Spin Waves in Magnonic Nanostructures

Joachim Gräfe[1], Markus Weigand[1], Eberhard J. Goering[1], Gisela Schütz[1]

[1]*Max Planck Institute for Intelligent Systems, 70569 Stuttgart, Germany*

KEY WORDS: X-ray Microscopy, XMCD, Magnonic Crystals, Spin Wave Focusing

Magnonic crystals are nanostructured metamaterials with periodically alternating magnetic properties, similar to photonic crystals, which have gained significant scientific interest in the past years [1-4]. A periodic variation is achieved by creating holes in a magnetic host material to form a so-called antidot lattice (ADL). The introduction of the artificial ADL allows to alternate the spin wave dispersion in the material and to form a spin wave guide or filter [2, 3]. Additionally, these antidots act as scattering centers for spin waves and can be used to form magnonic devices based on spin wave interference [4].

As the spin wave propagation in nanoscaled magnonic structures cannot be visualized by time resolved Kerr microscopy, typical investigations use all electrical spin wave spectroscopy or Brillouin light scattering and are unable to directly image the propagation of spin waves in nanometer sized magnonic crystals. Here, we present results from advanced time resolved x-ray microscopy (MAXYMUS@BESSY) with magnetic contrast. Spin wave modes ranging from 250 MHz up to 8 GHz in the rich spin wave band structure of ADL based magnonic crystals were imaged. Both propagating and localised modes are observed. Hybridization of modes with different localization within the ADL, as predicted in micromagnetic simulations, is experimentally confirmed. Furthermore, the mechanism behind the tailorable band structure and the selective transmission or damping is visualized. Based on this understanding a spin wave filter, tuning propagation lengths from 0.5 to >10 µm, is constructed and imaged in operation.

Additionally, we present an interference based Fresnel lens that is based on an antidot structure in permalloy. The spin wave propagation is then imaged by time-resolved x-ray microscopy to observe the interference that leads to the formation of a focal spot in a wide frequency range (2 – 10 GHz). In the focal spot the spin waves are confined to less than 800 nm within a uniform film. The intensity is increased by more than 20% above the emission intensity. Thus, the lens is overcompensating the damping. Furthermore, the focal spot can be moved in a 6x6 µm² area by changing the applied magnetic bias field.

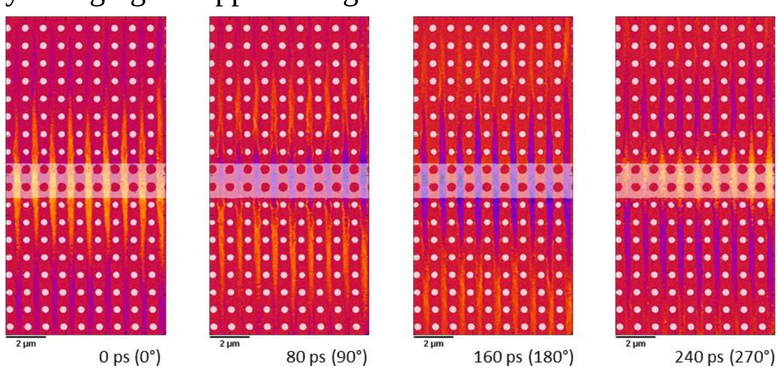

Figure 1: Dynamic X-ray micrographs with magnetic contrast (XMCD) at different time steps of a movie showing the propagation of a spin wave mode in an antidot lattice. The spin wave can only propagate between antidots. The applied external bias field allows propagation over 10 µm from the excitation source. The positions of the stripline and the antidots are indicated as white overlays.

[1] Kruglyak, V. V.; Hicken, R. J.: J. Magn. Magn. Mater. 306 (2006), 191

[2] Lenk, B. et al.: Phys. Rep. 507 (2011), 107

[3] Schwarze, T.; Grundler, D.: Appl. Phys. Lett. 102 (2013), 22

[4] Mansfeld, S. et al.: Phys. Rev. Lett.108 (2014) 047204