amorphous FINEMET

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Heat treatment may be considered as one of the most powerful tools to process ferromagnetics as it usually leads to marked changes of their magnetic properties. Our study of rapidly quenched FINEMET ribbons concerns the influence of heat treatment at different temperatures in the range of 300 - 820 K (below and near to crystallization temperature) on the magnetic reversal by reversible domain wall motion occurring in a low magnetic field region (Rayleigh region).

The reason for significant differences in behavior of mentioned material after heat treatment at different temperatures can be found not only in changes of the stress conditions in the sample, but also in the diffusion of atoms and the formation of atomic clusters. These structural changes will be reflected in the variation of total magnetic anisotropy and consequently in different domain wall thicknesses.

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Finite Element Model of Torque Sensor

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Reliable measurements of torque in harsh industrial conditions is still one of important problem with significant commercial potential. Magnetoelastic torque sensors are possible solution [1]. The example of sensing part of such sensor is presented in figure 1.

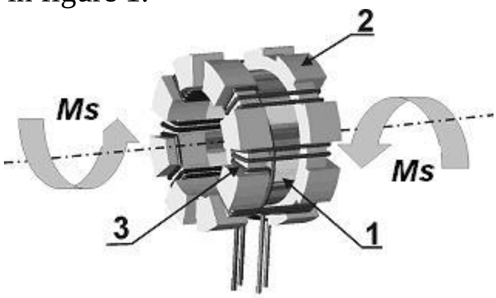

Fig. 1. Magnetoelastic torque sensor [2]: 1-magnetoelastic core, 2 – nonmagnetic backings, 3 – magnetizing and sensing windings

On the other hand, theoretical models explaining quantitatively characteristics of such sensors are still missing, what creates significant barrier in optimisation of such sensors and its practical implementation to the market.

Presented paper is trying to fill this gap. Finite element model of magnetoelastic sensor is implemented in open-source ELEMER environment. Interaction of mechanical stresses with magnetic field in the sensor's core was described considering recent advances in modelling of 3D magnetic permeability tensor in materials with stress-induced anisotropy [3]. It should be highlighted, that due to the use of open-source software, the results of modelling may be applied for optimisation of magnetoelastic sensors for commercial applications.

References:

[1] J. Ivan, *et al.*, IEEE Transactions on Magnetics 30 (1994).
[2] J. Salach, *et al.*, J. Magn. Magn.Mater., 316, e607 (2007).
[3] R. Szewczyk, Arch. Metall. Mater., 61, 607 (2016).

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Lanthanum substituted nickel ferrite obtained by mechanosynthesis

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Lanthanum substituted nickel ferrite have been obtained by mechanosynthesis using as starting materials nickel oxide, iron oxide and lanthanum oxide. The starting mixture of oxides corresponding to $La_xNi_{1-x}Fe_2O_4$ (La=0; 0.05; 0.10 and 0.15) have been milled up to 50 h using a high energy ball mill. The evolution of powder during mechanochemical process have been investigated by X-ray diffraction and Fourier Transformed Infrared spectroscopy. The powder morphology was investigated by electron microscopy and is changing upon modifying the milling time and sample chemical composition. Large amount of lanthanum lead to the decrease of sample magnetization and to the formation of a secondary phase beside spinel phase. The substitution of a 0.05% of Ni cations with La lead to the formation of a single cubic spinel phase. The magnetizations of the samples are discussed as a function of milling time and the amount of lanthanum.

References:

[1] T.F. Marinca, M.C. Olaru, B.V. Neamțu, F. Popa, I. Chicinaș, Ro. J. Techn. Sci. − Appl. Mechanics, 62 (2017) 206−217.

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A Measurement Method of Minor Hysteresis Loss of Electrical Steel Sheet by Means of a Single Sheet Tester

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In recent years, the number of inverter-driven electric machines has been increasing. The flux density in the cores of those machines is dc-biased. Minor hysteresis loops due to the dc-biased flux density result in the increase of iron loss. Therefore, evaluation of minor hysteresis loss is important to improve the effciency of electric machines. In this paper, two kinds of waveform control methods for obtaining minor loop under sinusoidal flux condition are investigated. In the first one (the dc-biased method [1]), the dc flux is superimposed on the ac flux which forms a minor loop. This method requires at least one fluxmeter for measuring the dc component ΔB of flux density b. Another one (the distorted waveform method) utilizes the distorted b waveform, in which different sinusoidal waveforms are combined. Minor loops formed by the small sinusoidal waveforms are generated at the tips of hysteresis loop. No fluxmeter is required because of the ac measurement. Fig. 1 shows the target b waveforms for the two methods. The parts corresponding to the minor loop are coincided with each other. In the distorted waveform method, the frequency of a whole loop is one quater of that of a minor loop. Fig. 2 shows the minor hysteresis loss W at 50 Hz. As a specimen, a M250-50A5 sheet is used. The broken line indicates the ordinary iron loss without minor loop. After $B_{max} \geq$ about 1.0 T, the increasing ratio of W becomes larger. When B_{max} is rather large, W tends to decrease. Results of two methods are nearly the same. However, it can be understood that the waveform control for the dc-biased method is not enough. The details of proposed methods and experimental results will be reported in the full paper.

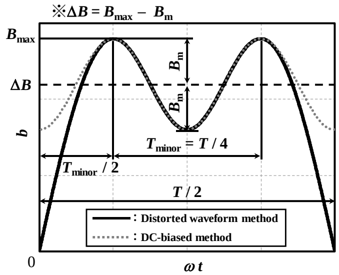

Fig. 1. Target waveforms of flux density.

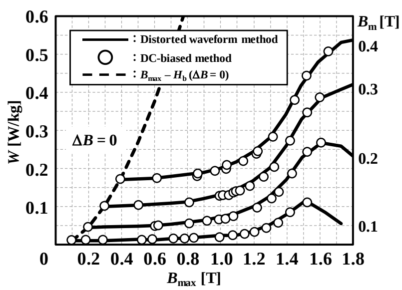

Fig. 2. Iron loss.

Reference:

[1] S. Yanase, Y. Okazaki, and T. Asano,"AC Magnetic Properties of Electrical Stel Core under DC-biased Magnetization," *JMMM*, nos. 215-216, pp. 156-158 (2000).

Temperature stability of the Transformer Position Transducer for Pneumatic Cylinder

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Detection of piston position inside aluminum shell of pneumatic cylinder is not easy task. Different methods were introduced, for example, such as direct mounting of sensors inside the piston rod, microwave sensors mounted on the piston, optical scale and magnetic scale, which are not reliable and are mechanically complicated. The most popular method used in the industry is using external sensors, which measure magnetic fields of permanent magnet mounted on the piston. It needs large number of sensors with complicated signal processing and expensive non ferromagnetic iron rod. A simpler method is to measure inductance of solenoid coil around cylinder [1]-[2].The problem of this solution is slow response and large temperature dependence [3]. Therefore we designed novel position sensor based on transformer configuration [4].

In this paper, temperature stability of a transformer-based position sensor for a pneumatic cylinder with an aluminum shell, an aluminum piston and different ferromagnetic iron rods is analysed and measured. 2D time harmonic axisymmetric finite element method (FEM) is utilized for simulations and design. Two iron rods with different magnetic characteristics are considered. We found that the effect of temperature dependence of shell resistivity is dominant, while the effect of permeability change is negligible. Based on the simulations and measurement we suggest simple method of temperature compensation.

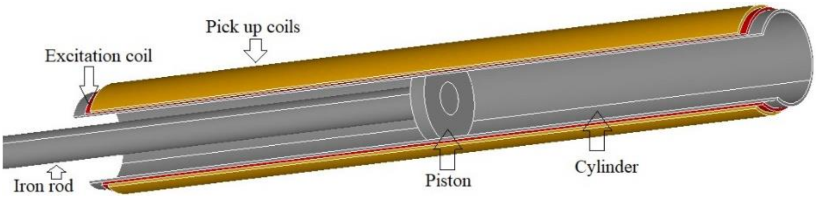

Fig. 1 Model of position sensor for pneumatic cylinder

References:

[1] H. Sumali, E.P. Bystrom, G.W. Krutz, IEEE. Sens. J. 89-94 (2003).

[2] P. Ripka, A. Chirtsov, M. Mirzaei, J. Vyhnanek, AIP Adv. 8, 048001 (2018).

[3] M. Mirzaei, P. Ripka, A. Chirtsov, J. Vyhnanek: IEEE Sensors conf. 2018, paper #1638, doi: 10.1109/ICSENS.2018.8589788

[4] M. Mirzaei, P. Ripka, A. Chirtsov, J. Vyhnanek, accepted for Sensors and Act. (2019).

Loss Evaluation of Nd-Fe-B Sintered Magnet by Using Heat Flow Sensor

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Temperature rising in permanent magnet synchronous motors (PMSMs) causes demagnetization of magnets, which results in the significant deterioration of machine performance. The temperature rising is complexly linked to heat transfer due to copper losses in stator windings, iron losses in cores, and eddy-current losses in the PMs. To identify a main cause of the temperature rising, it is desirable to qualitatively comprehend heat flow in the motor. In this study, as the first step for directly estimating the main cause of temperature rising in the PMSMs, we investigated the effectiveness of use of the heat flow sensor [1] by evaluating AC loss of the PM.

As shown in Fig. 1, a solenoid is used for exciting the PM. Heat flow sensors are pasted on top, bottom, and right sides of the PM. To suppress influence by airflow, both ends of the solenoid are covered with lids. B-coil is directly wound on the specimen with a winding length of 5 mm. AC loss is measuring by H-coil method or heat fluxes with heat flow sensors. H-coil has the same winding length as the B-coil. When using heat flow sensors, the glass epoxy plate with embedded H-coil is replaced with jigs made of acrylic resin. Fig. 2 shows the comparison between results of 3 times of both methods. This result indicates the heat flow sensor can be applicable to the AC loss evaluation of the PM because reproducibility of the heat flow sensor is ±2 %. More detailed discussion will be reported in the full paper.

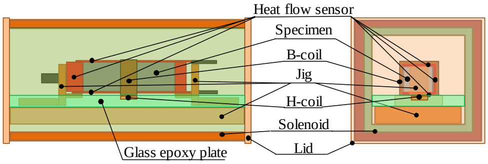

Fig. 1. Measuring system.

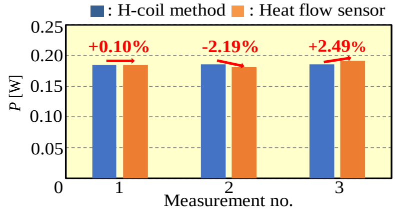

Fig. 2. Measured results.

Reference:

[1] C. A. Pullins, T. E. Diller, "In situ High Temperature Heat Flux Sensor Calibration," *International Journal of Heat and Mass Transfer*, vol. 53, pp. 3429-3438 (2010).

This paper is based on results obtained from the Future Pioneering Program "Development of magnetic material technology for high-efficiency motors" commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

Estimation of DC Hysteretic Property by Using Simplified Micromagnetic Hysteresis Model

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To further improve the efficiency of electric machines, it is essential to consider hysteretic properties of magnetic materials accurately. The play model and Preisach model are widely used in magnetic field analyses taking account of magnetic hysteresis. In general, these models need (quasi-) static hysteresis loops measured under appropriately controlled condition for their identification. In the case that the excitation frequency is extremely low, however, it is difficult to measure the magnetic properties accurately. Therefore, the model which can reproduce an arbitrary hysteresis loops by utilizing measured loops is effective. On the other hand, the simplified micromagnetic hysteresis model based on the Landau-Lifshitz-Gilbert (LLG) equation was proposed in [1], of which the parameters can be identified based on arbitrary static hysteresis loops. In this paper, we applied the method to estimating static hysteresis loops at arbitrary B_m, where B_m is the amplitude of a flux density waveform, and examined the influence of respective parameters on the accuracy of simulated hysteresis loops.

Fig. 1 shows the measured and simulated static hysteresis loops at B_m = 0.3, 0.8, and 1.2 T. The grade of specimen is M235-35A5. The parameters for the LLG equation are identified by using the measured hysteresis loops at B_m = 0.5, 0.9, 1.3 T and 1 Hz. The simulated loops are in good agreement with measured ones. At a high flux density, however, the shape of descending curve slightly differs between the simulated and measured hysteresis loops as shown in Fig. 2. More numerical and experimental results, and detailed discussion on the simplified micromagnetic hysteresis model will be reported in the full paper.

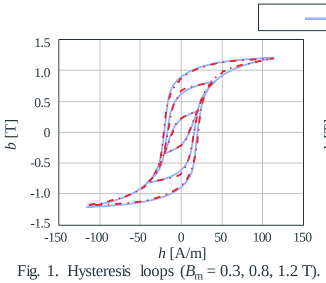

Fig. 1. Hysteresis loops (B_m = 0.3, 0.8, 1.2 T).

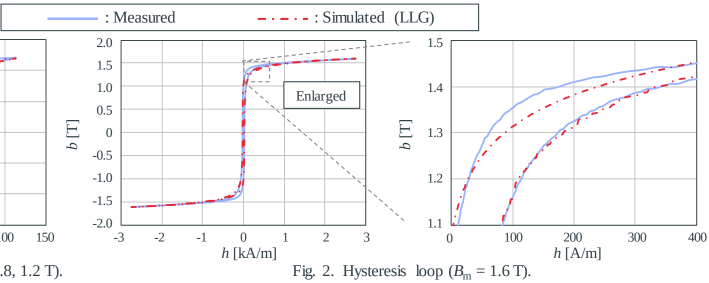

Fig. 2. Hysteresis loop (B_m = 1.6 T).

Reference:

[1] H. Tanaka, K. Nakamura, and O. Ichinokura, "Calculation of Iron Loss in Soft Ferromagnetic Materials using Magnetic Circuit Model Taking Magnetic Hysteresis into Consideration," *Journal of Magnetics Society of Japan*, vol. 39, no. 2, pp. 65-70 (2015).

The International Round Robin Test of Magnetostriction Measurement of Grain-oriented Electrical Steel by Means of a Single Sheet Tester and an Optical Sensor

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Transformer noise, which results from magnetostriction of grain-oriented (GO) electrical steel sheets, is a concern in industry. Therefore, a committee draft of the standard method for magnetostriction measurement by means of a single sheet tester equipped with an optical sensor, i.e. IEC 60404-17, is deliberated at IEC/TC68/WG2. A round robin test (RRT) of magnetostriction measurement using three kinds of GO test specimens is in progress. Doshisha Univ. acts as the reference laboratory.

In this paper, we report the preliminary results of the RRT. The aim of the RRT is to clarify factors affecting the accuracy of magnetostriction measurements, e.g. friction, resonance, and external noise in the proposed test apparatus, and then to determine an acceptable reproducibility of magnetostriction measurements using several setups based on the concept of IEC 60404-17. The validity of measurement is verified with butterfly loops in the transverse direction (TD) [1] shown in Fig. 1. The specimen is 23P5 sheet. A dotted line indicates the ratio of the saturation magnetostriction λ_s (28 μm/m) [2] and the saturation flux density B_s (2.03 T) [3] of the GO material. Fig. 2 shows the butterfly loops of 35S5 sheet in the rolling direction (RD) with two types of yoke, measured at the reference laboratory.

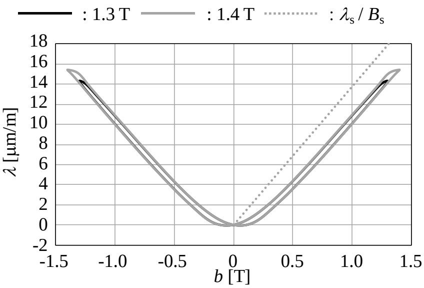

Fig. 1. Butterfly loops of 23P5 sheet in TD.

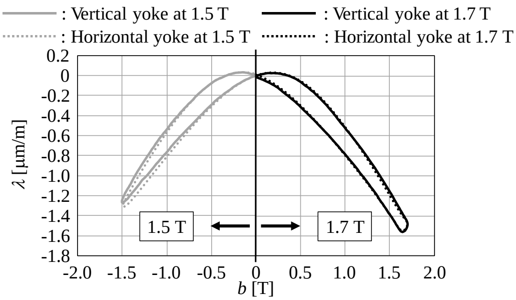

Fig. 2. Butterfly loops of 35S5 sheet in RD.

References:

[1] S. Arai, M. Mizokami, and M. Yabumoto, "Magnetostriction of Grain Oriented Si-Fe and Its Domain Model," *Przeglad Elektrotechniczny* (Electrical Review), vol. 87, no. 9b, pp. 20-23 (2011).

[2] S. Chikazumi and C. D. Graham, Jr, *Physics of Ferromagnetism*, Clarendon Press, p. 77 (1997).

[3] R. M. Bozorth, *Ferromagnetism*, D. Van Nostrand, p. 363 (1951).

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Study on energy harvesting with (100) [001] silicon steel sheet

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Vibration power generation using an inverse magnetostrictive effect has attracted much attention. Many devices have been proposed that utilize materials with large magnetostriction constants such as TbDyFe, Fe-Ga, FeCo and so on [1]. In this work, we propose to use (100) silicon steel sheet for power generation. Since (100) silicon steel sheet has two magnetic easy axes in the plane, the direction of the magnetic moment are easy to change when the tensile and compressive stress are applied. It is possible to obtain a large magnetic flux change by the vibration because silicon steel sheet is a soft magnetic material and has a large saturation magnetization. In addition, silicon steel sheet is less expensive than the materials described before.

Figure 1 shows the configuration of the power generation device. In this device, a closed magnetic circuit is formed by two strip-shaped silicon steel sheet (4.01×44.9×0.229 mm) of (100) [001] single crystal and a yoke of laminated electromagnetic steel plates. Permanent magnets between the silicon steel sheet provide a bias magnetic field. Pickup coils (0.1 mmφ, 100 turns, 5Ω) are wound around each silicon steel sheet. The cantilever-shaped device is fixed on a vibrator and forcibly vibrated at resonant frequency of 48.3 Hz. Induced voltage of one pickup coil is measured by an oscilloscope and a lock-in amplifier. Figure 2 shows the time responses of the voltage and the calcurated magnetic flux density. Voltage of 62 mVpp was measured and about 48 μW of maximum instantaneous power was obtained. In addition, the results show that the amplitude of the magnetic flux density was 0.7 T.

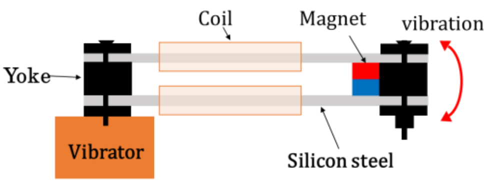

Fig. 1. Diagram of the generator

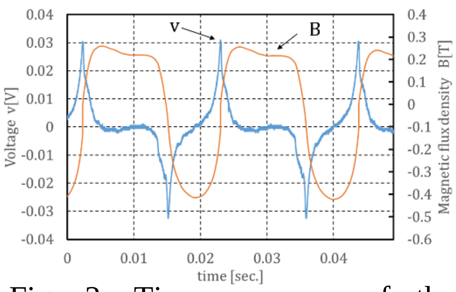

Fig. 2. Time response of the voltage and magnetic flux density at resonant frequency of 48.3 Hz.

References:

[1] S. Fujieda, S. Suzuki, A. Minato, T. Fukuda, T. Ueno, IEEE Trans. Magn. 50(2014)2505204.

Amorphous and Nanocrystalline Soft Magnetic Nanowires

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Amorphous glass-coated nanowires prepared by rapid solidification [1] are over 5 orders of magnitude longer than electrodeposited nanowires and can be prepared as single, isolated nanowires, rather than arrays of densely packed short ones. The high quenching rates, alongside the presence of the glass, give rise to large internal stresses, which result in high coercivities for magnetostrictive alloys ($\lambda \neq 0$), e.g. 7 kA/m for a 100 nm in diameter $Fe_{77.5}Si_{7.5}B_{15}$ nanowire with $\lambda = 25 \times 10^{-6}$.
Here we report on the preparation and study of glass-coated nanowires with low magnetostriction and unique structure (nanocrystalline), aiming to reduce coercivity for applications that require nanosized soft magnetic materials.
Amorphous glass-coated nanowires with diameters from 100 to 800 nm have been prepared from two alloy systems: (i) FINEMET - $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$, and (ii) Co-based - $(Co_{0.94}Fe_{0.06})_{72.5}Si_{12.5}B_{15}$. The FINEMET amorphous nanowires have been annealed at temperatures up to 650°C to induce the nanocrystalline structure. Ultra-high resolution transmission electron microscopy has been used to monitor the microstructure evolution with annealing. Magnetic characterization has been performed by inductive hysteresis loop measurements. The results show that nanocrystalline phase formation decreases coercivity, though it remains in the kA/m region (2 - 4 kA/m), indicating that magnetostriction is not averaged out effectively in the process. Low magnetostrictive Co-based nanowires ($\lambda = -1 \times 10^{-7}$) exhibit much lower coercivities in the as-cast state - from 400 A/m in a 180 nm nanowire down to 150 A/m for an 800 nm one. Further reduction is possible through stress relief annealing and glass coating reduction. Thus, a wide range of coercivities, including the needed low values, is attainable through rigorous control over composition, structure and nanowire dimensions.

References:

[1] H. Chiriac et al., Journal of Applied Physics 109, 063902 (2011).

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Broadband transverse magnetic properties in multiferroic Y-type hexaferrite $Ba_{0.5}Sr_{1.5}Zn_2Fe_2O_{22}$

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Ferrimagnetic compounds with magnetically induced ferroelectricity from changes in spiral magnetic ordering within the crystal have attracted significant interest in recent research activities because they can present unusual physical phenomena like remarkable magnetoelectric effects, with potential applications in ultra-dense magnetic storage devices as well as low power spintronic devices. Single phase multiferroics are of great interest for this new multifunctional devices, being Y-type hexaferrites good candidates, and among them the ZnY compounds due to their ordered magnetic behaviour over room temperature. Polycrystalline Y type hexaferrites with composition $Ba_{0.5}Sr_{1.5}Zn_2Fe_2O_{22}$ (BSZFO) i.e the optimal composition to exhibit multiferroic properties, were sintered in 1050º C-1250º C temperature range.

