Spin-Wave Amplification via Phase-Transition-Driven Temporal Interfaces

K. Sobucki[1] and P. Gruszecki[1]

[1] *ISQI, Faculty of Physics and Astronomy, Adam Mickiewicz University, Poznań, Poland*

Temporal modulation of medium properties has recently transformed photonics, enabling wave manipulation impossible with static structures [1]. We establish a general framework for magnonics of time-varying media by combining two key concepts: temporal interfaces—where abrupt changes in medium properties induce frequency conversion while preserving wavevector—and phase-transition-driven dynamics near magnetic phase transition. This combination demonstrates that Gilbert damping—conventionally the primary obstacle to spin-wave propagation—can be transformed into the engine of amplification [2].

Using ultrathin CoFeB films with perpendicular magnetic anisotropy and interfacial Dzyaloshinskii–Moriya interaction as a model system, we develop an analytical theory based on magnonic impedance that yields explicit expressions for transmission and reflection coefficients at temporal interfaces. We demonstrate that adiabatic field ramps suppress temporal reflections exponentially. All analytical predictions are validated by micromagnetic simulations.

The central result emerges from the analytical treatment of the complex spin-wave dispersion relation with Gilbert damping. We prove that at a specific field H_{EP} the system exhibits an exceptional point—a non-Hermitian degeneracy where both eigenvalues and eigenvectors coalesce. Our theory reveals three distinct dynamical regimes separated by the exceptional point field H_{EP} and the critical field H_c of the stripe-domain phase transition. In the slow-instability regime ($H_{\mathrm{EP}} < H < H_c$), the growth rate scales linearly with Gilbert damping, so increased dissipation counterintuitively enhances gain—an effect that vanishes in the conservative limit.

A temporal-slab protocol—a high-field → low-field → high-field sequence—synthesizes both elements: adiabatic interfaces provide reflection-free entry and exit, while the slow-instability regime accumulates exponential gain during the low-field plateau. This combination achieves frequency-preserving amplification up to 175-fold without continuous power injection or lithographic patterning. This framework establishes temporal modulation as a control parameter for reconfigurable magnonic devices.

References:

[1] E. Galiffi et al., Advanced Photonics 4 (2022) 014002.
[2] K. Sobucki and P. Gruszecki, arXiv:2512.07713 (2024).