Spin-wave excitations in a 3D woodpile magnonic crystal

M. Gołębiewski,[1] H. Guo,[2] K. Lenz,[3] R. Narkowicz,[3] J. Lindner,[3] M. Krawczyk,[1] and D. Grundler[2,4]

[1] *Institute of Spintronics and Quantum Information, Faculty of Physics and Astronomy, Adam Mickiewicz University, Poznań, Poland*

[2] *School of Engineering, Institute of Materials, Laboratory of Nanoscale Magnetic Materials and Magnonics, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland*

[3] *Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden–Rossendorf, Dresden, Germany*

[4] *Institute of Electrical and Micro Engineering, EPFL, Lausanne, Switzerland*

Three-dimensional (3D) magnonic crystals have long been predicted to host minibands, symmetry-protected edge excitations, and unconventional spin-wave transport, yet their coherent dynamics have remained experimentally inaccessible due to major fabrication and integration challenges. Here, we demonstrate the coherent excitation and detection of spin waves in an experimentally realized 3D magnonic crystal [1]. Using two-photon lithography combined with atomic layer deposition, we fabricate a face-centered-cubic woodpile architecture composed of nickel nanotubes with curved end-caps. The structure is integrated into a planar microresonator, enabling microwave magnetic-field excitation at 14 and 24 GHz and high sensitivity to both localized and extended resonances.

Angular-resolved ferromagnetic resonance measurements reveal a rich spectrum of coherent modes with clear fourfold symmetry, consistent with the underlying 3D lattice. Finite-element micromagnetic simulations quantitatively reproduce the resonance fields and identify two dominant classes of excitations: bulk modes extending through the interconnected nanotube network and strongly confined modes localized at the curved nanocaps. The cap modes form nearly angle-independent („flat") branches and exhibit a directed, wave-like phase evolution across neighboring caps arising from dynamic dipolar coupling.

These results provide the first evidence of phase-coherent, edge-dominated spin-wave dynamics in a 3D magnonic crystal and demonstrate the exceptional sensitivity of such systems to localized excitations. Our work establishes a scalable route toward 3D magnonic architectures and opens new opportunities for wave-based signal processing, tunable magnonic band structures, and energy-efficient 3D spintronic devices.

References:

[1] H. Guo, K. Lenz, M. Gołębiewski, et al. Small 22 (2026), e08983.

M.G. and M.K. acknowledge support from the National Science Center, Poland (UMO-2020/39/I/ST3/02413 and UMO-2023/49/N/ST3/03032). M.G. also received funding from the Adam Mickiewicz University Foundation in Poznań (2024/2025) and from the Foundation for Polish Science (FNP).