Transverse magnetic susceptibility (TS) is obtained when applying a bias DC magnetic field, while AC applied field and response is measured in a transverse direction. It has been proved to be a versatile tool to study singular properties of bulk and nanoparticle magnetic systems, especially to obtain their anisotropy and switching fields. With the help of a broadband system based on a LCR, TS measurements have been carried out on BSZFO polycrystalline samples, in the temperature range 80-350 K with DC fields up to ±0.5 T, revealing different behaviour depending on the sintering temperature. The relative amplitude of TS decreases with the increase in sintering temperature. Sample sintered at 1250º C is qualitatively different, suggesting a mixed Y and Z phase like CoY hexaferrites. Sintering at lower temperatures single phase Y-type compounds are obtained, but the TS behaviour of the sample sintered at 1150º C is shifted at temperatures 15 K higher. Regarding the DC field sweeps the observed behaviour is a peak that shifts to lower values with increasing temperature. However, the samples corresponding to single Y phase exhibit several maxima and minima in the 250 K – 330 K range at low DC applied field, which is a clear signature of the magnetic field induced spin transitions in this compound. The sintering temperature then also plays a key role in the temperature range in which the compound undergoes spin transitions.

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Influence of magnetic field orientation on ultrafast magnetization precession parameters in the Ni-Mn-Sn Heusler alloy film

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Characteristic parameters of ultrafast magnetization precession were studied in Ni-Mn-Sn Heusler alloy film as a function of angle θ_H and amplitude of the external magnetic field applied. The measurements were performed using transient Kerr rotation dual-color technique. It was found strong dependences of the precession frequency *f*, amplitude *A* and Gilbert damping parameter α on θ_H. For θ_H increasing from 5° to 50°, *f* increases about twice, while *A* decrease three times. Strong α reduction with θ_H increase was observed and discussed. The observed changes of the magnetization precession parameters have been explained in a simulation based on the phenomenological Landau-Lifshitz-Gilbert equation.

References:

[1] A. Bonda, L. Uba, K. Załęski, and S. Uba, *Phys. Rev. B* 99, 184424 2019.

Co-rich nanocrystalline alloys for GMI applications at elevated temperature

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The giant magnetoimpedance effect (GMI) is attracting a great deal of scientific and technological interest because of its applications in sensing elements. Extensive research activities in this area have been focused on the soft magnetic amorphous and nanocrystalline alloys in the form of ribbons and wires. In this work, the GMI effect was studied in $(Fe_{1-x}Co_x)_{81}Nb_7B_{12}$ (x=0.75, 0.86 and 1) nanocrystalline alloys in frequency range 1-100 MHz. The amorphous ribbons were nanocrystallized at 773 K for 1 hour in longitudinal (LF) or transversal (TF) magnetic field in order to induce a controllable magnetic anisotropy in parallel or transverse direction to the ribbon length. Reference samples were annealed in zero (ZF) magnetic field. The GMI response of LF annealed samples exhibits a single-peak behavior in whole frequency range investigated. On the other hand, ZF and TF annealed samples are characterized by a double-peak behavior. Our results show that the samples with higher amount of Co exhibit a stronger GMI response. The highest values of $\Delta Z/Z$ ratio ≈307% and sensitivity $\eta \approx 0.288\%/Am^{-1}$ were observed at frequency 90 MHz for $Co_{81}Nb_7B_{12}$ sample annealed in transverse magnetic field. A marked response to magnetic field annealing in these alloys can be utilized for tuning their GMI response. Examples of our recent work on testing the temperature stability of soft magnetic and GMI characteristics of field annealed ribbons designed for construction of GMI magnetic sensors capable of operation at elevated temperatures will be briefly highlighted.

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Effects of electron-phonon coupling on transport through strongly correlated T-shape double quantum dots

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Impact of local vibrational modes on the subtle interplay of correlations and strong correlations is studied by the noneqilibrium Green's function formalism based on the equation of motion method and slave boson approach. The setup we consider consists of two single-level or two-level quantum dots: the large dot with vanishing Coulomb interactions, which is connected to external spin polarized leads and the Kondo dot coupled solely to the first one. Local phonons are coupled either to only one of the dots or to both of them influencing both interference conditions and correlations. Apart from the well-known appearance of the phonon side peaks in the differential conductance also the dramatic changes of transmission in the closest surrounding of the Fermi level are observed what reflects in transport coefficients. The effects of phonons on magnetoresistance and spin filtering are also examined.

Magnetic and Structural Analysis of Cerium Substituted Nickel Zinc Ferrites

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In recent years there is a considerable advance in development of new magnetic materials, which are dominating in industrial applications, like soft magnetic spinel ferrites. Continuing improving their microstructure and electromagnetic properties, with the aim to reach by them unusual physico-chemical parameters, has become so an important task for contemporary electrical engineering. It can be done by a proper substitution of additives and changes in their synthesis. On the bases of our previous studies, aimed at finding suitable rare-earth additives [1-3], and the analysis of the state-of-the-art in given research field [4-6], we will focus ourselves to investigate the influence of Ce^{3+} ions substitution for Fe^{3+} ions in $Ni_{0.42}Zn_{0.58}Ce_xFe_{2-x}O_4$ (x = 0, 0.02, 0.04, 0.06, 0.08, 0.10) compounds on selected structural and magnetic properties. The samples were synthesized by means of wet glycine-nitrate technology at the temperature of 1200°C for 6 hours. The wide spectrum of characterization methods, such as X-ray diffraction, EDAX analysis, SEM micrographs, thermomagnetic analysis, magnetic curve measurements and complex permeability spectra will be used for the study of relevant properties of synthetized materials.

References:

[1] M. Šoka, M. Ušáková, R. Dosoudil, E. Ušák, J. Lokaj, AIP Adv., vol. 8, 047802, Jan. 2018.
[2] M. Šoka, M. Ušáková, R. Dosoudil, E. Ušák, E. Dobročka, IEEE Trans. Magn., vol. 51, no. 1, Jan. 2015.
[3] M. Šoka, M. Ušáková, E. Ušák, R. Dosoudil, J. Lokaj, IEEE Trans. Magn., vol. 50, no. 4, Apr. 2014.
[4] M. N. Akhtar, A. B. Sulong, M. N. Akhtar, M. A. Khan, J. Rare Earths, vol. 36, pp. 156-164, Feb. 2018.
[5] T. W. Mammo, N. Murali, Y. M. Sileshi, Physica B Condens. Matter., vol. 531, pp. 164-170, Feb. 2018.
[6] M. Hashim, M. Raghasudha, S. S. Meena, J. Shah, S. E. Shirsath, S. Kumar, D. Ravinder, P. Bhatt, Alimuddin, R. Kumar, R. K. Kotnala, J. Magn. Magn. Mater., vol. 449, pp. 319-337, Mar. 2018.

Do Fe-based bistable microwires behave as ideal hysterons in FORC measurements?

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Amorphous ferromagnetic Fe-based microwires (MWs) produced by Taylor-Ulitovsky method have unique magnetic properties, among which their bistability stands out. These glass-coated MWs have a magnetic structure consisting of a single longitudinal domain and small closure domains at the ends. A rectangular hysteresis loop is then observed according to the fast domain wall propagation along the microwire. This type of hysteresis loop is a very good physical example of a magnetic relay hysteron as described in Preisach model of hysteresis. As frequently the hysteron is the mathematical operator used to describe and interpret FORC (First Order Reversal Curve), the central idea of this work is to study FORCs in the bistable MWs and compare them to the expected ones of an equivalent system of hysterons to highlight similitudes and differences. On one hand, applying FORC technique to samples with canonical hysteresis loop will help us to better understand and learn how to interpret FORC measurements. On the other, FORC can help us to learn more things about the magnetic behavior of amorphous Fe-based microwires.
Measurements were carried out in an inductive magnetometer setup. We analyzed the hysteresis loops of glass-coated $Fe_{74}B_{13}Si_{11}C_2$ single MWs and systems of two just separated by their glass shell. To learn more about FORC interpretation of mutual magnetostatic interaction we used 5 cm long and 2 cm long samples and put them into a pick-up coil, which is 7 cm long. During the measurements, we used the ranges of magnetic field amplitude up to 1000 A/m and magnetic field frequency up to 400 Hz.
The single Fe-based MWs have perfect rectangular loops, while the arrays of two coupled wires have a step-wise hysteresis loop characterized by two Barkhausen jumps [1]. This canonical hysteresis was observed at low frequencies up to 50 Hz and low field amplitudes up to 300 A/m. These steps are related to the magnetostatic interaction between the wires. From quasistatic FORCs analysis, we can follow the switching process in each wire separately while they are coupled. Furthermore, with increasing amplitude and frequency, the stepped shape of the hysteresis loop takes on a "smoothed" appearance [2]. Then, FORC measurements at the highest values of frequency were obtained. The SFD (Switching Field Distribution) plots were helpful to analyze the magnetostatic interactions and find out "mutual" demagnetizing and "auto" demagnetizing effects in Fe-based microwires. FORCs analysis will help to deepen the knowledge about magnetostatic interaction and switching process of amorphous ferromagnetic microwires, which will point into the direction to further improve their properties for magnetic field sensing applications.

References:

[1] V. Rodionova, *et al.*, J. Appl. Phys. 111, 07E735 (2012).
[2] V. Rodionova, *et al.*, J Supercond Nov. Magn. (2011).

Metallographic and Magnetic Analysis of Direct Laser Sintered Soft Magnetic Composites

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In the present study, soft magnetic composite samples were made from different composition of iron and inorganic insulating material. For the purpose of optimizing 3D printing parameters, preliminary experiments were performed. Metallographic and computed tomography investigations were used to determine the appropriate sintering settings. Besides the microscopic and CT analysis, the permeability spectra and B-H hysteresis loops have been compared with the results obtained on powder cores prepared by the usual pressing and sintering technology. As an example, in Fig.1 the permeability spectra are compared. The frequency limit of laser printed sample is much higher than for the usual powder core due to the reduced intergrain eddy current losses.

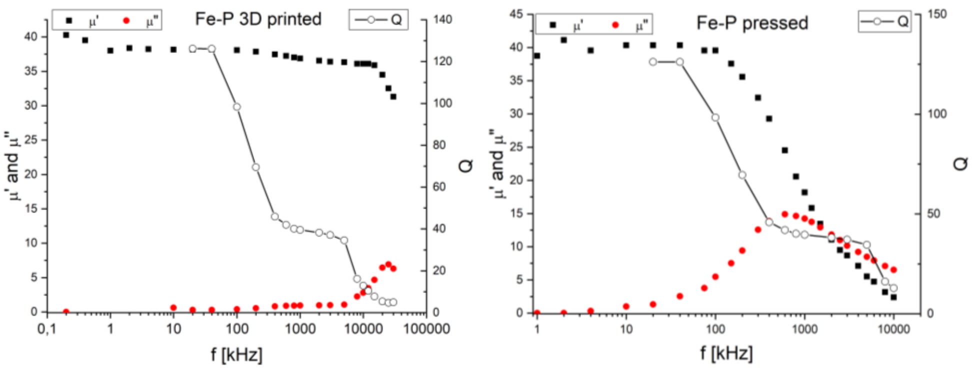

Fig.1. The permeability spectra for the samples prepared by 3D printing (Fig.1 - left) and conventional powder core (Fig. 1 - right) technologies

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Temperature and frequency behavior of soft magnetic glass-coated microwires

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The soft magnetic material that posses a giant magneto-impedance (GMI) represents a cost-efficient solution for the development of the magnetic sensors and devices due to their high magnetic field sensitivity [1, 2]. Although the GMI was first reported long time ago [3], it gains attention with the development of soft magnetic amorphous wires [4, 5]. As a result, different research groups intensively investigated various soft magnetic materials showing GMI effect, materials in different forms – wires [1, 2], ribbons [6], thin films and multiple layers [7] –. Microwires has shown extremely unique mechanical, magnetic, electrical, and corrosion behaviors which basically result from their amorphous nature, and therefore, make them very attractive candidates for many applications: biomedical, sensing, medicine, information technology, automotive industry, security. Among very widely application trends in the field of magnetic materials, those related to sensing operations are nearly used in all engineering and industrial sectors.

In our work, we describe the realization and characterization of two types of ferromagnetic microwires, with the basic compositions of Fe-Si-B and Fe-Co. These microwires are obtained by the Taylor-Ulitovsky method. Their magnetic characterization was carried out with a unique system designed by us, using the magnetic flux response. We will present the system and the acquisition part, and the processing of the H and J signals. The characterization was performed in the frequency range of 50 Hz – 100 kHz. After testing at room temperature, about 20 degrees Celsius, the system was placed in a climatic chamber. Since some samples have low Curie temperatures around 100 Celsius degrees, the temperature range was varied between 20 – 100 C.

References:

[1] M. Vazquez, H. Chiriac, A. Zhukov, L. Panina, T. Uchiyama: “On the state-of-the-art in magnetic microwires and expected trends for scientific and technological studies”, Phys. Status Solidi 208 (2011) 493–501.
[2] A. Zhukov, M. Ipatov, M. Churyukanova, A. Talaat, J.M. Blanco, V. Zhukova: “Trends in optimization of giant magnetoimpedance effect in amorphous and nanocrystalline materials”, J. Alloy. Comp. 727 (2017) 887–901.
[3] E.P. Harrison, G.L. Turney, H. Rowe: “Electrical properties of wires of high permeability”, Nature 135 (1935) 961.
[4] L.V. Panina, K. Mohri:”Magneto-impedance effect in amorphous wires”, Appl. Phys. Lett. 65 (1994) 1189–1191.
[5] R. Beach, A. Berkowitz:”Giant magnetic field dependent impedance of amorphous FeCoSiB wire”, Appl. Phys. Lett. 64 (1994) 3652–3654.
[6] B. Hernando, M.L. Sanchez, V.M. Prida, M. Tejedor, M. Vazquez: “Magnetoimpedance effect in amorphous and nanocrystalline ribbons”, J. Appl. Phys. 90 (2001) 4783–4790.
[7] L.V. Panina, K. Mohri, T. Uchiyama, M. Noda, K. Bushida:”Giant magneto-impedance in Co-rich amorphous wires and films”, IEEE Trans. Magn. 31 (1995)1249–1260.

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Research of Harmonic Effects on Core Loss in Soft Magnetic Composite Materials Based on Three-Dimensional Magnetic Test System

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A system can generate non-sinusoidal waveforms consisting of harmonics with variable orders, contents and phase angles with frequency domain feedback control method is developed in this paper. The 3-D magnetization structure is combined by three orthogonal “C-type” cores and six multilayer excitation windings, which are wound around the corresponding orthogonal core poles[1],[2], as shown in Fig.1.

Core loss measurement of soft magnetic composite materials (SMC) under both sinusoidal and non-sinusoidal excitations is performed. The effects of harmonic for core loss are analyzed. It found that core loss increases with the increase of the harmonic content. And the orders of harmonics mainly affect the number of small hysteresis loops. While the harmonic contents mainly affect the size of small hysteresis loops, and the harmonic phase angles mainly affect the location of small hysteresis loops, which will indirectly affect the final measured core loss.The improved method based on Modified Steinmetz Equation is used to predict the core loss. The applicability of this method for non-sinusoidal waveforms is also discussed in detail. Some of the experimental results are shown, as shown in Fig.2. More details will be presented in the full paper.

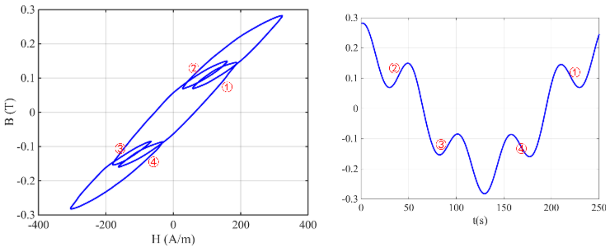

Fig.1 Test system Fig.2 Hysteresis loop (left) and *B* waveform (right) at fifth harmonic

References:

[1] Li Y , Liu Y , Liu F , et al. [J]. IEEE Transactions on Applied Superconductivity, 2014, 24(5):1-4.

[2] Zhang C et al. [J]. IEEE Transactions on Industrial Electronics, 2017, 64(3):2476-2485.

Study of the Detection of a Single Magnetotactic Bacterium

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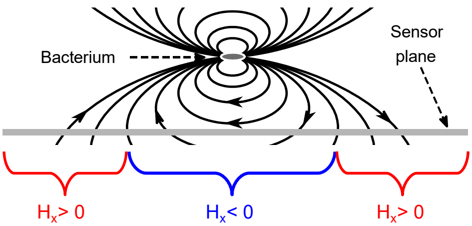
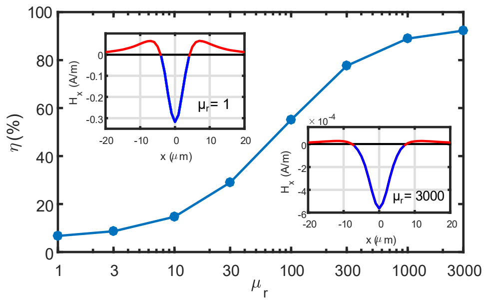
Magnetotactic bacteria are aqueous microorganisms that navigate in the Earth magnetic field using their internal chain of magnetic nanoparticles, which actuate as a compass needle. For instance, the species *Magnetospirillum gryphiswaldense* contains up to 25 cuboctahedral particles of magnetite (Fe_3O_4) with a size of about 45 nm. They are of great interest for biomedical applications, for instance as living micro-robots guided magnetically.[1] Aiming to detect the presence and movement of a single bacterium using a magnetic sensor, we study the characteristics of its field in the sensor position. Being much larger than the bacterium, the sensor is affected in different regions by fields with opposite sign. If the permeability of the sensor is low ($\mu_r \sim 1$), the net effect of the positive and negative fields is almost fully cancelled, whereas with $\mu_r >> 1$, the field distribution changes and the sensor output is greately increased. We combine analytical and numerical calculations by finite elements to evaluate the performance of the sensor, as a function of the permeability of the material, for different geometries and sensing conditions.





Left: Horizontal component H_x of the bacterium field in the sensor position. *Right*: Dependence, with the permeability of the sensor, of the figure of merit η, based on the double integral of H_x over the sensor area. η takes values close to 0 when the permeability is low, because the contribution of positive and negative fields regions nearly cancel each other. When the permeability is high, η approaches 100 % as one of the regions dominates.

References:

[1] S. R. Mishra *et al*. Nanoscale **8** (2016) 1309-1313.

The Spanish government supports this work under grant MAT2017-83631-C3.
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Evolution of the magnetic properties of structurally disordered $Ce(Fe_{0.9}Co_{0.1})_2$ metamagnet

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We have studied the crystalline structure, magnetic and magnetocaloric properties of $Ce(Fe_{0.9}Co_{0.1})_2$ alloy with the C15 cubic Laves phase, which is a well known metamagnet. Initially, sample was prepared by melt-spinning technique, which introduced structural disoder, as already reported by us for YCo_2 in Ref. [1]. Additionally, the as-cast ribbons were subjected to high pressure torsion to analyse the influence of microstructural modifications on the magnetic and magnetocaloric properties of plastically deformed samples. The C15 structure is known to be distorted to rhombohedral symmetry at 90 K in zero magnetic field. While decreasing temperature, the process is accompanied with the magnetic phase transition from the ferromagnetic to the antiferromagnetic state. In our case significant fraction of sample retains its ferromagnetic characteristic due to structural diosrder. Antiferromagnetically coupled fraction undergoes metamagnetic transition to the ferromagnetic state with applied magnetic field, which accompanies the structural transition from distorted rhombohedral structure to the cubic one. Magnetocaloric properties of plastically deformed sample are deteriorated significantly and the magnetic entropy change is reduced from about 1.45 J/kg K ($\Delta\mu_0 H$ = 2 T) to about 0.15 J/kg K for the inverse magnetocaloric effect observed in the vicinity of antiferro-ferro transition.

References:

[1] Z. Śniadecki *et al.*, Phys. Rev. B **98** (2018) 094418.

Macroscopic Magnetic Anisotropy Characterization for Fe-Si Steel Using a Wide Frequency Rotational Magnetizer

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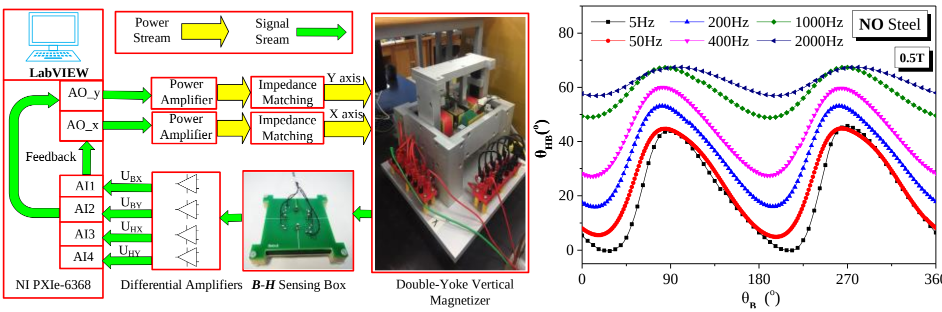
The rotational magnetic measurement for both non-oriented(NO) and grain-oriented (GO) steel is carried out with a newly constructed double-yoke vertical magnetizer up to 1.7T and in the range of 5Hz-2kHz. Macroscopic magnetic anisotropy which results from the joint effects of magneto-crystalline anisotropy, hysteresis and eddy current effects, is analyzed in detail according to the behaviour of ***H*** loci and lag phase angle θ_{HB} between ***B*** and ***H*** under circular rotational magnetization. As frequency increases, the lag phase angle exhibits upward trend which implies the increasing core loss as shown in Fig. 1(b). It is verified that the average lag phase angle approaches 0 as the sample approaches saturation at quisi-static case(5Hz). The lag phase angle fluctuation of GO steel is generally larger than that of NO steel due to its GOSS texture. The NO steel shows similar magnetic properties along different directions but still remains anisotropic. Such investigation will be useful in magnetic behaviour characterization and modelling.



(a) (b)

Fig. 1 (a) Rotational measurement system. (b) Lag phase angle of NO steel at different frequencies.

References:

[1] Spornic, D. Moussaoui, A. Kedous-Lebouc, J. Magn. Magn. Mater. 160 (1996) 147.

[2] Appino, F. Fiorillo, C. Ragusa and B. Xie, J. Magn. Magn. Mater. 320 (2008) 2526.

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High magnetization FeCo nanoparticles synthesized by chemical and physical routes

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FeCo binary alloys have excellent soft magnetic properties as high magnetization saturation and large permeability [1]. As nanoparticles (NPs) they can be used as magnetic fillers for new formulations of agnetorheological fluids [2]. Here we present results concerning the synthesis and characterization of FeCo and FeCo–V high magnetization NPs fabricated by chemical (reduction or thermal decomposition from metallo-organic precursors) and physical (laser ablation in liquid and ball milling) routes. The particles have been characterized by Dynamic Light Scattering (DLS), X-ray diffraction, TEM and SEM to determine the size, structure, morphology, and by Vibrating Sample Magnetometry (VSM) to obtain magnetic parameters.
Chemical reduction of Fe(III) and Co(II) salts in the presence of $AlNH_4F_4$ yields 20-50 nm laminar and acicular particles of FeCo NPs with M_s about 210 emu/g. Thermal decomposition leads spherical NPs but with lower M_s values (115 emu/g). To test physical routes, the starting material has been Vacoflux 50® ($Fe_{49}Co_{49}V_2$) from Vacuumschmelze. A picosecond pulsed laser at λ=355 and 532 nm in acetone produced NPs about 10-50 nm with saturation magnetization of 7 μemu/ml. By High Energy Ball milling we have obtained 0.5-1 μm NPs with *bcc* structure and about 195 emu/g saturation magnetization. Either route provides good quality NPs. The main differences among them concern the final quantity and morphology of the obtained products.

We acknowledge the Basque Government for financial support under PI-2017-1-0043 (PIBA) and ACTIMAT KK-2018/00099 (Elkartek) projects.

References:

[1] Z. Klencsár et al, *J. Alloys. Comp.* **674**, 153 (2016).

Magnetic properties of Co layer surrounded by NiO layers

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The exchange bias coupling (EBC) is a well-known phenomenon in magnetic thin films. Recently it was shown that manipulation of such interaction brings new ideas in applications e.g., modification of the exchange bias direction by the electric field can be applied in voltage-controlled spin devices [1]. For thermal stability of such devices, it is crucial to couple the ferromagnetic layer characterized by perpendicular magnetic anisotropy (PMA) with antiferromagnetic oxides, which have high Neél temperature (T_N). One of the good candidates is NiO, which has T_N=525K and supports PMA of Co layer in Au/Co/NiO system [2]. However, due to the deposition of the NiO layer in the oxygen-rich atmosphere (ORA), the Co layer is slightly oxidized reducing strongly T_N of the NiO layer.

Therefore, we study the NiO/Co/Au, where at the beginning the NiO layer is grown in ORA by pulsed laser ablation and afterward Co and Au layers are deposited by magnetron sputtering. The samples were grown in magnetic field H_{dep}=-1.7 kOe to induce EBC. This system shows: i) PMA up to the Co thickness (t_{Co}) of 0.9 nm and ii) significant exchange bias field H_{EB}=170 Oe at t_{Co}=0.7 nm. Analyzing the saturation field obtained from magnetization reversal measured using polar magnetooptical Kerr magnetometer for a t_{Co} range above the spin reorientation transition we found that the surface and volume components of the effective anisotropy equal ($K_S^{NiO/Co}+K_S^{Co/Au}$)=0.75 mJ/m^2, K_V=-0.82 MJ/m^3, respectively. This indicates that due to surface contribution from NiO/Co the PMA of Co layer is supported in a similar way as was found for Co/NiO interface [1]. Therefore, we expected that significant PMA should also be present for NiO/Co/NiO system. Indeed, the PMA is found in the Co thickness range between 0.5 nm and 1 nm with twice larger H_C and H_{EB} comparing with those values observed in NiO/Co/Au and Au/Co/NiO. This shows an additive interfacial contribution to the EBC of the Co layer when it is sandwiched between NiO layer.

Reference:

[1] T. Ashida, *et al.*, Appl. Phys. Lett. 106, (2015).
[2] P. Kuświk, *et al.*, J. Appl. Phys. 119, 215307 (2016).

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Research on the Influence of Processing Technology on Magnetic Properties of Nanocrystalline Alloys

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Compared with other magnetic materials, nanocrystalline alloy has specific advantages. It can be made into strips that much thinner than silicon steel sheets and its conductivity is lower, which effectively reduces the high frequency loss [1]. The permeability of nanocrystalline alloy is higher than that of ferrite, so the capacity and power density of the equipment made from nanocrystalline alloys can be larger at the same volume. In addition, the operating noise of nanocrystalline alloy is lower than that of amorphous alloy.

In this paper, the effect of processing technology on magnetic properties of nanocrystalline alloys is studied. The magnetic rings are processed by different technologies on annealing, insulation and strip thickness. Magnetic properties of the above three magnetic rings are measured respectively at low and high frequency. The variation of hysteresis loss and eddy current loss with frequency is compared by using loss separation formula. The inductance values at different frequencies at the same turns are measured. The parameters of the magnetic rings are shown in Table 1, and the magnetic ring is shown in Fig. 1.

Table 1 The parameters of the three magnetic rings.

Ring Sample	Strip Type	Layer Insulation	Annealing	A_e(mm^2)	L_e(mm)
1	17μm	Yes	600℃	798.2	421.1
2	17μm	A little	570℃	797.2	421.1
3	20μm	Autoxidation	550℃	798.2	421.1

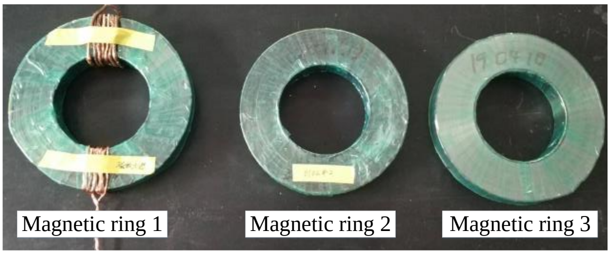

Fig. 1 Three kinds of magnetic ring samples.

References:

[1] L. Chen, Y. Wang, Z. Zhao, *et al.*, IEEE Magnetics Letters. 8, 1-5 (2017)

Magnetic characterization of selected soft ferrites in Rayleigh region

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Ceramic soft magnetic materials, known as ferrites, are widely utilized in modern electronic industry as magnetic cores of inductive components. Most of this components works with relatively low electric currents, as modern electronic devices are designed in a way providing minimal energy consumption. This results in very low values of magnetizng fields affecting magnetic cores of inductive components. However, in the literature there is lack of information about magnetic characteristic of ferrite materials in low magnetizng fields.

The paper is dedicated to investigation of magnetic characterisitics of the selected soft ferrites in low magnetizing fields, corresponding to the specific area of magetization curve know as Rayleigh region [1]. The investigated ferrites were selected due to their chemical composition and physical properties. Each investigated material was formed into the ring-shaped magnetic core. The investogation was performed with the electronic hysteresisgraph system. On the basis of obtained results, parameters of the Rayleigh hysteresis model were designated [2]. The results from Rayleigh model were comapred with measurement data in order to verify the possibility of application of Rayleigh hysteresis model for soft ferrites. The result of verification is positive. High compliance between measurement and modeling data was obtained, providing that Rayleigh hysteresis model is correct for ferrite materials magetized in low fields region.

References:

[1] Y.F. Ponomarev, Phys. Met. Metallogr. 104(5), 469-477 (2007).
[2] M. Kachniarz., R. Szewczyk, Acta Phys. Pol. 131(5), 1244-1249 (2017).

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Spin wave defect states in magnonic quasicrystal

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Phasons are the structural defects which are specific for quasicrystal. They are a local rearrangements of the constituent elements in the quasiperiodic structure. The phasons in atomic systems diffuse within the structure and coexist with phononic excitations. Here, we investigated the phasons in artificial magnonic quasicrystals – a Fibonacci sequence of Py and Co stripes. We considered phasonic defects in this system as a peculiar kind of static rearrangement of magnetic stripes. The phasonic defects are introduced by swapping the neighbouring Py and Co stripes in selected Py|Co pairs. The main goal of this study is to find the impact of the phasonic-like disorder on the spectrum and on the localization of spin wave eigenmodes in magnonic quasicrystals.

We investigated the perturbed Fibonacci sequences of stripes with lower concentrations of phasonic defects. The introduction of such defects does not change the average values of material parameters for considered composite structures. Therefore, in the regime of long-wavelengths, the spectrum of eigenmodes is the same as for the unperturbed Fibonacci sequence. In the frequency ranges corresponding to the band gaps we observed the gradual smoothing of IDOS which results in the bandgap closing for larger concentration of phasonic defects. We found out, that each spin wave defect mode occupies only few selected locations of phasonic defects. The selection of occupied defect(s) is different for different spin wave modes.

The calculations were done using the plane wave method with the supercell approach and were furtherb compared to the outcomes of the finite element method performed with the aid of the COMSOL Multiphysics package.

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Effect of air gap length on the flux distribution and vibration of corner joints in single phase transformers

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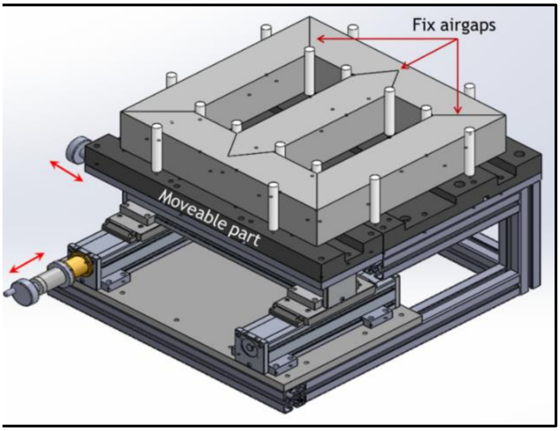
The size and consistency of the air gap in the joints of transformers is one of the important parameters in manufacturing low noise transformers. This study aimed to develop an understanding of the influence of the air gap length of a mitred corner joint on both the 2D flux distribution and the vibration.

A transformer table was designed and constructed to enable both single and three phase transformer cores to be accurately assembled and tested with the capability of moving one of the yokes with a precision of 10µm (figure 1).



Results are presented for an investigation of a single phase core which was subject to controlled magnetisation whilst measurements were made from an array of search coils in the vicinity of the joint. Vibration measurements were made using a 3D scanning laser vibrometer in the same region.

It was found that increasing the joint length led to a rotation of the flux density vector close to the corner joint with little variation from the inside to the outside of the joint. The vibration was found to be complex and significantly higher at the joint with the outer edge being particularly sensitive.

This study was partially supported by Baosteel

Toroidal low permeability CT exposed to AC homogeneous external magnetic field: analytical study, computational simulations & experimental results

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Generally, current transformer (CT) uses high permeability and low coercivity force magnetic core in order to approach ideal CT behaviour with high phase and amplitude accuracies. Unfortunately, such magnetic core becomes very sensitivity to DC component which leads to core saturation. To increase DC immunity range, permeability (μ_r) has to be lowered. Possible solutions to decrease μ_r is to add air gap in the magnetic circuit or use low permeability magnetic material [1] as nanocrystalline and amorphous flat loop, PPM powder,etc. As mentioned above, this will have impact on phase and amplitude accuracies but also on the transformer sensitivity to AC external magnetic field [2].
In this paper, a complete theorical study with measurements will be presented, highlighting in particular, the impact of the permeability level on magnetic sensitivity.
One solution to minimise external magnetic field effect on low μ_r transformers is to increase quality levels on core and winding geometries. This paper will also present some clues to convert electrical performance requirements into manufacturing quality requirements.

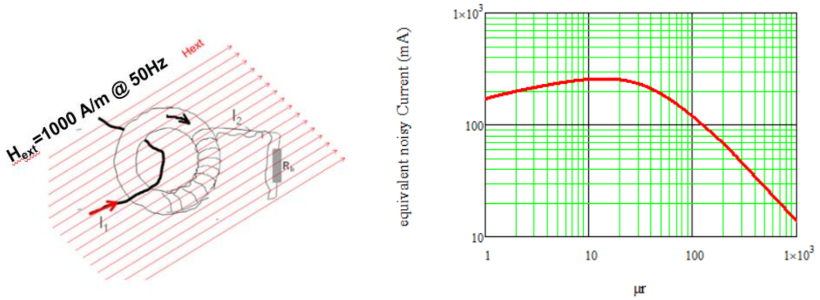

Figure : CT exposed to AC homogenous magnetic field and equivalent noisy current vs permeability in case of low quality winding.

References:
[1] H. Fukunag, *et al.*, IEEE Transactions on Magnetics 38, 3138-3140(2002).
[2] International Standard IEC 61000-4-8.

Spin Polarized Low Energy Electron Microscopy of ultrathin Co films on silicene

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After fabrication of graphene in 2004 the preparation of new 2D materials became a topic of numerous studies. Beside a number of exotic phenomena expected in such materials, like quantum spin and quantum anomalous Hall effects, 2D superconductivity, magnetism etc, they are also considered as an important part of future electronic, spintronic and valleytronic devices [1,2]. Xenes, TMDs and other 2D structures possess charge carriers with very high mobility and a band gap that by applying electric/magnetic field allows tuning their optical, catalytic and other physical and chemical properties. In order to make use of 2D structures in novel devices it is necessary to provide conductive and spin selective contacts. Such electrodes can be made of ferromagnetic thin films.

In this contribution we are studying the growth mode, morphology and basic magnetic properties of ultrathin Co films prepared in situ on silicene. The silicene layer is formed by a mild annealing of ultrathin Au films grown on the Si(111) substrate [3,4]. Then ultrathin Co layers are deposited at room and low temperatures (down to 100 K). Basic structural properties of the deposited Co films are studied with LEED, their growth and morphology – with Low Energy Electron Microscopy (LEEM) technique, and magnetic properties with Spin Polarized LEEM (SPLEEM).

References:

[1] M. Ezawa, Phys. Rev. Lett. 109, 055502 (2012).
[2] W. Han, APL Materials 4, 032401 (2016).
[3] M. Kopciuszyński et al, in preparation.
[4] T. Jaroch, R. Zdyb, in preparation.

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Novel Fe-based amorphous and nanocrystalline powder cores for high-frequency power conversion

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The high-saturation flux density (B_s >1.5 T), ultra-low coercivity (H_c<1 A/m), and high-permeability of amorphous metals, as compared to soft-ferrites, are in great demand for device miniaturisation in high-frequency power converters. As the operating frequency (f) of device approaches kHz range, the eddy-current loss ($W_e \alpha f^2$) abruptly increases as compared to the hysteresis loss ($W_h \alpha f$) and consequently the total core loss is dominated by W_e for f >100 kHz, which limits the flux concentration advantage of these materials for the high-frequency application. To overcome this challenge,the cores made using amorphous metal powders are a solution. This can be achieved by using a suffiently small particle size distribution along with insulating materials so as to restrict the eddy current path within each particle.

In the present work, we demonstrate the high-frequency materials loss performance of amorphous and nanocrystalline Iron-based powder cores of size ≤ 20 μm. The amorphous powders of different size distribution were produced by gas atomization and investigated for their structural and thermal properties. Differential scanning calorimetry (DSC) revealed two crystallisation temperatures (T_x) that correspond to the Fe_3Si and Fe_2B phases, respectively. Subsequently, the amorphous powders were submitted to heat treatment at various temperatures (T_{peak} ±50° C) to convert the amorphous powders into a nanocrystalline structure. The volume fraction of the nanocrystalline phase was controlled by the annealing temperature from 23% to 47 % with a slight increase in crystallite size from 11.7 to 13.4 nm. Further, magnetic powder cores were fabricated by nanocrystalline and structurally relaxed amorphous powders by mixing with resin and characterised for the materials loss performance and permeability from 50 KHz – 1 MHz frequency. A significant improvement in the material loss performance was observed at high frequencies, which suggests the reduced inter-particle eddy currents due to efficient particle insulation by the resin [1].

References:

[1] P. Kollár, Z. Birčáková, J. Füzer, R. Bureš, M. Fáberová, J. Magn. Magn. Mater., 327, 146-150 (2013).

Phase and group delay of the spin waves scattered on magnetic barrier

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The magonics devices are considered to be competitive to electronic and photonic systems due the small wavelength of spin waves at the GHz frequencies. This devices are based on the wave processing and therefore the controlling of the phase of spin waves is crucial for their operation. We are going to discuss the propagation (and tunneling) of spin waves over (and through) the magnetic barrier formed by the spatial changes of material parameters (magnetization saturation or magnetic anisotropy). We will investigate how the material and structural parameters (width of the barrier) affect the phase of spin waves[1]. In tunneling regime, we will discuss the counterintuitive effect of the saturation of group delay with the increase of the barrier width called Hartman effect[2]. In scattering regime, we are going to describe the changes of phase and group delay when the frequencies of the spin waves passes the resonances of the barrier.

References:

[1] J. W. Kłos, Y. S. Dadoenkova, J. Rychły, N. N. Dadoenkova, I. L. Lyubchanskii, J. Barnaś, Scientific Reports **8**, 17944 (2018).
[2] O. V. Dobrovolskiy, R. Sachser, S. A. Bunyaev, D. Navas, V. M. Bevz, M. Zelent, W. Śmigaj, J. Rychły, M. Krawczyk, R. V. Vovk, M. Huth, and G. N. Kakazei, ACS Appl. Mater. Interfaces **11**, 17654 (2019).

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Analysis Of Incremental And Differential Permeability in NDT Via Simulation And Experiment

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The growing demand of the industrial production request a quick detection and accurate measuring targets such as: yield strength (Rp0.2), tensile strength (Rm), coating thickness, etc. Usually, the parts are subjected to destructive tests, which are expensive and time consuming. Beside this, the time delay between sample collection and testing can reach up to several hours. In order to overcome these limitations, nondestructive testing (NDT) systems for the continuous inline determination of mechanical parameters in the entire steel strip are required. Since three decades, Fraunhofer IZFP designs several equipment variants and develops a wide range of technologies. The final goal is to control the production steel quality combining NDT data and process information [1-2].

In this work, two electromagnetic methods based on the so–called incremental (IP) [3] and differential permeability have been analyzed, in order to investigate flat parts from strip production. For better interpretation of measuring results and equipment optimization, it was necessary to simulate both methods by finite element methods. Most challenging is the modelling of the magnetic hysteresis behavior of the ferrite yoke and the ferromagnetic samples in static and dynamic mode. Because it is a yoke probe NDT system, the excitation and detection coils are wound around the yoke. Then, the sample is magnetized via the ferrite yoke:

- For DP method: a sine waveform voltage excitation, at high amplitude level with low frequency LF = [10- 100] Hz is applied.
- For IP method: a combination of two excitation sources are applied; the signal from the DP method is simultaneously superimposed to the high frequency (HF= 20×LF) excitation of very low amplitude.

For both methods, the current measurement is then performed around detection coil. After a specified signal processing, the real and imaginary part of the impedance is analyzed for different samples. The robustness of the finite element modelling is assessed by comparison of simulated and measured signals.

References:

[1] W.A. Theiner, Nuclear Engin. Design, 257-264 (1987).
[2] B. Wolter, Y. Gabi, C. Conrad, Applied Science, 1-29 (2019).
[3] Y. Gabi, O. Martins, B.Wolter and B.Straß, AIP Advances, 8 (2018).

Airborne Particulate Matter Characterization with Magnetic Methods, Mössbauer Spectrometry and Micro-weighing of Filters

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The particulate matter (PM) is collected on the borosilicate filters in the low-volume air samplers PNS-15 (Atmoservice, Poland) operating outside the three buildings in Warsaw (Poland) since 2014. The whole collection comprises of 407 filters. Each filter was exposed to total PM for 72 hours (3 days) with the effective air-flow volume of 2.32 m^3 per hour and accumulated the dust with grain-size significantly less than 100 μm. The mass of filters was precisely measured using a laboratory balance WAX 62 (RADWAG, Poland) with internal calibration and accuracy of $2 \cdot 10^{-2}$ mg. In order to obtain the mass of PM, the mass of filter with PM was measured and then mass of the clean filter was subtracted. The PM masses were in the range of 2-15 mg. The concentration-dependent magnetic parameter – magnetic susceptibility (χ) was normalized on mass and calculated for individual filters. In order to identify mineralogical phases of PM (magnetically soft and hard) the variety of experimental methods [1] has been applied (thermomagnetic measurements, Day plot analysis of parameters of magnetic hysteresis loop and scanning electron microscopy). Moreover, a speciation of Fe in the iron-bearing minerals has been determined with transmission Mössbauer spectrometry [2,3].

References:

[1] M. Jeleńska, B. Górka-Kostrubiec, *et al.*, Atmospheric Pollution Research 8, 754-766 (2017).
[2] B. Mahieu, *et al.*, J. de Physique Colloques 37, C6-837-C6-840 (1976).
[3] E. Petrovský, *et al.*, Stud. Geophys. Geod. 57, 755-770 (2013).

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Effect of Multiaxial Stress on the Excess Losses in Electrical Steel Sheets

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Mechanical stresses strongly influence the magnetic properties of electrical steel sheets, affecting especially the hysteresis and excess iron loss components [1, 2]. Earlier it was shown in [1] that the excess loss correlates with the hysteresis loss under uniaxial stress. In this paper, we show that this correlation is valid also in the case of multiaxial stress. The iron losses of M400-50A samples were measured with a custom made rotational single sheet tester under sinusoidal flux density (amplitude B) and various frequencies f and multiaxial stresses $\boldsymbol{\sigma}$ [2]. The energy loss densities are segregated into classical, hysteresis $w_{\text{hy}}(B, \boldsymbol{\sigma})$ and excess loss $w_{\text{ex}}(B, f, \boldsymbol{\sigma}) = c_{\text{ex}}(\boldsymbol{\sigma})B^{1.5}f^{0.5}$ components using statistical loss theory separately under each stress configuration. On the other hand, the excess losses are correlated to the hysteresis losses with a single coefficient k similarly to [1] as $w_{\text{ex}}\left(B, f, \boldsymbol{\sigma}\right) = k\sqrt{w_{\text{hy}}\left(B, \boldsymbol{\sigma}\right)}B^{1.5}f^{0.5}$. Fig 1 shows that the excess loss densities calculated with the above approach represent well the segregated ones under various stress configurations. This finding simplifies the prediction of iron losses under multiaxial stresses, since $c_{\text{ex}}(\boldsymbol{\sigma})$ does not need to be determined.

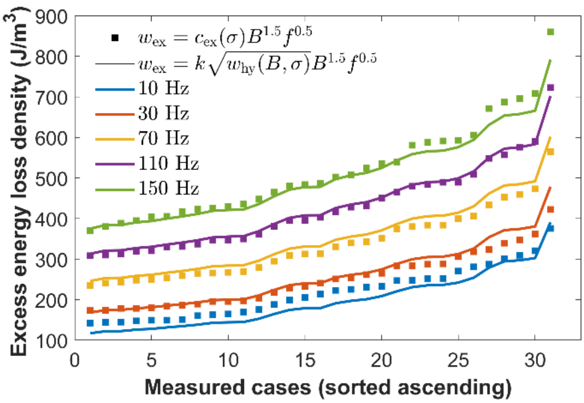

Fig. 1. Segregated and modeled excess losses for various cases

References:

[1] D. Singh, *et al*. Effect of mechanical stress on excess loss of electrical steel sheets, IEEE Trans. Magn., vol. 41, no 11, pp. 1001204, Nov. 2015.
[2] U. Aydin *et al*. Effect of multi-axial stress on iron losses of electrical steel sheets, J. Magn. Magn. Mater., vol. 469, pp. 19-27, 2019.

Soft magnetic properties of the Morasko Meteorite-based alloys

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Soft magnetic properties of the Morasko Meteorite have been already reported by Idzikowski *et al.* [1]. These properties are mainly governed by the presence of bcc-FeNi and a small amount of fcc-FeNi phase. The Morasko Meteorite contains about 92 wt. % of Fe and 7 wt. % of Ni with trace amounts of P, Co, C, Cu, S [2]. In this work we report on the magnetic properties of Ni-enriched Morasko Meteorite-based alloy with equiatomic composition of $Fe_{50}Ni_{50}$ with a small addition of Cu and Co.The alloys were rapidly quenched by melt-spinning in order to synthesize ribbons with metastable structure which can be thermomechanically treated to optimize the material properties. Scanning calorimetry measurements of these alloys reveal two overlapping exothermal peaks at about 550-640°C. These reactions are irreversible. High pressure torsion (HPT) was used as a severe plastic deformation method. X-ray diffraction analysis confirms the formation of fcc-FeNi and the possible presence of A6 tetragonal structure, which has been already reported to be the intermediate phase during $L1_0$ FePd formation after application of HPT [3]. The obtained materials are magnetically soft with saturation magnetization exceeding 150 emu/g at room temperature and coercive field lower than 15 Oe. HPT-treated samples reach saturation in much lower external magnetic fields, what can be connected with decreasing anisotropy caused by changes in the microstructure of the sample after HPT process.

References:

[1] B. Idzikowski *et al.*,Acta Physica Polonica A **118** (2010) 1071-1073
[2] V.F. Buchwald, Handbook of Iron Meteorites **3** (1975) 836-838
[3] N.I. Vlaslova *et al.*, Acta Mater. **61** (2013) 2560-2570

This work was co-financed by the project "Środowiskowe interdyscyplinarne studia doktoranckie w zakresie nanotechnologii" No. POWR.03.02.00-00-I032/16 under the European Social Fund – Operational Programme Knowledge Education Development, Axis III Higher Education for Economy and Development, Action 3.2 PhD Programme.

Dielectric, magnetic and electromagnetic interference shielding properties of ferrites

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The ferrites are a group of dielectric materials with ferromagnetic or superparamagnetic properties. These properties can be changed by their chemical composition, size, defects concentration, grains, and grain boundaries distribution. The ferrites and ferrite nanoparticles are tested as catalysts, as sensors, as drug delivery platforms and as contrast in magnetic resonance imaging. Moreover, the ferrite nanoparticles and nanocomposites with carbon-based nanomaterials can be used as microwave absorbers in a broad frequency range. This is related to the high dielectric and magnetic losses [1-4].

In this studies dielectric, magnetic and microwave absorption properties were described. The ferrites were synthesized by a simple co-precipitation method. The structure and morphology of prepared samples were described using the X-ray diffraction method and transmission electron microscopy. The influence of particle size, chemical composition, shape and modification of grain boundaries on the dielectric and electric properties was described in detail. The electromagnetic shielding properties were determined on the basis of measurements of complex permittivity and complex permeability for pure particles and nanocomposites. The analysis of reflection loss and shielding effectiveness was performed in broad frequency and temperature range. On the basis of performed measurements, the complex electrical conduction mechanism was proposed. It was confirmed that conductivity dispersion is related to the long-range mobility and to the short-range mobility, and that the transition between them is smooth.

References:

[1] A. Šutka, K.A. Gross, Sensors Actuators, B Chem., 95-105 (2016).
[2] C. Dey, *et al.*, J. Magn. Magn. Mater., 168-174 (2017).
[3] C. Bárcena, *et al.*, Chem. Commun., 2224-2226 (2008).
[4] R. Valenzuela, Novel applications of ferrites, Phys. Res. Int. (2012).

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Development of structure and magnetic properties of $Fe_{67}Co_{20}B_{13}$ soft magnetic nanocrystalline material

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Since several years, new approach to nanocrystalline soft magnetic materials has been developed. It is driven by the increasing demand of power conversion industry. The requirement for these materials are good magnetic softness and significantly higher magnetization than that typical of soft magnetic materials with amorphous or nanocrystalline structure (e.g. Finemet, Nanoperm, Hitperm).
This resulted in different approach to alloys' compositions. Instead of nanostructure forming elements (e.g. Si, B, Nb, Hf, Cu), contribution of ferro-magnetic elements has to be increased. This results in the choice of alloys compositions such as $Fe_{67}Co_{20}B_{13}$. Although it is possible to obtain a fully amorphous ribbon by conventional melt-spinning technique, conventional furnace annealing will not lead to obtain a nanostructure, thus such alloy will not be magnetically soft.
The new approach to heat treatment of amorphous alloys was proposed by Makino [1]. So called ultra-rapid annealing (URA) method is based on keeping the amorphous ribbon between hot metal blocks for several seconds. When the process is carried out with optimal parameters (temperature and time), it is possible to obtain nanocrystalline material exhibiting magnetic softness (as a result of the optimal nanocrystalline structure) and high magnetization (as a result of high content of ferromagnetic elements).
In this work, we investigated the $Fe_{67}Co_{20}B_{13}$ alloy annealed at 380, 400, 420, 440°C for 1-300 s. The evolution of magnetic properties (e.g. hysteresis loop shapes, coercive field and induction values were studied in detail. Furthermore, development of structure was examined with particular attention to crystalline volume fraction and grain size.

References:

[1] Chiba, M., Urata, A., Matsumoto, H., Yoshida, S., Makino, A., IEEE Transactions on Magnetics, IEEE Transactions on Magnetics 47(10),6027580, pp. 2845-2847

Static Hysteresis modelling of FeSi NO sheets in rolling and transverse directions

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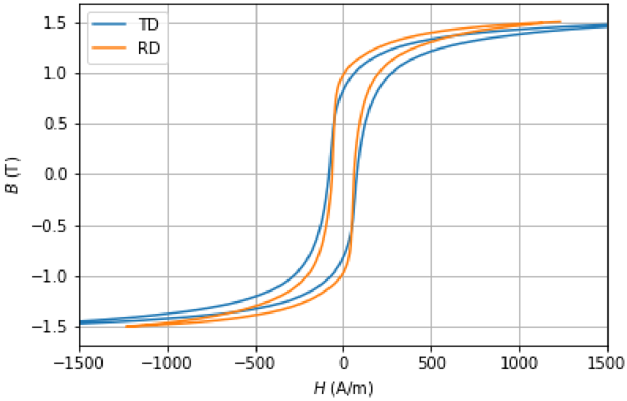
In order to predict magnetic losses or magnetic weveforms in NO FeSi sheets when excited in both rolling (RD) and transverse direction (TD), engineers need an efficient vectorial hysteresis model.
One of the last developed model which has a lot of desirable properties is a vector play model (VPM) firstly introduced by Berqvist [1] such as being intrinsically vectorial. Efficient identification protocols [2,3] exist to identify the cells parameters.
This paper will modify and test this last model in order to predict magnetic quantities in rolling and transverse directions of FeSi NO magnetic materials.



References:

[1] A. Bergqvist, “Magnetic vector hysteresis model with dry friction-like pinning,” Physica B: Condensed Matter, vol. 233, no. 4, pp. 342–347, 1997.
[2] F. Sixdenier and R. Scorretti, “Numerical model of static hysteresis taking into account temperature,” International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, pp. e2221–n/a, 2017, e2221 jnm.2221.
[3] K. Jacques, S. Steentjes, F. Henrotte, C. Geuzaine, and K. Hameyer, “Representation of microstructural features and magnetic anisotropy of electrical steels in an energy-based vector hysteresis model,” AIP Advances, vol. 8, no. 4, p. 047602, 2018.

Effects of Core Welding in Electrical Machines Performances - Measurements and Modeling

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There is a growing interest towards increasing the efficiency of electrical machines to reduce the ecological footprint. The efficiency of an electrical machine is closely related to the understanding and accurate estimation of the associated losses. One loss component is related to the welding of the electrical steel sheets as a part of manufacturing [1, 2].

This paper studies the effect of the core welding on a typical industrial induction motor. The effect of core welding on the magnetic permeability and core losses is first analyzed with the help of magnetic measurements on the unwelded and welded ring cores assembled from the stator sheets. Further, the derived material parameters are applied in finite element analysis of the induction machine and the effect of welding on the machine performance parameters is analyzed. It was observed that stator core losses increased about 10% due to the welding effect. A mock-up prototype is then manufactured to measure the stator core losses which follow the simulated values closely.

Fig1. Welded stator lamination stack

References:

[1] W. M. Arshad *et al.*, "Incorporating Lamination Processing and Component Manufacturing in Electrical Machine Design Tools," *2007 IEEE Industry Applications Annual Meeting*, New Orleans, LA, pp. 94-102 (2007).

[2] Y. Kurosaki *et al.*, "Importance of punching and workability in non-oriented electrical steel sheets," *Journal of Magnetism and Magnetic Materials*, pp. 2474-2480 (2008)

Hyperfine interactions in $(Fe_{100-x}Ge_x)_{0.95}Ni_{0.05}$ alloys (x = 0, 5, 10, 15, 20)

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The structural and magnetic properties of Fe-based alloys $(Fe_{100-x}Ge_x)_{0.95}Ni_{0.05}$ (x = 0, 5, 10, 15, 20) were characterized by X-ray diffraction, X-ray photoelectron spectroscopy (XPS), magnetostatic and ^{57}Fe Mössbauer spectroscopy measurements. The X-ray measurements show that all investigated compounds have a body-centered cubic (bcc) structure which means that germane atom did not cause changing in crystal structure in studied Fe-Ge stoichiometry. The investigation of magnetic properties of $(Fe_{100-x}Ge_x)_{0.95}Ni_{0.05}$ proved their ferromagnetic behaviour. The XPS analysis of all studied samples was performed. The multiplet splitting of Fe3s core level lines was analyzed. Based on fitting of as-measured Fe3s spectra the magnetic moment of iron as well as the exchange overlap integral of 3s and 3d shells (J_{sd}) were estimated. The Mössbauer spectroscopy allowed to study the local environments of the Fe-centered atoms in the investigated alloys and provided also information about the changes in the local structure due to the modification of chemical composition by various germane content. Addition of Ge affected the disordering $Fe_{0.95}Ni_{0.05}$ initial state and also influenced on the number of nearest neighbour Fe–Fe atoms, consequently.

Synthesis and characterization of nano magnetite-maghemite particles stabilized with polyethylene glycol, obtained by mechanical milling

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In this work we present the synthesis and characterization of nano-spinel particles of magnetite-maghemite obtained by mechanical milling of sub micrometric hematite in presence of polyethylene glycol (PEG) as stabilizing medium. This method allow us to obtain nanoparticles of magnetite-maghemite free of impurities, with less aggregation and particle size distribution narrower than those obtained by us in a previous work, where a mixing of hematite and deionized water was used for total conversion of hematite to spinel system. As precursor reagents we used microstructured analytical grade hematite (α-Fe_2O_3) and an aqueous solution of PEG. The milling products were characterized by X-Ray Diffraction (XRD), Transmission Electron Microscopy (TEM), Transmission Mössbauer Spectroscopy (TMS) and Vibrating Sample Magnetometry (VSM). X-ray diffractograms showed only the presence of spinel phases magnetite-maghemite in the products, while Mössbauer spectroscopy confirmed the presence of two sextets characteristic of ions Fe^{3+} and $Fe^{2.5+}$ in magnetite or mixtures magnetite-maghemite. TEM micrographs showed quasi-spherical particles with low aggregation and mean diameter around 14 nm. Room temperature magnetization loops are consistent with multi domain nano spinel particles, with a saturation magnetization around 60 emu g^{-1} and coercive field around 160 Oe. The results suggest that mechanical milling in presence of PEG is a simple and promissory route to scale the production of spinel nanoparticles with good magnetization, useful for applications in nanotechnology.

References:

[1] M. Unni, *et al.*, ACS Nano 11(2), 2284-2303 (2017).
[2] L. Branquinho, *et al.*, Scientific Reports 3, 2887 (2013).
[3] H. D'Couto, Journal of the US SJWP, 32-45 (2008).

Magnetic properties of soft magnetic FeCoB nanocrystalline materials obtain by the semi-industrial ultra-rapid annealing system

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The high induction metallic glass ribbons obtained via melt spinning technique with the chemical formula $Fe_{67}Co_{20}B_{13}$ are presented. Comparison between properties obtained via different types of the heat treatments using conventional annealing and ultra rapid annealing were investigated. The crystallization temperatures and kinetics of the crystallization process in dynamic mode were annalysed by the differential scaning calorimetry. The X-ray diffraction method was used to deremine the degree of crystallization. Magnetic properties were analysed for the thoroidal cores prepared from the ribbons annealed in the semi-industrial ultra-rapid annealing system.

This study was partially supported by NCBR grant: TECHMATSTRATEG1/347200/11/NCBR/2017

Large coercivity modulation in Fe/FeRh/W(110) bilayers across antiferromagnetic – ferromagnetic phase transition in FeRh alloy

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Low dimensional FeRh films exhibiting temperature induced AFM⇔FM transition are promising materials for the heat assisted storage media applications [1]. Ultrathin FeRh layer with thickness of 50 Å and 100 Å were grown on the W(110) substrate. Next, thin Fe (10 Å) film was deposited as capping layer. The magnetic properties were studied in-situ using longitudinal magnetooptical Kerr effect (LMOKE).

The temperature dependence of the coercivity field H_C (see Fig.1, filled symbols) for Fe/FeRh bilayers revels a large coercivity enhancement during cooling process, when the FeRh system undergoes transition from FM state to AFM state. The comparison of the Kerr rotation at saturation values ROT_{SAT} which were taken as a measure of the magnetization (see Fig. 1, open symbols) and H_C for the Fe/FeR bilayers shows that the observed changes in coercivities are fully associated with the AFM⇔FM transition in the FeRh alloy as corresponding changes in Kerr rotation and coercivities occur in the identical temperatures and are characterized by similar hysteresis.

Finally, strains originating from mismatch between FeRh layer and W(110) substrate strongly affects the temperature profile of AFM⇔FM transition. Accordingly, the temperature window of the coercivity modulation can be tuned by the FeRh film thickness, as shown in the figure below.

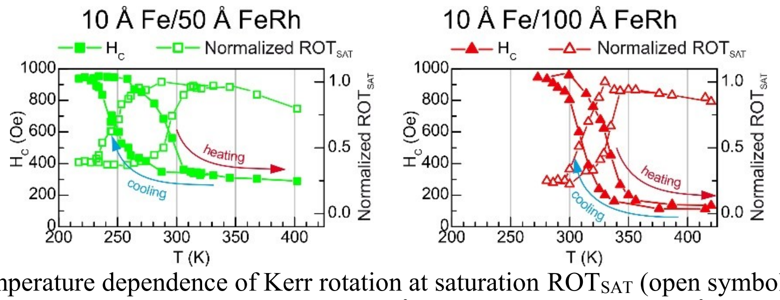

Fig.1 Temperature dependence of Kerr rotation at saturation ROT_{SAT} (open symbols) and coercivity field H_C (filled symbols) for Fe/(50 Å) FeRh (left) and Fe/(100 Å) FeRh (right).

References:

[1] J.-U. Thiele, S. Maat, and E. E. Fullerton, Appl. Phys. Lett. **82**, 2859 (2003).

This work was supported by the National Science Center of Poland under Project No. 2015/19/B/ST3/00543 and partially by the AGH University of Science and Technology statutory task No. 11.11.220.01/6 under a subsidy from the Ministry of Science and Higher Education. J. Korecki thanks the statutory research funds of ICSC PAS for their support.

Damping of magnetization precession in Co_xFe_{100-x} films

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It was believed that a low damping ($\alpha<0.001$) of magnetization precession is rather not expected in metallic films due to the conduction electrons which provide an additional channel of dissipation of the angular momentum from the spin system. The materials with the lowest known damping are dielectrics like yttrium iron garnet (YIG). Recently it has been found that metallic $Co_{25}Fe_{75}$ polycrystalline films also can have ultra-low damping [1]. This unusual behavior can be understood in terms of the minimum in the density of states at the Fermi level [1].

The total damping of thin films is a sum of intrinsic and extrinsic contributions. The most important extrinsic contributions in thin films are the spin pumping effect and the radiative damping. The total damping of $Co_{25}Fe_{75}$ polycrystalline films is as low as 0.002, but its intrinsic damping is even lower of order 0.0005 [1], i.e. comparable to YIG. It has been also shown that the main contribution to the total damping comes from the spin pumping effect.

Here we show results of magnetization damping in $Co_{25}Fe_{75}$ polycrystalline films in contact with various materials (Ti, Cu, Au, NiO) to study the influence of the spin pumping effect. We found that it is crucial to use a proper buffer layer to achieve a low damping measured in the in-plane configuration [2]. Surprisingly, even the ultrathin Cu buffer layer was sufficient to reduce the damping threefold (to $\alpha<0.003$). Moreover, the measured intrinsic damping is of order 0.0005 as in previous study [1,2]. The other materials used as a buffer result in much higher damping values. We have also found that although the NiO layer is dielectric, it increases the damping substantially due to the spin pumping effect. The measured spin mixing conductance is 4.8×10^{19} m^{-2}, which large in comparison to those of Pt, Pd, and Au [2].

References:

[1] M.A.W. Schoen *et al.*, Nature Physics 12, 839 (2016)
[2] H. Głowiński *et al.*, Journal of Alloys and Compounds 785, 891 (2019).

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Effect of Electrical Polarity on Dielectric Breakdown in a Soft Magnetic Fluid

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This paper is devoted to a soft magnetic fluid based on transformer oil and iron oxide nanoparticles stabilized with oleic acid. The investigated magnetic fluid is characterized from magnetization and magnetic susceptibility point of view. Quasi linear increase in magnetization of saturation with increasing magnetic volume fraction (ranging from 0.05 to 0.35 vol%) has been found. The particle size distribution has been obtained by applying the superposition of Langevin fitting functions on the magnetization curve. Measurements of AC magnetic susceptibility revealed almost zero magnetic losses in a wide frequency range. Especially at 50 Hz the magnetic nanoparticles in the studied samples are well relaxed. This behavior makes the magnetic fluid suitable for electrical engineering applications, e. g. in power transformers. In this regard, the dielectric and insulating properties of the magnetic fluid must be also verified [1,2]. Herein, we focus on a dielectric breakdown in the transformer oil and three magnetic fluid samples. The breakdown tests are carried out in the needle-sphere electrode geometry with the high negative potential applied once to the needle and then to the sphere. The experiments revealed a remarkable polarity effect on the dielectric breakdown voltage of the magnetic fluids. A significant increase in the breakdown voltage was measured in the case with the negative high potential applied to the needle electrode, as compared with the high potential on the sphere. To provide the explanation of the observed effect, the electric field distribution, space charge and potential effect of local magnetic fields in the vicinity of the magnetic nanoparticle is taken into account.

References:

[1] M. Rajnak, *et al*., Physical Review Applied, 11, 2, 024032 (2019)
[2] J. Kurimsky, *et al*., Journal of Magnetism and Magnetic Materials, 465, 136-142 (2018).

This study was partially supported by the Slovak projects VEGA 2/0141/16, VEGA 1/0340/18, APVV-15-0438, APVV-17-0372 and APVV-18-0160; and EU projects: ITMS 26220220186 and COST CA15119 NANOUPTAKE.

Hyperfine Interactions in Fe/Co-B-Sn Amorphous Alloys by Mössbauer Spectrometry

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Hyperfine interactions in amorphous and nanocrystalline rapidly quenched Fe-B-Sn-based alloys with Co/Fe substitution were followed by ^{57}Fe Mössbauer spectrometry. Samples were prepared by planar flow casting and subsequently annealed in the regions of phase transformations determined by differential scanning calorimetry. Structure analysis has been performed by X-ray diffraction, magnetic thermogravimetry, and transmission electron microscopy. Presence of bcc-Fe(Sn) and bcc-Fe,Co(Sn) crystalline phases was revealed. In order to follow evolution of the local atomic rearrangement, Mössbauer spectrometry was applied. Hyperfine interactions between ^{57}Fe nuclei and electron shells were investigated both in the as-quenched state and also after the nanocrystallization. In this way, characterization of the local short-range order was possible. Mössbauer effect experiments were performed in transmission geometry at different temperatures and in external magnetic field.

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Magnetic And Electric Properties Of Al-doped $Ca_2Fe_2O_5$ Brownmillerite Compounds

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We have examined the magnetic, electric and structural properties of the $Ca_2Fe_{2-x}Al_xO_5$ system with $0 \leq x \leq 1.2$. The examined samples were prepared using CaO, Fe_2O_3 and Al_2O_3 powders in form of annealed tablets. The magnetic moment and magnetic hysteresis measurements showed that only the compound with x=0 showed the ferromagnetic behavior up to room temperature. The samples with $x \neq 0$ exhibited the magnetic moment only in very low temperature and the absence of hysteresis loop. However the Mossbauer measurements performed at room temperature exhibited the typical spectra observed for ferromagnetic or antiferromagnetic arrangement for all examined samples $0 \leq x \leq 1.2$.
The measurements of the electric conductivity have revealed that at low frequencies all investigated samples show plateau being a characteristic of the dc conductivity which follows Arrhenius behavior as a function of reciprocal temperature. The brownmillerite $Ca_2Fe_{1.6}Al_{0.4}O_5$ has been characterized by the lowest activation energy (0.28 eV) of dc conductivity. The deconvolution of the Nyquist plots into two semicircles related to the grain and grain boundary contributions showed that the grain boundary is dominant in the case of pure $Ca_2Fe_2O_5$ whereas the doped samples show the predominance of grain contribution. The electronic structure calculations was used to describe the ground state properties of examined samples based on *Pnma* space structure. The exchange-correlations potential was used in the form of new SCAN-meta-GGA that was suggested to be highly accurate for systems with very different kinds of bonds. The calculations were performed using the projector augmented wave method (PAW) , which is implemented in the Vienna ab initio Simulations Package (VASP). The calculations showed the existence of two kinds of magnetic moments at Fe cations coming from FeO_6 - octahedral and FeO_4 – tetrahedral cages.

Magnetic properties of ErNiSb half-Heusler phase

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Here, we report on the magnetic behavior of the half-Heusler compound ErNiSb, which crystalizes in the cubic MgAgAs-type structure (space group *F*-43*m*, no 216). Recent studies on this material were focused on its thermoelectric properties and possible applications [1-3]. In a wide temperature range, the magnetic susceptibility of ErNiSb follows a modified Curie-Weiss law with the effective magnetic moment $\mu_{eff} = 9.45(4)\ \mu_B$, which is very close to the theoretical Russel-Saunders value for a free Er^{3+} ion ($[g_J(J+1)^{1/2}] = 9.59$). The paramagnetic Curie-Weiss temperature equals $\Theta_{CW} = -5.7(2)$ K, indicating weak antiferromagnetic interactions between the erbium magnetic moments. In the entire temperature range investigated, the temperature dependence of the inverse magnetic susceptibility deviates from a straight-line behavior, probably due to strong crystalline electric field effect (CEF) [4]. At 2 K, the magnetization varies with magnetic field in a manner characteristic of paramagnets, attaining in a field of 5 T a value of 5.5(1) μ_B/Er atom that is strongly reduced with respect to that calculated for a free Er^{3+} ion (gJ = 9). The latter finding can be attributed to the CEF effect. In summary, ErNiSb was found to bear localized magnetism due to Er^{3+} ions, yet no long-range magnetic ordering emerges in the compound down to 1.8 K. Another unusual feature is strong CEF interaction that governs the magnetic behavior in ErNiSb up to room temperature.

References:

[1] K. Kawano, *et al.*, Applied Physics Letters. 91, 062115 (2007).
[2] K. Kawano, *et al.*, Journal of Applied Physics. 104, 013714A (2008).
[3] K. Ciesielski, *et al.*, Materials Today: Proceedings. 8, 562 (2019).
[4] I. Karla, *et al.*, Physica B: Condensed Matter. 271, 294 (1999).

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Characterisation of Non Oriented Electrical Steels based on the Dynamic Hysteresis Loop (DHL)

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Non-Oriented (NO) electrical steels are silicon steels in which magnetic properties are practically the same in any direction of magnetisation in the plane of the material. Due to the approximate homogeneous nature of NO steels, magnetisation process of the material can be evaluated by numerical solution of the 1-D diffusion equation [1]:

$$\frac{\partial B_z(x,t)}{\partial t} = \rho \frac{\partial^2 H_z(x,t)}{\partial x^2} \qquad (1)$$

which link the flux density $B_z(x,t)$ and the field strength $H_z(x,t)$ directed in z-axis in a thin ferromagnetic lamination of resistivity ρ.

Hysteresis loops of the magnetic materials and magnetic cores may take many different shapes, which depend on the magnetising conditions, properties of the materials, and quality of the magnetic cores [2]. In this work Epstein size lamination of 0.5 mm thick NO 3 % *SiFe* was charactersised. DHL of the sample was measured under sinusoidal induction at peak flux densities of 1.1 T, 1.3 T and 1.5 T and frequencies of 50 Hz, 400 Hz and 800 Hz, the results are shown in Fig 1.

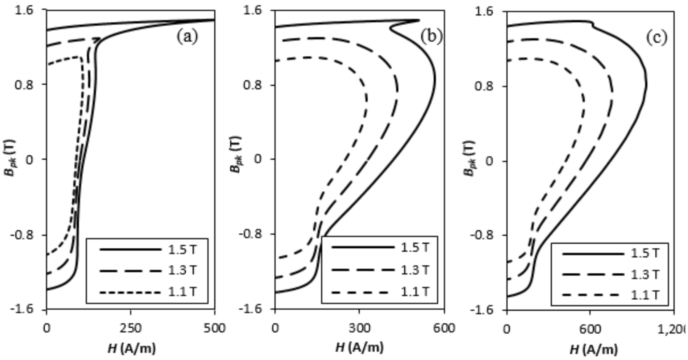

Figure 1 DHL of the sample at peak flux densities of B_{pk}=1.5 T, B_{pk}=1.3 T and B_{pk}=1.1 T and frequencis of (a) 50 Hz (b) 400 Hz and (c) 800 Hz

An approach was developed [3] to calculate the specific energy loss from the measured DHL. A closse agreement with a maximum difference of less than 3 % was found between the measured and calculated energy losses.

References:

[1] S. Zirka, et. al., JMMM, Vol. 394, Nov. 2015, pp 229-236
[2] G. Bertotti and I. Mayergoyz "*The Science of Hysteresis*", Academic Press 2005
[3] H. Hamzehbahmani, IET Electric Power Applications, Accepted for publication, 2019

Electrical steels were provided by Cogent Power Ltd, and the experimental work were performed at Wolfson center for magnetics at Cardiff University.

Magnetocaloric response of biphasic GdPd alloys

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Emergent global concerns of energy efficiency and climate changes have promoted research on magnetocaloric materials due to their potential applications for environmental-friendly and energy-efficient magnetic refrigeration at room temperature [1]. These materials can be classified into first- and second-order phase transitions. While the former show larger magnetocaloric effect (MCE) than the latter, it is at the expense of thermal and magnetic hysteresis and moderate refrigerant capacity. For that reason, Gd has been considered as the benchmark MCE material for its Curie transition occurs near room temperature as well as it being non-hysteretic. Theoretical reports have shown that bi-phasic soft magnetic MCE composites with proper selection of their Curie temperatures (T_C) and tuning of their phases, could lead to an enhancement of refrigerant capacity (as high as 83%), which is also experimentally found [2-4].
This work investigates the MCE of alloying Pd to Gd, which yields the formation of an extra GdPd phase, forming a composite ($Gd_{100-x}Pd_x$ where x=5, 10, 15 and 20 at.%) with a separation of Curie temperatures between the phases of ΔT_C=45 K. The two Gd and GdPd phases can be observed from X-ray diffraction and magnetization results, showing more GdPd phase with increasing Pd content. MCE results present two characteristic ΔS_M peaks, further indicating the presence of biphasic magnetic composites with Pd alloying. The two minima observed from the exponent n of field dependence of ΔS_M reinforced the presence of the Curie transitions of the two phases.

References:

[1] V. Franco, *et al*, Prog. Mater. Sci. **93**, 112-232 (2018).
[2] R. Caballero-Flores *et al*, Appl. Phys. Lett. **98**, 102505 (2011).
[3] J.Y. Law, *et al*, J. Alloys. Comp. **675**, 244-247, (2016).
[4] P. Gębara, *et al*, J. Magn. Magn. Mater. **442**, 145-151, (2017).

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Magnetite nanoparticles surface-modified with organic compounds

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Magnetite nanoparticles (Fe_3O_4 NPs) are widely used in various fields of science and technology, but their greatest interest is in the medicine. Due to their numerous advantages, such as biocompatibility, lack of toxicity, possibility of surface modification and unique magnetic properties, they are applied for example as contrast agents for MRI, controlled drug delivery or hyperthermia treatment [1]. The magnetic properties of Fe_3O_4 NPs strongly depends on their chemical and physical parameters, which can be regulated by controlled synthesis process. Moreover Fe_3O_4 NPs with size below 12 nm, exhibit superparamagnetism at room temperature, what is characteristic for isolated nanoparticles.
The aim of the research is to synthetize magnetite nanoparticles by co-precipitation method in alkaline medium and characterize them. To prevent aggregation, the surface of Fe_3O_4 NPs was modified with DMSA. The nanoparticle crystal structure and morphology were determine by XRD and transmission electron microscopy (TEM). To investigate the role of DMSA and to understand the adsorption mechanism, the FTIR measurements were carried out. Moreover, samples in the form of powder and ferrofluids with different concentrations, were examined using Mössbauer Spectroscopy. The spectra were recorded in a wide temperature range (from 4K to RT). For powder sample, the superparamagnetic doublet appears at room temperature. In the case of concentrated ferrofluid suspension, the spectrum consist of asymmetrically broadened lines (conversion of the doublet into an extended sextet), which may indicate the occurrence of dipole interactions. In the case of diluted sample, the inter-particle interactions are not as strong as for concentrated sample. The spectrum shows gradual transition from an asymmetrically sextet to broaden singlet with the increasing temperature [2].
Additionally, in order to characterized the magnetic behaviour of prepared Fe_3O_4 nanoparticles at different temperatures, magnetization and zero field cooling-field cooling (ZFC/FC) curves has been measured with a vibrating sample magnetometer.

References:

[1] S.S.R. Kumar, F. Mohammad, Adv Drug Deliv Rev., 63(9): 789-808 (2011).
[2] S. Mørup, M. F. Hansen, C. Frandsen, Beilstein J. Nanotechnol. 1, 182–190 (2010).

The use of loss separation models on CoFe Alloys

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Cobalt Iron has been used as a soft magnetic material for its high saturation magnetisation and mechanical strength in small electrical machines where weight, size and reliability are important.

This study has looked at two thicknesses of $Co_{49}Fe_{49}V_2$, 0.15mm and 0.20 mm. The samples have been annealed to produce the best magnetic properties and have been cut to allow measurement of the magnetic properties both in the rolling and transverse direction. Magnetic properties have been measured in a frequency range of DC – 1500 Hz up to magnetic flux densities of 2.3 T.

The total power loss per cycle is split into three components, the hysteresis losses, the classical eddy current losses, and the excess or anomalous losses, by analyses of the frequency dependence. In loss separation theory the change of the thickness should only be dependent on the classical eddy current losses which are proportional to the square of the thickness. This study shows that there are additional losses gained in reducing the thickness in the classical losses and excess losses as well as there dependence on the magnetisation direction, due to differences in manufacturing processes.

Determination of stress dependent magnetostriction using a magneto-mechanical model and experimental B-H curves

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Magnetic properties of materials used in electrical machines depend strongly on the stress induced during the manufacturing process. To address this stress dependency, different models using the magnetostriction as a magneto-mechanical coupling term have been developed. The magnetostriction is an even function of magnetization with a nonlinear dependency on compressive and tensile stress. However, the magnetostriction models developed in the literature often require complicated measurements for validation.

In this work, the magnetostriction model proposed in [1] is identified from measured B-H curves under different elastic stress associated to the Jiles-Atherton-Sablik (JAS) model [2]. The Langevin function used in the original JAS model has been replaced by a double Langevin function, which improves the accuracy of the model for high magnetic field intensities [3]. Figure 1 gives the experimental B-H curves and those obtained by the JAS model using the Langevin and the doube Langevin function. Figure 2 gives the evolution of the modeled magnetostriction with respect to the magnetization and elastic stress.

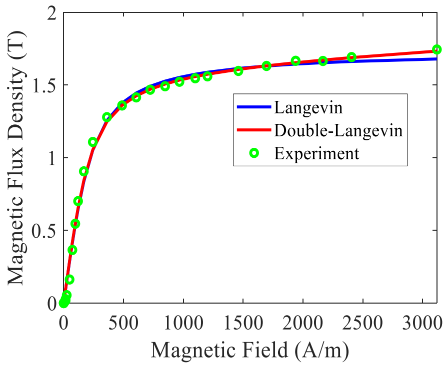

Fig. 1. Measured and modeled B-H curves using Langevin and double Langevin fuction

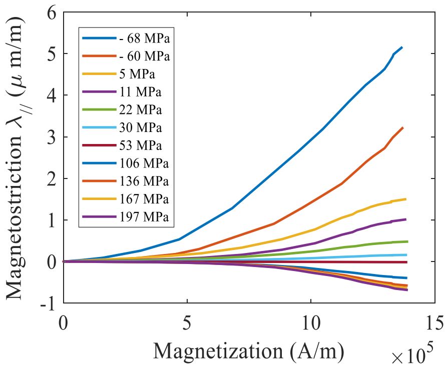

Fig. 2. Modeled magnetostriction for different stress state

References:

[1] D. Singh, *et al.*, IEEE Trans. Magn., Vol. 52, No.11, (2016).
[2] M. J. Sablik and D. C. Jiles, IEEE Trans. Magn., Vol. 29, No.4, (1993).
[3] S. Steentjes, *et al.*, AIP Advances, Vol. 7, No.5, (2017).

The influence of cooling rate, chromium and silicon addition on the structure and properties of AlCoCrFeNiSi high entropy alloys

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High entropy alloys (HEAs) are alloys containing at least five different chemical elements mixing with a similar proportions (between 5 and 35 at.%). The same content of the all chemical elements causes the high disordering in the liquid state. Despite the high entropy these alloys can crystallize in one or few phases. According to the unique crystalline structure HEAs are characterized by high mechanical strength and hardness [1].
High concentrations of many elements cause the diffusion to slow down. It was found that the diffusion activation energy is higher for several elements than in pure metals and alloys with small additions of other elements, which leads to lower diffusion coefficients. This results in increased resistance to corrosion and oxidation [2].
The aim of this study was tested possibility of formation of Al-Co-Cr-Fe-Ni-Si (Al-Co-Cr-Fe-Ni-Si, Al-Co-Fe-Ni-Si, Al-Co-$Cr_{0.5}$-Fe-Ni-$Si_{0.5}$, Al-Co-Fe-Ni-$Si_{0.5}$) HEA alloys. The samples were prepared by two different method to determine influence of cooling rate on the structure and properties of alloys. The structure of alloys was investigated using X-ray diffraction method and scanning electron microscopy. It was confirmed, that the addition of chromium and silicon causes significant changes in the structure of alloys – new crystallographic phases are formed for alloys with different Cr and Si content. The magnetic properties were examined using vibrating sample magnetometer and Mössbauer spectroscopy. Additionally, the hardness and corrosion resistance of alloys was investigated. It was noted, that the Al-Co-Cr-Fe-Ni-Si is characterized by the highest corrosion resistance and it has the highest hardness equal to abrasion resistant steel.

References:

[1] M. Tsai, J. Yeh, High-Entropy Alloys: A Critical Review, Materials Research Letters, 2:3, 107-123, 2014
[2] Z. Lu, H. Wang, M. Chen, I. Baker, J.W. Yeh, C.T. Liu, T.G. Nieh, An assessment on the future development of high-entropy alloys: Summary from a recent workshop, Intermetallics, 66, 67-76, 2015

Transformations of the Micro-Magnetic Structure Elements of Iron-Garnet Films Induced by the Magneto-Electric Interaction

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The magnetoelectric activity effect of vertical Bloch lines (VBL) was experimentally revealed in epitaxial bismuth-substituted iron garnet films. Changes in the film's domain structure (DS) in AC electric field were investigated by the method of optical dark field microscopy [1] with the direct visual observations. This paper is a continuation of our earlier researches [2-4] of magnetoelectric effects in thin garnet films. This research method under used experimental conditions allowed us to identify the effect which is visually manifested as a broadening of the regions of VBL localization. The reported results indicate that in bismuth-substituted iron garnet epitaxial films have a transformation of the micro-magnetic structure elements with inhomogeneous magnetic structure (VBL in particular) caused by the magnetoelectric interaction since the electric field affects the distribution of magnetization in films. In our opinion, the external electric field (applied in the easy axis direction) induces additional amplification of the initially existing micro-slope of the domain wall region in the vicinity of the VBL. Described features of the film's domain structure behavior in the presence of external electric field may be caused by changing of the magnetic anisotropy parameters of iron garnet films.

References:

[1] A. Thiaville, *et al*., J. Appl. Phys. 69, 6090 (1991).
[2] V. Koronovskyy, S. Ryabchenko, V. Kovalenko, Phys. Rev. B. 71, 172402 (2005).
[3] V. Koronovskyy and Y. Vakyla, J. Appl. Phys. 118, 184101 (2015).
[4] V. Koronovskyy, Y. Vakyla, EML. 11, 6 (2015).

Dielectric Properties Of Gas-To-Liquid Based Nanofluid With Different Nanoparticle Percentage Representation

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In this paper, the inhibited gas-to-liquid (GTL) based transformer oil as new carrier liquid for nanofluid was used. The magnetite nanoparticles and oleic acid as surfactant were used for formation of magnetic nanofluid. The used magnetic nanofluids had different concentrations (0.05% – 3.0%) and they were compared with pure carrier GTL. The magnetization saturation and magnetic susceptibility were obtained by magnetometer and susceptometer. The dielectric behaviour of nanofluids was studied by dielectric spectroscopy based on measurements of parts of complex permittivity in domain from ultra-low frequencies to medium frequencies (0.1mHz – 2MHz). All measurements were carried with temperature dependence from 303.15K to 363.15K. Both parts of the complex permittivity show appreciable dielectric dispersion according to volume of particles in GTL carrier. The results of FDS also showed that the different polarization phenomena are depend on temperature and the proportion of dispersed particles in the carrier liquid.

Enhanced exchange interaction between Fe and FeO in Fe/MgO/FeO epitaxial heterostructures

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For ferromagnetic(FM)/antiferromagnetic(AFM) bi-layers ability to grow controllable, well-defined interface is crucial for interface driven phenomena such as exchange coupling between FM and AFM [1].
Recently, we succeeded in stabilization of an epitaxial wüstite (FeO) film on MgO(001) [2]. In our present study we examined chemical and magnetic properties of FeO in an epitaxial Fe/MgO(d_{MgO})/FeO trilayers for different MgO thicknesses, d_{MgO}. Analysis of the chemical structure revealed a stoichiometry improvement of the FeO layer in Fe/MgO/FeO in comparison with a Fe/FeO bilayer. Furthermore, we showed that deposition of a subtle MgO layer at the Fe/FeO interface results in enhanced exchange interaction between Fe and FeO. For d_{MgO}=1.4Å we noted a 200% enhancement of exchange bias in Fe/MgO/FeO as compared with Fe/FeO.

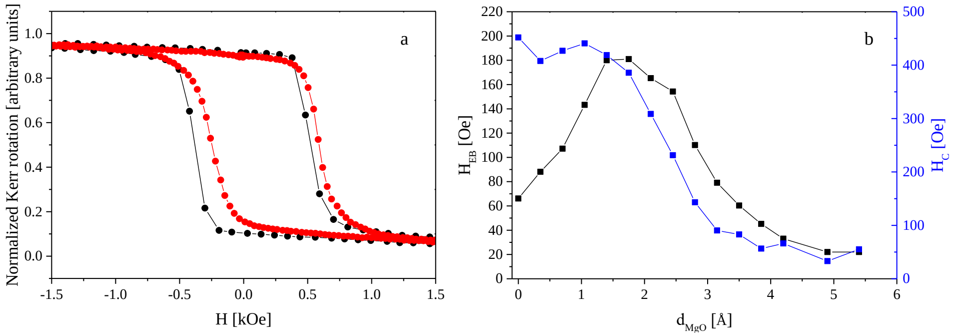

Figure 1(a) Representative LMOKE hysteresis loops at 80K obtained for Fe/FeO(black points) and Fe/MgO(1.4Å)/FeO(red points). (b) Exchange bias field (black points) and coercive field (blue points) dependence on MgO thickness (d_{MgO}) in Fe/MgO(d_{MgO})/FeO,

References:

[1] W. Zhang and K.M. Krishnan, Mater. Sci. Eng. R **105**, 1 (2016).
[2] A. Kozioł-Rachwał *et al.* Appl. Phys. Lett. **108**, (2016).

This work was supported by the "Antiferromagnetic proximity effect and development of epitaxial bimetallic antiferromagnets – two routes towards next-generation spintronics" project which is carried out within the Homing programme of the Foundation for Polish Science co-financed by the European Union under the European Regional Development Fund.

Field-Free Spin-Orbit Torque-Induced Magnetization Switching in Exchange-Biased W(Pt)/Co/NiO

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Spin-orbit torque (SOT)-induced magnetization switching provides an alternative for non-volatile memory and logic devices. SOT-switching of perpendicular magnetization is usually observed in an external magnetic field collinear with the current, which however, is impractical in device applications. Here, we investigate the SOT generated by heavy metal (W, Pt), which induces switching of Co layer in perpendicularly magnetized exchange-biased (EB) multilayer structures $Si/SiO_2/W(Pt)/Co/NiO$ deposited by magnetron sputtering (W, Pt, Co) and pulsed laser deposition (NiO). The in-plane EB at the interface of ferromagnetic Co and antiferromagnetic NiO induces the effective in-plane magnetic field of about +130 Oe in case of W and +30 Oe for system with Pt. This leads to deterministic SOT-driven field-free switching. In 10 x 100 μm^2 Hall bars with 0.81 nm thick Co the lowest critical current density of $7.6 \cdot 10^{10}$ A/m^2 (Fig.1) was measured in W, that is about ten times smaller than in analogous Pt/Co/NiO structure.

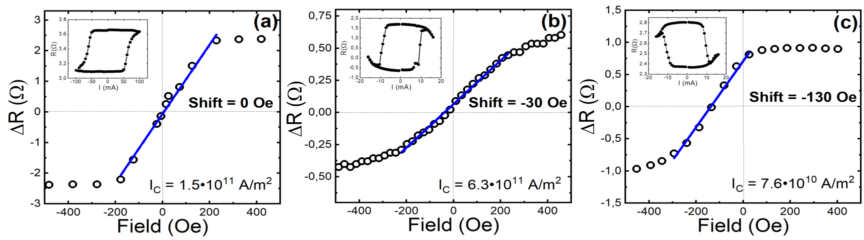

Fig. 1: The switching diagrams for in-plane exchange-biased systems: (a) Pt/Co/MgO, (b) Pt/Co/NiO, (c) W/Co/NiO respectively. Observed shifts are consistent with the exchange-bias field.

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Synthesis and characterization of biocompatible polymers stabilized iron oxide nanoparticles for biomedical applications

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This paper reports the synthesis by a modified polyol method of monodisperse iron oxide (Fe_3O_4) nanoparticles stabilized with polyvinylpyrrolidone (PVP)/ polyethyleneimine (PEI) biocompatible hydrophilic polymers for biomedical applications. The presence of magnetite (Fe_3O_4) phase was confirmed by using X-ray diffraction (XRD) and Raman Spectrometry on powder. FT-IR spectroscopy confirmed the presence of PVP/ PEI on the nanoparticles surface and the Zeta potential also supported the fact that the nanoparticles are coated with a layer of PVP/PEI and that they have good stability in aqueous medium. SEM analysis showed that the prepared Fe_3O_4 nanoparticles have a spherical structural morphology with a diameter of particles of approximately 15 nm. Hysteresis loops shows a ferromagnetic behavior at room temperature for all samples.

References:

[1] G. Unsoy, U. Gundoz, O. Oprea, D. Ficai, M. Sonmez, M. Radulescu, M. Alexie, Current Topics in Medicinal Chemistry, 15, pages 1-19, (2015).
[2] D. Herea, H. Chiriac, N. Lupu, M. Grigoras, G. Stoian, B. Stoica, T. Petreus, Appl. Surf. Sci., 352, pages 117-125, (2015).
[3] W. Wei, W. Zhaohui, Y. Taekyung, J. Changzhong, K. Woo-Sik, Sci. Technol. Adv. Mater. 16, pages 1-43, (2015).
[4] K. Chatterjee, S. Sarkar, K.J. Rao, S. Paria, Adv Colloid Interf Sci 209, pages 8-39, (2014).

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The effect of surface roughness on the performance of grain oriented electrical steel

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and Philip I. Anderson

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Barkhausen noise gives a measure of the freedom of domain wall motion. It is known that highly polished electrical steel has the effect of increasing permeability as well as lowering power losses. The aim of this study is to improve the surface finish to reduce pinning effects from this region.
Samples of Grain Oriented electrical steel has had the tension and electrical coatings removed before being polished on both sides to varying degrees of total surface roughness. The samples are then measured under applied magnetic fields up to flux densities of 1.9 T and the total Barkhausen noise and total losses per cycle are recorded.
The samples with a poorer surface finishes should produce larger Barkhausen noise. The Barkhausen noise measured from each sample shows that, initially, as surface roughness decreases the amount of Barkhausen noise also reduces; however, this trend did not continue. This suggests that although varying the surface finish affects the amount of Barkhausen noise produced, it may not be the main contributor of Barkhausen noise production at higher quality surface finishes.

Effect of crystal direction on loss separation of grain-oriented electrical steel

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Global electric power generation is gradually growing over the last years and it is expected to increase from the current approx. 25 kTWh (2017) to nearly 40 kTWh up to 2040 [1]. Therefore, the development of more efficient electrical equipment is vital for better use of the power grids. One of the most important materials used to manufacture those electrical equipment is the grain-oriented electrical steel (GOES), used on magnetic core of electrical transformers. During the electrical transformer operation, the magnetic flux is aligned with rolling direction, i.e., easy magnetic axis. However, some transformer parts, like the T-joint and corners, have high share of magnetic induction at transversal direction, due a rotational magnetization [2]. For that reason, the investigation of the energy loss mechanisms are important to develop better electrical transformers. In this work, the energy loss separation it is analyzed for 4 different grades of GOES, being two high-permeability (HI-B) and two regular grain oriented (RGO) electrical steel. For each grade, 16 sheets at rolling (RD) and transversal (TD) directions were cut to perform the Epstein Frame test at 5 mHz (quasi-static), 50 Hz and 60 Hz. Regarding the magnetic induction, the RD sheets were submitted to 1.0 T, 1.5 T and 1.7 T and the TD sheets to 0.5 T, 0.9 T and 1.3 T. Different HI-B and RGO grades presented distinct behaviors depending on the intensity and direction of the external magnetic field applied to the sheets, as the sample Figure 1 shows below. The remaining graphics and complete comparison between the steel grades will be presented on the full article. The investigation of the energy loss mechanisms presented the on this paper aims to support the transformer manufacturers to achieve a more efficient and better design transformer.

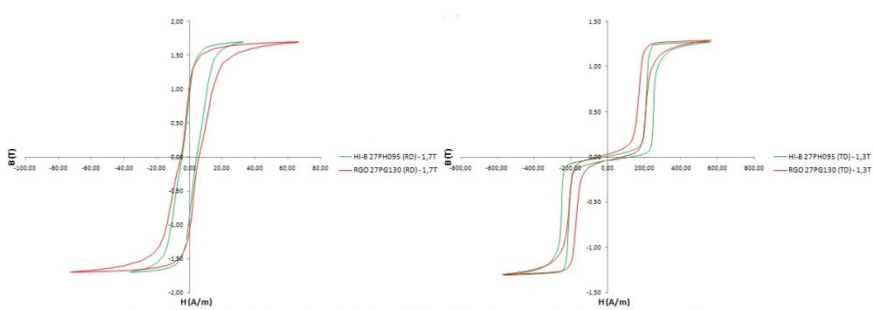

Figure 1 - Epstein frame sample hysteresis loops measured on both 0.27-mm-thick HI-B and RGO sheets under 1,7 T (RD) and 1,3 T (TD).

Investigation of the magnetic flux density dispersion on the gaps of the FeSiNbCuB magnetically soft nanocrystalline block core

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Energy conversion is currently one of the most important and extensively explored issues on a global basis. At present, great emphasis is placed on research on advanced soft magnetic materials intended in particular for applications in power electronics [1]. Chokes used in power electronics circuits, where there is a wide spectrum of voltage and current harmonics, are elements with large and difficult to limit power losses. Due to the fact, that the energy returned to the network flows through the chokes, the reduction of losses, their dimensions and mass, with demanded inductance and nominal parameters, are extremely important. Significant reduction of power losses in chokes is possible due to the use of modern, FINEMET type - soft magnetic nanocrystalline materials, which are characterized by a steep magnetization characteristic $B = f(H)$ and low power losses in the core. Present state-of-the-art shows, that there is no comprehensive knowledge about the value of the magnetic flux density dispersion B_d on the gaps of nanocrystalline core and the possibilities of its minimization. The magnetic flux density dispersion B_d is the source of local eddy currents, which are the cause of increase of power loss in the chokes' core.

A developed method for measuring the magnetic flux density dispersion B_d in the $Fe_{73.5}Si_{13.5}B_9Nb_3Cu_1$ nanocrystalline cores with four gaps is presented together with the study of the effect of gap width and the method of its filling on the power losses in the core

References:

[1] Leary A.M., Ohodnicki P.R., McHenry M.E., Soft Magnetic Materials in High-Frequency, High-Power Conversion Applications, JOM DOI: 10.1007/s11837-012-0350-0 (2012)

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The influence of heat treatment parameters on structure and magnetic properties of a Fe-Co-B nanocrystalline alloy

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In the recent years, the increased interest in nanocrystalline, magnetically soft alloys with enhanced magnetisation has been observed. High magnetisation may be obtained by proper selection of chemical composition, with predominant role of high content of ferromagnetic elements, as well as proper tailoring of phase composition. This, in turn, limits the space for grain refining elements, such as Cu, Zr, Nb etc., so conventional furnace annealing of metallic glass precursors does not lead to the formation of the desired nanocrystalline structure. The novel heat treatment was proposed, ultra-rapid annealing (URA), which allows to obtain nanostructured alloys by very fast heating-up of glassy ribbons and isothermal holding for a few seconds [1]. Such treatment provokes intense nucleation and prevents from excessive grain growth.
In this work, the comparison of structure and microstructure of $Fe_{67}Co_{20}B_{13}$ alloy treated conventionally and by URA was made. The amorphous ribbons were annealed in quartz ampoules for 1 hour and between hot inox steel blocks for various times. Volume fraction and average grain size were assessed from x-ray diffraction patterns, morphology of crystalline phase, bcc-Fe(Co), was observed with transmission electron microscope, and quasi-static magnetic hysteresis loops were recorded. The obtained results showed that ultra-rapid heating of metallic glass resulted in the reduction of grain size, and was the most important parameter of ultra-rapid annealing. Short annealing time reduced the grain growth. As the result, the application of URA allowed to obtain the magnetically soft amorphous-nanocrystalline alloy with coercive field of about 20 A/m and saturation induction of 1.76 T.

References:

[1] K.G. Pradeep, *et al.*, ISSN 1359-6454, 295-309 (2014).

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Magnetic Permeability Measurement Device Based on Hall Effect

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A new, fully portable device is presented, which can be used to measure magnetic permeability and residual stress. The device is based on the use of Hall sensors and a permanent magnet. Hall sensors are placed at the edges of a yoke, consisting of two parallel ferromagnetic bars and a permanent magnet. Through this arrangement, the ambient magnetic field is cancelled and the obtained magnetic flux density value is related to the magnetic permeability of the ferromagnetic coupon under test, where the sensor is placed. The optimal placement of the Hall sensors was calculated through software simulations. The constructed device includes the above-mentioned sensing element, a microcontroller, a temperature sensor, an Analog-to-Digital converter, an RF transmitter, a Bluetooth module and a battery. The collected data are wirelessly transmitted to a receiving device, consisted of a microcontroller, an RF receiver, a Liquid Crystal Display and a battery. As a result, the output information can be viewed either on the dedicated device or on any other Bluetooth-compatible device (e.g. smartphone or tablet). The sensor is suitable for on-field measurements, being wireless, energy efficient and robust, obtaining high-speed contactless measurements. By measuring the gradient of the magnetic flux density, it is possible to detect defective spots and act accordingly, by using RF annealing techniques, in order to repair them.

Acknowledgements
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Experimental and qualitative correlation between optical parameters of lasers with long or short pulses and magnetic properties of grain-oriented silicon iron sheets submitted to surface laser treatment

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Electrical machines mostly incorporate soft magnetic materials used as flux multipliers. Hence, any reduction in iron losses of the machine‘s core yields in saving energy. Among the techniques, 180° domain refinement by local laser treatment is a non-contact method that shows good results [1,2]. The present study reassessed the impact of laser treatment on the magnetic properties of grain oriented SiFe sheets by categorizing each treatment according to its effect on the sheet surface into three types: irradiation, scribing and surface ablation. Each effect will be described and defined. The results show a reduction in total power loss up to 56% for specified induction levels and frequencies. This loss reduction is accompanied by a significant improvement in the apparent magnetic permeability especially in the case of surface ablation. Different laser's pulse widths in the Infrared zone are used: a femtosecond laser mainly adapted to the surface ablation process and a nanosecond laser used for the irradiation and scribing process[3]. In this paper, the laser pattern is kept constant for the whole trials on the samples. Only optical laser parameters are investigated.
The aim of this work is to present the relationship between laser parameters and their effects on the material surface and the bulk, by according it to surface topography (groove‘s depth, affected zone), induced thermal stress, and magnetic properties of the sheet, including the iron loss, the apparent permeability and the dynamic magnetization property[4].

References:

[1] S. Patri *et al.*, 0022-2461, 1693-1702 (1996)
[2] P. Beckley and D. Snell, 1059-9495, 209-213 (1994).
[3] I. Petryshynets *et al.*, 2158-3226, 047604 (2018).
[4] O. Maloberti *et al.*, 0304-8853, e507-e509 (2006).

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Measurement Based Methodology for Quantification of Welding Effects on Iron Losses in Electrical Machines

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Electric motor designers often struggle to accurately model the different effects of welding. Welding has a severe impact on the magnetic properties of stacked electrical steel laminations. Several effects occur due to the presence of the welding joint. The thermal energy added to the material during the welding process locally deteriorates the magnetic permeability of the material due to residual thermal strain, increasing the hysteresis losses. The eddy current losses are increased by the local eddy currents induced in the welding seam and by the interlaminar eddy currents induced in the short circuits through the welding seam and edge burr contacts. These interlaminar eddy currents are difficult to model since they are related to parasitic electrical contacts between the burr edges of laminations. All of these effects potentially result in additional core losses in stator and rotor and decrease the efficiency of the machine. These effects have previously been measured in various ways in [1-3]. However, in this work a methodology is presented that allows for the individual measurement and modelling of the different welding effects. Each effect can be isolated and modelled separately using a Magnetic Equivalent Circuit Model. This is done using standard Epstein frame measurements and welded stator lamination measurements, which offer valuable information about specific welding techniques. This information can be used for incorporating welding effects into the design of electrical machines and for making more thorough decisions on the application of specific manufacturing techniques.

References:

[1] K. Bourchas, *et al.*, IEEE Trans. On Industry Applications 53.5, 4269-4278 (2017).
[2] A. Krings, *et al.*, IEEE Trans. on Industry Applications 50.1, 296-306 (2014).
[3] Y. Kurosaki, *et al.*, JMMM 320, 2474-2480 (2008).

Advanced approach for Static Part of LS Iron Loss Model

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Over the past two decades, the Loss-surface hysteresis model has been developed to provide an accurate, robust and uncomplicated estimate of iron losses in electromagnetic applications [1]. Its concept is to describe separately the static and dynamic behaviors of materials. Initially, we invented a technique for predicting the dynamic loss contribution and used an approach similar to that of Mayergoyz [2] for the static one. As time goes by, we need a simpler rate-independent model that requires fewer measurements for the parameter identification. As a result, in this research, we propose an improved static model considering simplicity as the most critical criterion while always ensuring the accuracy. One modeling approach of static hysteresis is to build reversal curves of materials which are generally not easy to handle. Instead, we represent mathematically the difference between these curves and the rising or decreasing curve of the major hysteresis loop, which varies monotonically following the induction level. The input data required are the experimental 1st magnetization curve, the major hysteresis loop and a few centered-cycles at lower levels. The number of parameters to identify is flexible but explicit and dependent on the accuracy demand of user. Besides, management of reversal points and history erasure allows the model to maintain the physical sense. In this paper, we will discuss in detail its principle, identification and validation procedure.

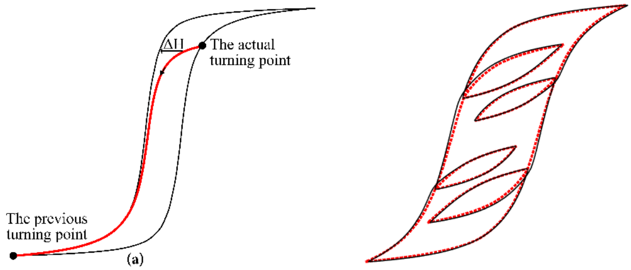

Figure 1 (a) Reversal curve and main hysteresis loop, (b) modeling result for a waveform with harmonic of induction

References:

[1] T. Chevalier et al.« A new dynamic hysteresis model for electrical steel sheet », *Phys. B Condens. Matter*, vol. 275, no 1, p. 197-201, janv. 2000.
[2] I. D. Mayergoyz, *Mathematical Models of Hysteresis*. Springer Science & Business Media, 2012.

Eddy Current Speed Sensor with Magnetic Shielding

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Contactless magnetic speed sensors are resistant against dust and oil, which brings them advantage over optical sensors. The most popular sensor type is based on reluctance variation. Eddy current speed sensors work for all conducting moving bodies including those with smooth surface. They have simple construction and preset favorable solution especially at high speeds. The authors analyzed and tested eddy current speed sensor with axisymmetric configuration [1], which has one excitation coil and two pick up coils. A perpendicular flat shape eddy current speed sensor was presented in [2]. The presented models in [1] and [2] are both coreless and without shield and magnetic yoke. This makes them sensitive to the presence of conducting and/or ferromagnetic bodies in their vicinity. In this paper, an eddy current speed sensor with magnetic yoke and shielding using 0.5 mm silicon steel lamination is presented (Fig. 1). Another advantage of using ferromagnetic core is increased sensitivity. The speed sensor is designed and analyzed using finite element method and its parameters are verified by measurement. Aluminum and solid iron moving bodies are both used in the modeling and measurement and effects of magnetic materials of the shielding are investigated in this paper. Different excitation frequencies and speeds are considered in the measurements and analysis.

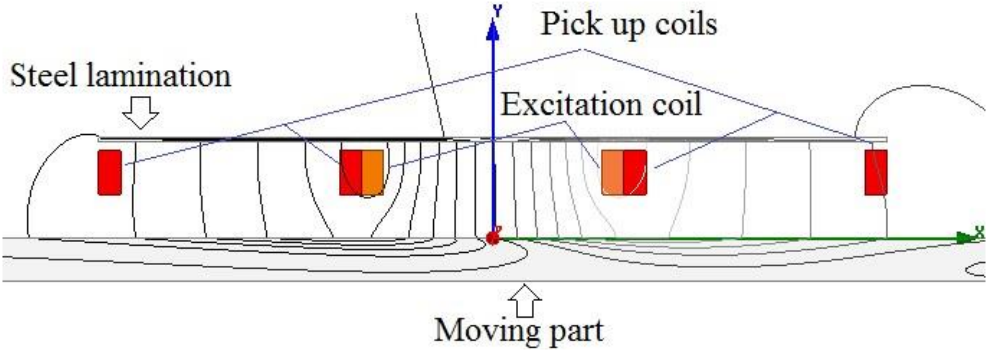

Fig. 1 Eddy current speed sensor with steel lamination shielding. The excitation frequency was 100 Hz and the measured speed was 10 m/s.

References:

[1]M. Mirzaei, P. Ripka, A. Chirtsov, J. Vyhnanek, IEEE Mag., (2018).

[2] N. Takehira, A. Tanaka, IEE Proceedings, Prt. A, 89-94 (1988).

Ultrafast magnetization precession and Gilbert damping dependence on Pt spacer layer thickness in Co(1nm)Pt(0-4nm)Co(1nm)

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Ultrafast magnetization dynamics was investigated in Co(1nm)Pt(0-4nm)Co(1nm) trilayer as a function of Pt-spacer layer thickness (t_{Pt}) using dual-color time-resolved magneto-optical Kerr effect (TR-MOKE). The magnetization precession parameters: frequency, amplitude and relaxation time were determined for different external magnetic field amplitudes (H) as a function of t_{Pt}. The precession frequency changes in the range 18-24 GHz at H=6 kOe and exhibits nonlinear dependence versus t_{Pt} with a maximum at about t_{Pt}=1.4 nm. The precession amplitude remains constant for H>1 kOe and increases about twice with the t_{Pt} increase. It is found that the effective Gilbert damping parameter determined with the use of TR-MOKE technique varies in the range 0.08-0.5, depending on the Pt spacer layer thickness and the estimated value of interlayer exchange coupling strength.

References:

[1] A. Bonda, L. Uba, K. Załęski, and S. Uba, *Phys. Rev. B* 99, 184424 2019.
[2] S. Łazarski, W. Skowroński, J. Kanak, Ł. Karwacki, S. Ziętek, K. Grochot, T. Stobiecki, F. Stobiecki, arXiv:1903.03368v1

New robust machine learning ABC method for Hysteresis Parameters determination

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Nowadays, the electrical engines and electromagnetic machines are designed according the customer requests and safety norms. In several applications, it is necessary to combine experimental investigations to robust numerical modeling in order to target the optimized operating conditions.For many electromagnetic advanced technologies, the magnetic hysteresis behavior of the ferromagnetic components engenders difficulties in hysteresis analytical models selection as well as in their identification process. Nonphysical hysteresis parameters make the identification process complex and time consuming.For well-known steel grades, a hysteresis parameter database is available in literature, especially for Jiles-Atherton model. The development of new steel grades such as: press hardened parts, biphasic steel strip, etc.lead to a long identification process. These last two decades, several identification methods were used like deterministic, which are limited especially when the initial parameter set is far from the solution. The stochastic methods like genetic algorithms GA [1], neural networks NN [2] and modern methods based on swarm intelligence as particle swarm optimization technic PSO [3] offer more accurate solution but request a lot of time and huge amount of input.

For the first time, in framework of this study, the ABC method will be applied on nonlinear, hysteresismodels. The purpose of this work is to apply the artificial bee colony method ABC inspired by the collective behavior of bees [4] to identify input parameters of two different hysteresis models. The ABC methods will be assessed by comparison of measured andmodeled hysteresis loops.

References:

[1] J. V. Leite, *et al*,.IEEE Trans on Magnetics,. 1397-1400, (2003)
[2] P. R. Wilson,*et al*,.IEEE Trans on Magnetics, 3774-3780(2001)
[3] L. S Coelho, *et al*,.IEEE Trans on Magnetics, pp. 283-286 (2012)
[4] D. Karaboga, *et al*,.Foundation of Fuzzy Logic and Soft Computing, 789-798(2007).

Dipolar interactions among magnetic dipoles of iron oxide nanoparticles dispersed in mili-size hydrogel objects

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This contribution is devoted to quantify the modification of the magnetic response of iron oxide nanoparticles (NPs) dispersed in a hydrogel, due to dipole-dipole interactions, when the geometry and density of their spatial distribution is modified in a controlled manner. This problem is of crucial importance for the application of magnetic hydrogels. This happens because the hydrogel expands and small pieces of it may aggregate, thus modifying sensibly the NPs distribution.
Millimetric-size, spheroid-like hydrogel objects were synthesized through a one pot route. The experimental strategy was based on two experiments. In the first one hydrogel swelling by hydration was used to modify the intensity of dipole-dipole interactions, by varying inter-dipole mean distance [1]. In the second one, chain and disk-like arrays of spheroids were studied and compared with an isolated spheroid. The magnetic response of these NPs ensembles was recorded by VSM magnetometry, ac susceptibility and Specific Absorption Rate (SAR) of energy under radiofrequency irradiation. The MFISP model, which evaluates the effect of dipolar interactions by introducing and defining an effective demagnetizing tensor [1,2] was used to analyse the results. Alternatively, a model based on a semi-discrete approach was developed and applied. The results demonstrate that density and anisotropy of the NPs distribution affects the magnetic susceptibility of the NPs ensembles consistently with the theoretical expectations of the models. These observations are of importance in applications of magnetic NPs, as for example *in vitro* and *in vivo* magnetic hyperthermia, where geometry and density of NPs distribution is highly determined either by culture or tissue specific features.

References:

[1] F. H. Sánchez *et al.*, Phys. Rev. B 95, 134421 (2017).
[2] P. Mendoza Zélis *et al.*, Phys. Rev. B 96, 174427 (2017).

This study was partially supported by CONICET Grant No. PIP11220110100720CO and UNLP Grant No. 11/X807, both from Argentina, as well as the TWAS-CONICET Associateship Scheme Grant, Ref. 3240302357

Stress monitoring and annihilation in ferrous magnetic rods and tubes

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In this paper we present a new method for the monitoring and annihilation of residual stresses in ferrous rods and tubes. Stress monitoring is achieved by monitoring the uniformity of elastomagnetic waves generated, propagating and received inside these ferrous rods and tubes. The principle of measurement is based on the magnetostrictive delay line technology [1]. The principle of stress annihilation is based on the localized RF heating, resulting on stress annihilation. Experimental results on low carbon steels in the form of rods and tubes indicated a significant decrease of stresses, thus permitting a longer life time of these steels. Work is under way for the modeling of the MDL response, which will permit the use of the method in stress monitoring along the length of magnetostrictive steels.

References:
[1] E. Hristoforou, "Magnetostrictive Delay Lines: Engineering Theory and Sensing Applications", Review Article, Meas. Sci. & Technol., 14, p. R15-R47, 2003.

E. Hristoforou wishes to acknowledge financial support of the Ministry of Science and Higher Education of the Russian Federation in the framework of Increase Competitiveness Program of NUST «MISIS», contract № K2-2019-012.

Giant Magneto Impedance: Coating and Annealing

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Effect of coating with different chemical complexes on giant magneto impedance effect (GMI) was experimentally investigated in Fe and Co-based amorphous wires. The successive ionic layer adsorption and reaction (SILAR) technique was used for coating of the samples at room temperature. The SILAR method mainly based on adsorption and reaction on the ions from the solution and rinsing [1]. Co and Fe-based amorphous wires samples were coated with CoO, asphalting, and ZnO chemical complexes. The coating thickness were determined to be about 1 μm thick. Maximum GMI ratio for Co and Fe-based samples were measured at 4 MHz and 5 MHz frequency, respectively.

Influence of annealing at different temperatures on GMI was also experimentally investigated in CoO and ZnO coated Fe and Co-based amorphous wires. The coated samples were annealed at 300 °C, 400 °C, 500 °C and 600 °C temperatures for 30 minutes. It is observed that the GMI% ratio for Co- and Fe-based ZnO coated samples was highest at 500 ºC, while it was maximum for CoO coated Co-based samples at 400 ºC and for CoO coated Fe-based samples at 500 ºC.

The highest GMI ratio, which was 216, among the tested samples was detected on the sample of Fe-based, ZnO coated and annealed at 500 ºC at 5 MHz, while the smallest GMI ratio, which was 88, was found to be on Co-based as-cast sample at 4 MHz. The measurements show that the GMI ratio is a combined effect of coating, annealing, frequency, magnetostriction, anisotropy of material and magnetic field.

Reference:

[1] O. Caylak, N. Derebasi, T. Meydan, "Giant Magneto-Impedance Effect in As-cast and Post-production Treated $Fe_{77.5}Si_{7.5}B_{15}$ Amorphous Wires," *Sensor. Lett.*, vol. 5, pp. 123-125, 2007.

Microwave assisted synthesis of composite Fe_3O_4/zeolite–X nanoparticles for the magnetic removal of hexavalent chromium from aqueous solutions

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Toxic heavy metals are considered harmful derivatives of industrial activities; they are not biodegradable and their accumulation in living organisms can become lethal. Among other heavy metals, chromium is considered hazardous, especially in the hexavalent (Cr^{6+}) form. Numerous established studies show that exposure to Cr^{6+} via drinking water leads to elevated chromium levels in tissues, which may result in various forms of cancer. The purpose of this research is to investigate the removal rate of Cr^{6+} ions from aqueous solutions by using synthetic zeolite-X as adsorbing material.

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Identification and analysis of static and dynamic magnetization properties sensitive to surface laser treatments within the electromagnetic field diffusion inside GO SiFe electrical steels

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Surface laser treatment of soft magnetic materials, such as GO SiFe electrical steels, is mainly used to reduce iron losses. Meanwhile, it may also limit mechanical vibrations and noise in electrical machines by modifying the static and the dynamic magnetic properties and eventually the induced electromagnetic and magnetostrictive forces. Laser treatment effect on mesoscopic electromagnetic properties of soft magnetic materials is presented. An experimental procedure using the Single Sheet Tester is performed on a magnetized plate with specific exciting induction level and frequency. Transient average magnetic flux density through the sample cross-section and its corresponding applied magnetic field are measured. Data are identified in the time-domain with numerical results obtained by solving the diffusion equation using a 1-D discretization approach. The identification strategy requires a material law that includes both non-linear static and dynamic properties and describes the magnetic behavior due to domains and walls. Next, parametric and physical studies are performed on materials submitted to different laser treatments in order to determine and interpret their effect on the identified magnetic properties and the time response in the sheet's depth. The results show that the static and the dynamic properties can be simultaneously improved. These analysis help us understand the impact of laser treatments on the static and the dynamic behaviour in order to improve the material magneto-mechanical performances within magnetic circuits inside electrical machines.

References:

[1] O. Maloberti, *et al.*, J Magn Magn Mater 304, e507-e509 (2006).
[2] O. Maloberti, *et al.*, IEEE Trans. Magn., Vol 44, No. 6, 1-4 (2008).
[3] M. A. Raulet, *et al.*, IEEE Trans. Magn., Vol. 40, No. 1, 872-875 (2004).

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Microwave assisted co-precipitation for the preparation of Fe_3O_4/β-Cyclodextrin core/shell type nanoparticles

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In this work Fe_3O_4/β-Cyclodextrin core shell type nanoparticles are being prepared via Microwave assisted co-precipitation and the effectiveness of the method is being compared to the traditional solvothermal ones. The comparison is carried out according to the resulting properties of the synthesized nanoparticles. The properties of the particles were characterized via FTIR, XRD SEM and VSM. The β-Cyclodextin (β-CD) grafted onto nanoparticle surface contributes to an enhancement of the adsorption capacity of Fe_3O_4 nanoparticles because of the strong complexation abilities of the β-CD polymer with metal ions and of the hydrophobic cavity with organic contaminants through host-guest interactions.

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Structure and performance tests of a magnetocaloric cooling device with linear motion of the magnetic field source

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Magnetic refrigeration is a cooling technology utilizing the magnetocaloric effect, which is a fundamental property of ferromagnetic materials and is accompanied by adiabatic changes of their temperature and isothermal changes of entropy under the influence of an external magnetic field. A magnetic cooling device model incorporating gadolinium regenerator and utilizing linear movement of the magnetic field source from neodymium magnets has been built by us and described in the paper [1]. The aim of this work was to optimize construction of main subassemblies of our earlier magnetic cooling device model, and to evaluate functional parameters of the optimized device. The magnetocaloric effect based cooling device model utilizing linear motion of the magnetic field source and cyclic flow of a coolant through the regenerator has been developed and built. The device includes two identical regenerators consisting of gadolinium plates, 120 mm long and 0.8 mm thick, and a gap between the adjacent plates is 0.4 mm wide. Magnetic field source has been made as a closed system so as to achieve better parameters of this subassembly. For the heat transfer, a liquid with specific heat of 4000 J/kg K has been applied. A driving system for the magnetic field source has been designed and made. This system ensures position setting precision of 0.01 mm during the start and stoppage of the field source, at the acceleration/braking at the level of 6 m/s^2, which enables operation of the magnetic field drive at the frequency from 0.2 to 1.5 Hz. Moreover, a driving system for circulating fluid pumping with the required operational synchronization, has been designed and made.
The cooling device model developed under this work can operate within the frequency range from 0.2 to 1 Hz, and reach a temperature gradient at the level of 10.3K.

References:

[1] R. Kolano, A. Kolano-Burian, M. Hreczka, M. Polak, J. Szynowski, W. Tomaka, Acta Physica Polonica A, vol. 129 (2016)

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Effect of Co substitution on crystallization and magnetic behavior of $FeCoCu_{0.55}B_{14}$ metallic glass

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Effects of Co for Fe substitution on magnetic properties, thermal stability and crystal structure of $Fe_{75.45-x}Co_xCu_{0.55}B_{14}$ (x = 0, 2.5, 5, 7.5, 10) melt spun amorphous alloys are investigated. The Cu content are firstly optimized by use the thermodynamical approach (minimum value of the mixing enthalpy). The formation of crystalline phases are described using differential scanning calorimetry, X-ray diffractometry and transmission electron microscopy. The onsets of crystallization process for bcc-Fe type phase (primary crystallization) and bct-Fe_3B type phase (secondary crystallization) are defined by thermal analysis using heating rate of 10°C/min. Then basing on measured values the classical heat treatment process (with heating rate 10°C/min) in vacuum for wound toroidal cores is optimized to obtain best soft magnetic properties (B(H) dependencies and magnetic core loss P_s) at frequency 50 Hz. For heat treated samples the X-ray diffraction method is used to determine the unit cell parameters of bcc-Fe type nanocrystallites as well as their average crystallite size. Therefore, for optimal heat treated samples and their as spun metallic glasses the complex magnetic permeability in the frequencies 10^6 -10^9 Hz and temperature range from -50°C to 100°C is measured. The final emphasis is placed on the correlation between the crystal structure parameters and the magnetic properties (coercivity, saturation magnetization, magnetic core losses and complex magnetic permeability). Analysis of transmission electron microscope images and electron diffraction confirmed that high magnetic parameters are related to the coexistence of the amorphous and nanocrystalline phases

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Computation of current waveform in ferrite power inductors for application in buck-type converters

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We propose a calculation model for the analysis of the current waveform in ferrite power inductors subjected to large-signal square-wave voltage, a typical regime of present-day Switch Mode Power Supplies (SMPSs) [1]. This problem is characterized by the non-linear response of the inductor across a wide range of current values, up to the limit of inductor saturation (see Fig. 1.a). Consequently, non-linear differential equations must be adopted in the description of the circuit. In this paper, after application of suitable analytical expressions for the inductance profile, we solve the equations of the circuit through an effective iterative method, by which the current is computed through successive approximations. These results are eventually verified by comparison with experiments performed on a bucktype converter. Figure 1.b reports an example of such comparison, regarding currents obtained under real SMPS voltage waveform at 500 kHz.

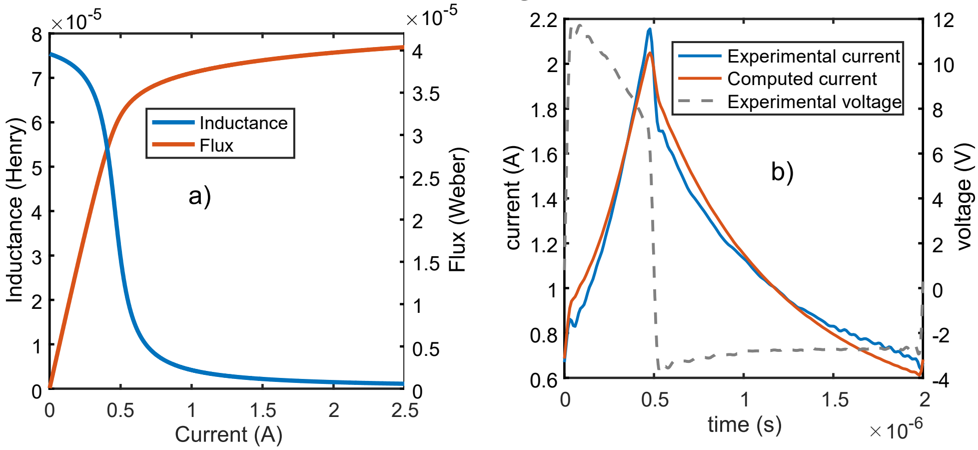

Figure 1. a) Differential inductance and flux vs. current in a ferrite core inductor (N30); b) computed and experimental currents obtained under a SMPS voltage waveform (dashed line) at 500 kHz.

References:

[1] A. Oliveri, *et al.*, *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 66, no. 6, pp. 2394-2402, June 2019.

Influence of milling time on the magnetic properties of $Fe_{70}Zr_{30}$ amorphous alloy

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Microstructure and magnetic properties of a mixture of pure 70 at. % Fe and 30 at. % Zr produced by mechanical milling has been characterized as a function of the milling time. Mechanical alloying leads to the formation of an almost fully amorphous alloy after 50 h. A continuous increase of the amorphous fraction with the milling time is observed. The enhancement in the soft magnetic behavior of the samples with the increase of milling time is ascribed to the averaging out of the magnetocrystalline anisotropy as crystal size decreases and amorphous fraction increases. However, the magnetoelastic large order anisotropy (in the range of the powder particle size) prevents a decrease of coercivity, H_C, below 1 kA/m. As expected, H_C increases with temperature as the Curie temperature is approached. The incorporation of Fe atoms from the remnant α-Fe nanocrystals to the amorphous matrix is the responsible for the increase of the Curie temperature. Compositional heterogeneity leads to a distribution of the physical properties rather than a sharp behavior characteristic of the theoretically pure system. Mössbauer spectroscopy as a function of temperature is consistent with magnetic results and helps to determine the ferromagnetic or superparamagnetic character of the remnant α-Fe nanocrystals.

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Magnetocaloric effect in heterogeneous half-Heusler MnCo(Fe)Ge obtained by mechanical alloying

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Half-Heusler alloys have been proposed as interesting systems for magnetocaloric studies [1]. The absence of rare-earth metals and the tunability of the transition both in temperature and order character [2] are very attractive in these compositions. However, development of pure intermetallic phases is not trivial and generally requires long annealing times at high temperatures. In this study, we succeed strongly reducing both temperature and annealing time to produce a single phase $MnCo_{0.8}Fe_{0.2}Ge$ half-Heusler alloy from a mechanically alloyed system. Magnetocaloric effect (maximum magnetic entropy change at 1.5 T field change: $|\Delta S_m|$~1.5 $Jkg^{-1}K^{-1}$, at ~275 K) and the second order character of the transition have been studied. The influence of the annealing conditions on the Curie distribution of the system has been studied using a recent method to obtain the average Curie temperature and the broadening of the distribution from the analysis of the approach to saturation curves [3].

References:

[1] V. Franco, *et al.*, Prog. Mater. Sci. 93, 112 (2018).
[2] S. Lin, *et al.*, IEEE Trans. Magn. 42, 3776 (2006).
[3] A.F. Manchón-Gordón, *et al.*, J. Non-Cryst. Solids 520, 119460 (2019).

This study was partially supported by AEI/FEDER-UE (Project MAT 2016-77265-R) and the PAI of the Regional Government of Andalucía. A.F. Manchón-Gordón acknowledges a VPPI-US fellowship.

Microstructure, magnetic properties and local Fe environments evolution in melt spun NiFeGa ribbons

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Ribbons of the shape memory $Ni_{55}Fe_{19}Ga_{26}$ alloy have been prepared by melt spinning technique. In order to study the effect of heat treatment on the microstructure and magnetic properties, the powder samples made from ribbons were continously heated up to different temperatures from 473 K to 1273 K at 10 K/min and then annealed at this temperature in argon atmosphere for 10 min. The samples were then cooled down to room temperature at 10 K/min. It was found that the Curie temperature changes with the anneling temperature. The differences in the Curie temperature are due to the precipitations of the gamma phase that can be inducted by annealing at temperatures higher than 773 K. Mössbauer spectroscopy was used to determine the different contribution of the phases coexisting in the samples, where the ferromagnetic ordering depends strongly on the Fe-Fe interactions.

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Influence of Co substitution for Fe on magnetic properties and crystal structure of soft magnetic $Fe_{81.3}Mo_{0.2}Cu_{0.5}Si_4B_{14}$ alloy

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The magnetic properties correlated with crystal structure of soft magnetic ribbons of the nominal composition $Fe_{81.3-x}Co_xMo_{0.2}Cu_{0.5}Si_4B_{14}$ x=0, 5, 10, 15, 20 (at.%) synthesized by a melt spinning technique is reported. The crystallization process was monitored by differential scanning calorimetry (DSC) that allows identification of the primary crystallization temperature and then optimize the proper heat treatment parameters to maximize the magnetic properties. The resulting crystal structure of the properly annealed cores is investigated by means of X-ray diffraction (XRD) and transmission electron microscopy (TEM) and is shown to consist of α-Fe nanograins with the sizes of 100-275 Å obtained both from XRD data and TEM images. Additionally, the magnetic hysteresis loops and magnetic properties such as a core power losses of studied samples are determined. The microstructure, Co content, nanograins size of the annealed samples are then discussed and corroborated with magnetic measurements

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Manipulation of the Domain Wall Shape in Cylindrical Microwires by Thermal Treatment

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A key prerequisite for well-controlled manipulation of a domain wall position is a detailed knowledge of its internal spin structure. The domain wall motion in amorphous glass-coated microwires is still in the focus of extensive research, due to peculiar features like extremely high domain wall velocity [1] or domain wall inclination [2]. While several previous works have been devoted to the indirect observations of a domain wall in microwires, direct measurements were still lacking due to particular features of non-planar cylindrical topography.

Here, we study a surface domain wall pinning and domain wall distortions of large magnetic domains in thin cylindrical wires. Our measurements are carried out by a novel experimental technique [4] based on the magneto – optical Kerr effect (MOKE). Stabilization of domain wall is achieved by simple magnetic potential well created by two opposite magnetic fields. The periodic back-and-forth motion of a head-to-head domain wall is detected by LASER beam and MOKE time-resolved measurements are used to reconstruct a surface shape of a domain wall.

We show that current annealing drastically changes the domain wall inclination in thin FeSiB microwire. The observed effect can be understood in terms of internal stress re-distribution that stems from Joule heating during thermal treatment. Time-resolved observations of the domain wall reveal strong intra-domain wall effects such as distortion due to circumferential dependence of local wall velocities. The role of cylindrical geometry on a domain wall inclination is ascertained.

References:

[1] R. Varga, *et al*., Phys. Rev. B 76, 132406 (2007).
[2] A. Chizhik, *et al*., Appl. Phys. Lett. 109, 052405 (2016).
[3] O. Váhovský, *et al*., J. Magn. Magn. Mater. 483, 266–271 (2019).

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Impact of the magnitude of the magnetization on the induced anisotropy in transverse field annealed nanocristalline cores

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We study the correlation between the induced anisotropy obtained on nanocrystalline $Fe_{73.0}Cu_{1.1}Nb_{3.1}Si_{15.7}B_{7.1}$ toroidal cores crystallized under transverse field at 570°C, and the polarization J_c on the SiFe nanograins. To do this, an original disposition is used, by mixing treated cores with $Si_{3\%}Fe$ "boosting" cores featuring same geometry, using the interfacial magnetic charges to increase the field in the treated cores. The field created by the coil being μ_0 H_a = 33 mT, playing on the dilution ratio between treated and boosting cores, resulting field ranging between μ_0 H = 33 mT (without dilution) and μ_0 H = 133 mT were obtained inside treated cores at the beginning of crystallization. The K_u values obtained at the scale of the cores at the end of crystallization range from 11 J/m^3 to 20 J/m^3.
To simulate the evolution of J_c during the crystallization process, the configuration of treated and "boosting" cores in the sample holder was implemented in "Flux2D" FEM simulation environment with the dedicated polarization laws. Dealing with treated cores, the law $J_{core}(H)$ at the scale of the core reflects the law $J_c(H)$ featured by SiFe nanograins during the crystallization process. $J_c(H)$ was determined as a function of the crystallized fraction f_c following [1]-[2].
The correlation between the simulated J_c and the experimental final values of K_u /f_c (i.e. the anisotropy in nanograins) was then studied. This was done considering the polarization J_{cf} obtained at the end of the crystallization process or the polarization $\langle J_c \rangle$ averaged on the entire crystallization process, wondering about a possible memory effect.

References:

[1] O. Geoffroy, H. Chazal, Y. Yao, T. Waeckerle, J. Roudet, IEEE Trans. Magn. 50 (2014) 1–4.
[2] N. Boust, O. Geoffroy, H. Chazal, S. Flury, T. Waeckerlé, A. Demier, B. Gony, Journ Magn Magn. Mat. 478 (2019) 122-131

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Structure, electronic, and magnetic properties of Gd_2MnFeO_6 perovskite: First principle calculations and Experimental study

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Herein we report the structure, electronic structure, and surface morphology, optical and magnetic properties of Gd_2MnFeO_6 perovskite nanoparticles synthesized by a facile sol-gel technique. The Rietveld refinement analysis of X-ray diffraction pattern confirms the formation of pure orthorhombic perovskite Gd2MnFeO6 nanoparticles with Pbnm space group. The scanning electron microscopy reveals the ellipsoidal shaped particles in the samples. Spin-polarized band structure and partial density of states reveal the ferromagnetic behavior of the sample. Magnetization curves such as ZFC, FC, and hysteresis loops are further confirmed that the sample shows ferromagnetic at room temperature. The mixture of ferromagnetic behavior arose from Gd^{3+}, Mn^{3+} and Mn^{4+} ions with different exchange interactions.

References:

[1] S. Ramesh, P. Venugopal, E. Mosquera, Journal of Magnetism and Magnetic Materials 443, 45-50 (2017)
[2] S. Vasala, M. Karppinen, Progress in Solid State Chemistry, 43 (2015) 1-36.
[3] S. Ramesh, S. Marutheeswaran, J.V. Ramaclus, D.C. Paul, Superlattices and Microstructures 76 (2014) 213-220
[4] S. Ramesh, J.V. Ramaclus, B.B. Das, E. Mosquera, Materials Research Bulletin 105 (2018) 121-125.

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Substantial improvement in magnetic performance of nanocrystalline Co-Fe-B-Si-Nb ribbons through magnetic annealing

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Tape wound nanocrystalline magnetic cores offer better stability of permeability over a broad temperature range in comparision to soft ferrite materials. This work presents the performance of a high-flux density soft-magnetic nanocrystalline material whose constituent elements are less expensive than commercial nanocrystalline alloys and performance matches those of industry-standard tape wound magnetics. Furthermore, the core loss of material at 1 MHz is 30% lower as compared to commercial NiFe powder cores, with the advantage of two-fold permeability. The exceptionally lower permeability as compared to standard nanocrystalline materials allows a high amount of Ampere-Turns without saturating the magnetic core [1,2].
The Co-based nanocrystalline materials are developed using amorphous metal ribbons as precursors by employing a controlled annealing process in the presence of a high-strength magnetic field in the transverse direction. The magnetic annealing process benefits in two ways: 1) it controls the growth of the nanocrystalline grains, and 2) induces the magnetic anisotropy to suppress the domain wall motion during magnetisation reversal process [3].

References:

[1] Kulkarni, S., *et al.*, IEEE Transactions on Magnetics, 2014. **50**(4).
[2] Masood, A., *et al.*, Journal of Applied Physics, 2013. **113**(1).
[3] Herzer, G., *et al.*, Acta Materialia, 2013. **61**(3): p. 718-734.

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Physical properties of the $Ce_{1-x}Pr_xCoGe_3$ system with suppression of magnetism

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Heavy fermion (HF) state is most often observed in intermetallic compounds containing an addition of lanthanides or actinides with *f*-electrons and is characterized by strong increase of the effective electron mass. The hybridization of the *f* electrons with conduction ones can lead to fascinating phenomena like: fluctuating valence, Quantum Critical Point (QCP) or superconductivity. In HF systems the magnetism comes from the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction. On the other hand, there is a screening of magnetic moments due to the Kondo interaction. There is a competition between these opposing interactions, RKKY and Kondo, which can lead to the QCP. In the present study, we show results on physical properties of the $Ce_{1-x}Pr_xCoGe_3$ system. The origin of this system comes from the $CeCoGe_3$ compound, which shows a complicated magnetic structure with three antiferromagnetic phase transitions at T_{N1} = 21 K, T_{N2} = 12 K, and T_{N3} = 8 K [1,2]. On the other hand, $PrCoGe_3$ is a paramagnet with non-heavy fermion metallic behavior [3, 4]. Our X-ray diffraction analysis have shown that all the studied compounds are isostructural, single phase, and crystallize in the non-centrosymmetric tetragonal $BaNiSn_3$–type structure. We have investigated these alloys using various experimental methods: magnetic susceptibility, specific heat, electrical resistivity and thermoelectric power. Substitution of Ce with Pr suppresses the magnetic ordering and drives the RKKY and Kondo interactions to their minimum, instead of their compensation near the QCP. This indicates on an interesting state of Pr ions in the crystal structure. The obtained results have been examined with respect to the common models.

References:

[1] V. K. Pecharsky, *et al.*, Phys. Rev. B 47 (1993) 11839.
[2] A. Thamizhavel, *et al.*, J. Phys. Soc. Jpn. 74 (2005) 1858.
[3] T. Kawai, *et al.*, J. Phys. Soc. Jpn. 77 (2008) 064717.
[4] M. Méasson, *et al.*, J. Phys. Soc. Jpn. 78 (2009) 124713.

Doping-Induced Softening of M-Type Hexaferrites

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Hexagonal ferrites, known since 1950s as permanent magnets materials, have found recently new applications as multiferroics due to doping-induced functionalization [1, 2]. It should be however, notices that substitution of A or ferric ion modifies the magnetic properties even in M-type hexaferrites $AFe_{12}O_{19}$ of the simples crystal structure, depending on the valence and ionic radius. We studied the structure and magnentic properties of $SrFe_{12}O_{19}$ (SrM) nanopowder obtained by sol-gel and hydrothermal method doped with Nd^{3+} ions as well as Nd-stabilized SrM substituted with Al^{3+} and Sc^{3+} ions. X-ray diffraction studies (X'Pert PANalytical, CuK_{α}) reveald a single hexagonal phase ($P6_3/mmc$ space group) in all samples and the crystallite sizes were found to decrease with increasing doping level (FEI Nova NanoSEM). Magnetic hysteresis loops were measured in the temperature range 10-300 K (PPMS, Quantum Design). One can observe that the doping effect on coercivity and lattice parameters depends strongly on the ionic radius of substituting ions, whreas the magnetization at low doping level is determined by the lattice position of substituted ferric ions. A considerable magnetic softening is observed in $Sr_{0.95}Nd_{0.05}Fe_{12-x}Sc_xO_{19}$ as shown in Fig. 1 and 2. For the same composition we reported a conical magnetic ordering at low temperatures [3].

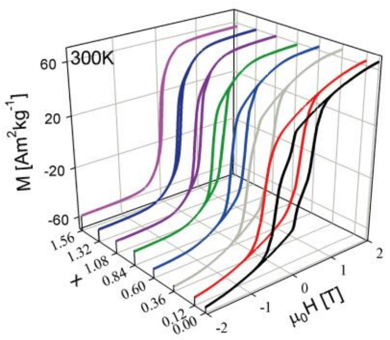

Fig. 1.

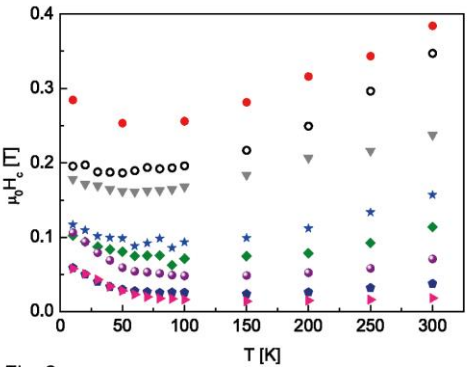

Fig. 2.

References:

[1] T. Kimura, Annu. Rev. Condens. Matter Phys. 3, 93-110 (2012).
[2] Y. Tokura, S. Seki, N. Nagaosa, Rep. Prog. Phys. 77, 07650 (2014).
[3] A. Hilczer *et al.*, Ceram. Int. 45, 1189-1195 (2019).

Investigation of cytotoxicity of novel ferrite materials for biomedical application

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Magnetic nanostructures have been greatly known for various biomedical applications like drug delivery, MRI, cancer treatment by hyperthermia, bio-imaging, Tissue repairing, tumour therapy, and biomedical theranostics. The idea of all these applications is the use magnetic nanostructures with superparamagnetic state. Ferrites of alkali metals such as KFeO2 nanoparticles with the diameter of 12 nm have been synthesized via chemical method of synthesis. Various properties of KFeO2 nanoparticles such as particle size, biocompatibility, cytotoxicity and optical have been evaluated.

Keywords: Superparamagnetic, ferrite, biomedical, cytotoxicity

References:

[1] Ankush Kumar Tangra, Sarbjit Singh, Nian X. Sun, Gurmeet Singh Lotey, Journal of Alloys and Compounds Vol. 778, pp. 47-52 (2019).
[2] Sarbjit Singh, Ankush Kumar Tangra, Gurmeet Singh Lotey, Electronic Materials Letters, Vol. 14, Issue 5, pp.594-598 (2018).

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MOKE-wide-field-microscopy-based vector analysis of magnetic properties of nanocomposite amorphous ribbons

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Studied nanocomposite amorphous ribbons $Fe_{64.5}Co_{20}Nb_5B_{8.5}P_2$ 10mm wide and 22μm thick, are characterized by an in-plane uniaxial magnetic anisotropy (with the easy axis oriented perpendicularly to the ribbon axis, **RA**), which had been induced by an annealing of the sample in an in-plane-oriented magnetic field [1, 2]. An advanced, supported by digital-image-processing techniques, wide-field-Kerr-microscopy [3], was used to study the spatial distribution of components of magnetization vector and both hysteresis loops signals S_{RA} and S_{TRA}, driven by either H_{RA} or H_{TRA} magnetic fields, applied along either the **RA** or along transverse to the **RA** direction, respectively. It was found that local magnetic properties of the samples change along the TRA direction, transverse to the **RA** one. While applying H_{RA} magnetic field, stripe magnetic domains with: (i) magnetization along the TRA direction and (ii) the period of ca. 50 micrometers, were observed (similar as in Refs [1, 2]). Large irregular domains, with magnetization oriented along the TRA direction, were created by the H_{TRA} field (in this case, the process of magnetization reversal was dominated by the domain-wall-propagation mechanism). In the middle region of the ribbon, unexpected domain structures (with magnetization oriented along the TRA direction) in the form of a maze type of domain, characterized by the period of about 9 μm and the preference of orientation of domain walls along the **RA** direction, were detected, while applying the H_{RA} field. While applying the H_{TRA} field, a square hysteresis loops S_{TRA} were observed, which were connected with magnetization reversal process dominated by many nucleation centers.

References:

[1] A. Kolano-Burian, J.Appl.Phys. 114, 153911 (2013)
[2] A. Kolano-Burian, *et al.*, J.Appl.Phys. 115, 183904 (2014)
[3] I.V. Soldatov, R. Schäfer, Phys. Rev. B 95 (2017)

This study was supported by the National Centre for Research and Development under the project TECHMATSTRATEG1/347200/11/NCBR/2017.

Crystallization and magnetic properties of amorphous $(Fe_{0.7}Co_{0.3})_2B$ and $(Fe_{0.675}Co_{0.275}X_{0.05})_2B$ (X = W, Re) alloys

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FeCo-based compounds, characterized by high magnetization, are treated as a soft magnetic phase ingredient of composite materials for permanent magnets. Development of proper micro(nano)structure enables employment of the exchange-spring behaviour of these compounds to optimize magnetic properties of composite magnets. B. Balasubramanian *et al.* have shown that co-deposition of hard magnetic nanoparticles, with their easy axes aligned in the direction of magnetic field, with the soft $Fe_{65}Co_{35}$ phase, improves room temperature energy product up to 20 MGOe [1]. Theoretical calculations have confirmed the correlation of the magnetocrystalline anisotropy to the occurrence of tetragonal distortion. Anisotropy value is maximized for the lattice constant ratio of $c/a \approx 1.25$ [2]. It can be caused, for instance, by the chemical disorder and boron atoms addition [3].

Fully amorphous ribbons of $(Fe_{0.7}Co_{0.3})_2B$ and $(Fe_{0.675}Co_{0.275}X_{0.05})_2B$ (X = W, Re) were obtained in the melt-spinning process. Differential scanning calorimetry analysis showed the sample $(Fe_{0.675}Co_{0.275}Re_{0.05})_2$ was characterized by the highest thermal stability with the crystallization temperature defined as that corresponding to maximum of the first crystallization peak, equal to 574ºC. All investigated alloys were isothermally annealed at two different temperatures. The $(Fe,Co)_2B$ phase crystallized with lattice parameter depending on the alloy composition as a result of various annealing conditions. The difference is about 0.044 Å for *a* and 0.036 Å for *c* parameter. The alloy with Re substitution possesses the highest saturation magnetization from among all investigated samples, up to 1126 emu/cm^3.

References:

[1] B. Balasubramanian, P. Mukherjee, R. Skomski, P. Manchanda, B. Das, D.J. Sellmyer, Sci. Rep. **4** (2014) 6265.
[2] T. Burkert, L. Nordström, O. Eriksson, O. Heinonen, Phys. Rev. Lett. **93** (2004) 027203.
[3] I. Turek, J. Kudrnovský, K. Carva, Phys. Rev. B **86** (2012) 174430.

This work was supported by the National Science Centre, Poland, within the project No. 2016/23/N/ST3/03820.

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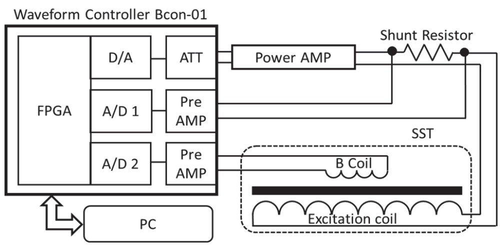

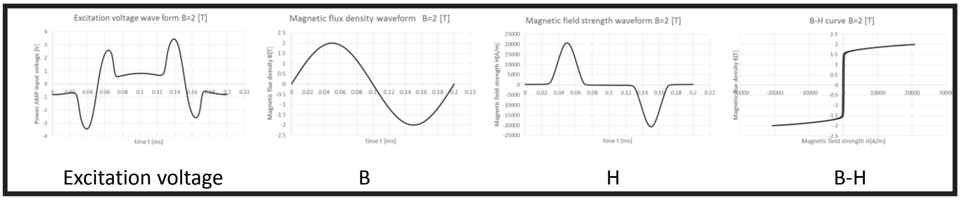

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Volkswagen Poznań is a utility vehicle and components plant. The VW Caddy and VW Transporter have been produced in Poznań for more than 15 years. From there, the vehicles are distributed to markets throughout the world. Volkswagen Poznań is currently the largest employer in Greater Poland and one of the largest in the country. The company employs over 11,000 employees. In October 2016 a new plant for the Crafter in Białężyce next to Września was opened. In Poznań's Wilda a foundry operates and supplies high quality aluminium components to many Volkswagen AG plants throughout the world. Last year employees of the company produced nearly 240,000 vehicles and 4.5 million casts. These are record achievements in the 25-year history of the enterprise.

Caddy/T Plant in Antoninek

The Caddy and T plant constitutes the main headquarters of the enterprise. Here popular light utility vehicles, such as the Caddy 4 and T6, are produced. Each day at the plant in Antoninek employees of the plant produce 750 vehicles which are made available to customers almost all over the world. In order to achieve this, more than a million parts from several hundred suppliers are received by the plant.

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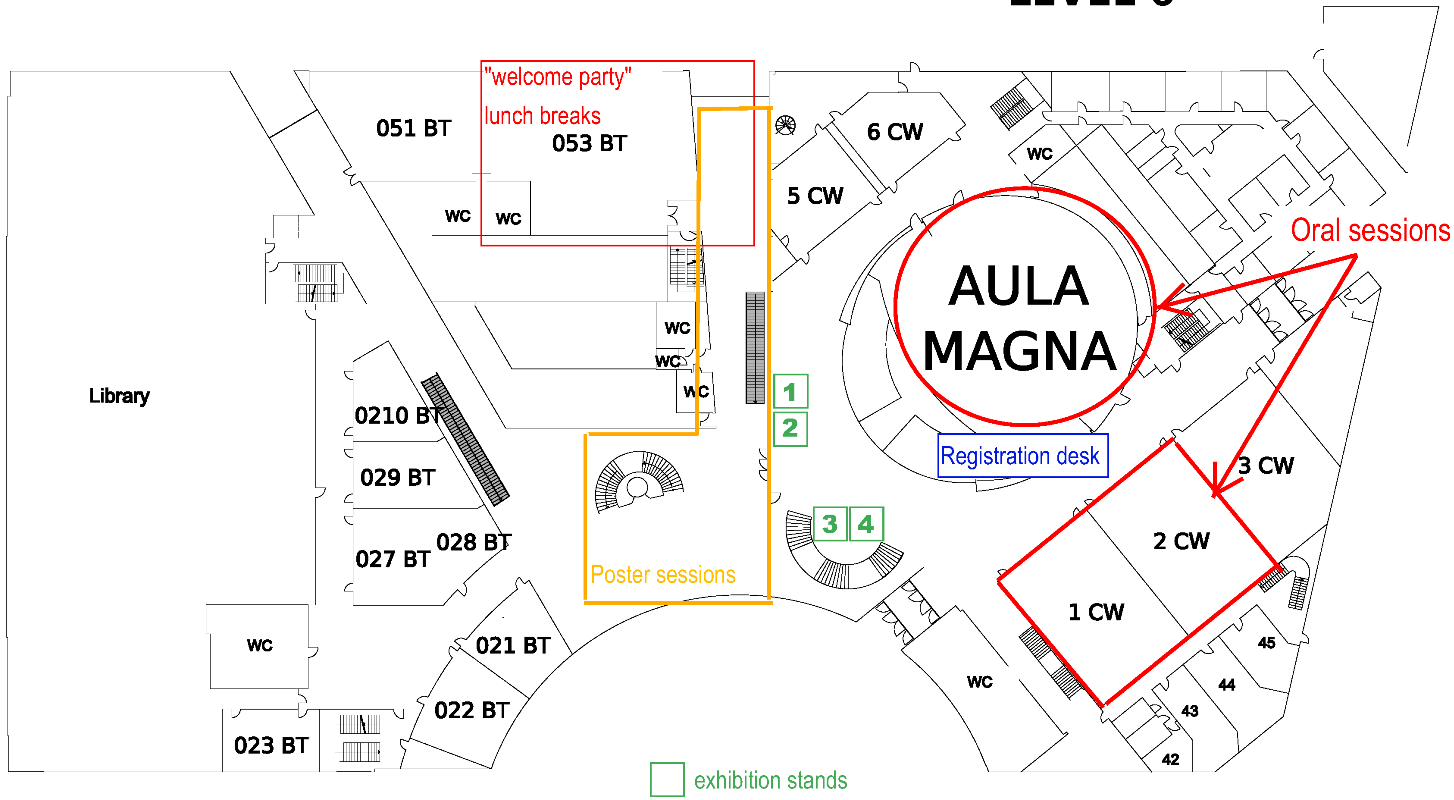

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SMM24 Schedule: September 4-7, 2019

	WED. Sept. 4	THURSDAY Sept. 5	FRIDAY Sept. 6	SATURDAY Sept. 7	SUN. Sept. 8
09.00-09.15		**OPENING**	*SESSION* V (9.00 - 11:00) **T. Waeckerlé** **M. Krawczyk** O-36 O-32 O-35 O-14	*SESSION* VIII (9.00 - 10:30) **F. Fiorillo** **A. Zhukov** O-09 O-06	9.00 - 16.00 *Excursion to Castle in Kórnik*
09.15-09.30					
09.30-09.45		*SESSION* I (9.30 - 11:00) **V. Franco** **R. Schäfer** O-45 O-12			
09.45-10.00					
10.00-10.15					
10.15-10.30					
10.30-10.45				10.30 - 11.00 COFFEE BREAK	
10.45-11.00					
11.00-11.15		11.00 - 11.30 COFFEE BREAK	11.00 - 11.30 COFFEE BREAK	*SESSION* IX (11.00 - 13.00) **A. Dyrdał** O-07 O-25 O-51 O-50 O-46 O-13	
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11.30-11.45		*SESSION* II (11.30 - 13:00) **A. Makino** **R. Wiesendanger** O-49 O-29	*SESSION* VI (11.30 - 13.00) **R. Shull** O-05 O-48 O-47 O-16		
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12.00-12.15					
12.15-12.30					
12.30-12.45					
12.45-13.00					
13.00-13.15		*Conference photo*	13.00 - 14.30 LUNCH	13.00 - 14.30 LUNCH	
13.15-13.30		13.15 - 14.30 LUNCH			
13.30-13.45					
13.45-14.00					
14.00-14.15					
14.15-14.30					
14.30-14.45		*SESSION* III (14.30 - 16.30) **T. Belgrand** O-19 O-15 O-26 O-03 O-17 O-22	*SESSION* VII (14.30 - 16.15) **J.M. Grenèche** **N. Ito** O-30 O-24 O-23	*SESSIONS* Xa/Xb (14.30 - 16.45) *Parallel*	
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15.00-15.15					
15.15-15.30					
15.30-15.45				Xa: O-39 O-02 O-33 O-40 O-04 O-01 O-10 O-20 O-41 Xb: O-27 O-28 O-21 O-44 O-18 O-53 O-31 O-38 O-43	
15.45-16.00					
16.00-16.15	16.00 - 19.00 REGISTRATION				
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16.30-16.45		*POSTER SESSION* I Posters 1 - 75, 85, 106, 121, 134			
16.45-17.00				*POSTER SESSION* II Posters 76 - 157 excluding 85, 106, 121, 134	
17.00-17.15					
17.15-17.30			17.15 - 18.45 Sightseeing of VW Września		
17.30-17.45					
17.45-18.00					
18.00-18.15					
18.15-18.30					
18.30-18.45		*SESSION* IV (18.30 - 19.45) O-42 O-37 O-08 O-34 O-11			
18.45-19.00			18.45 - 19.30 Bus transportation from VW Września	18.45 - ... **CLOSING**	
19.00-19.15	19.00 - ... *Choir concert and Welcome party*				
19.15-19.30					
19.30-19.45					
19.45-20.00					
20.00-20.15				20.00 - ... Guided tour of *Old Town*	
20.15-20.30		20.15 - ... *Banquet*			
20.30-20.45			20.30 - ... *IOC meeting*		
20.45-21.00					

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