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Imaging spin textures in magnetic nanostructures

A zoo of spin textures in Fe/Gd-based multilayers

Skyrmions and antiskyrmions are topologically protected spin textures with opposite topological charge. Particularly in coexisting phases, these two types of magnetic quasi-particles may show fascinating physics and potential for spintronic devices. Fe/Gd multi-layers (MLs) provide a highly tune-able system which shows skyrmions stabilized by the competition of dipolar fields, magnetic anisotropy, and exchange energy.

We modified the magnetic properties of the MLs by Ir insertion layers. Using Lorentz transmission electron microscopy (LTEM) imaging at our project partner in Brno , we observed coexisting antiskyrmions (Fig. 2d,e), Bloch skyrmions (Fig.2a,b) and type-2 bubbles (Fig.2c). The nucleation process of the antiskyrmions was analyzed by LTEM and micromagnetic simulations (Fig.3).

[M. Heigl et al., arXiv:2010.06555]

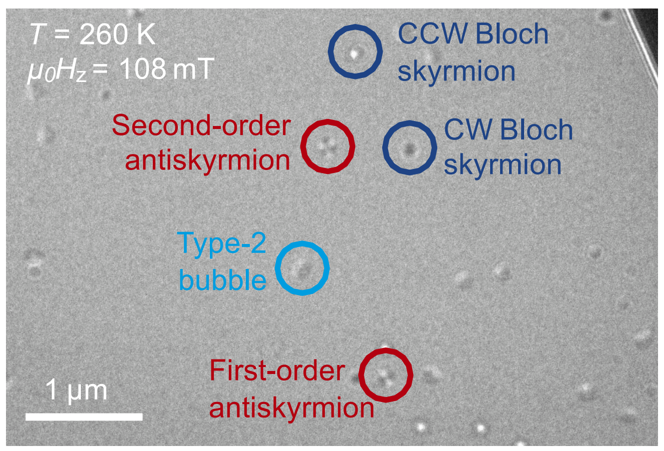

Fig.1 *LTEM image of a Fe/Gd-based ML showing a variety of coexisting spin objects.*

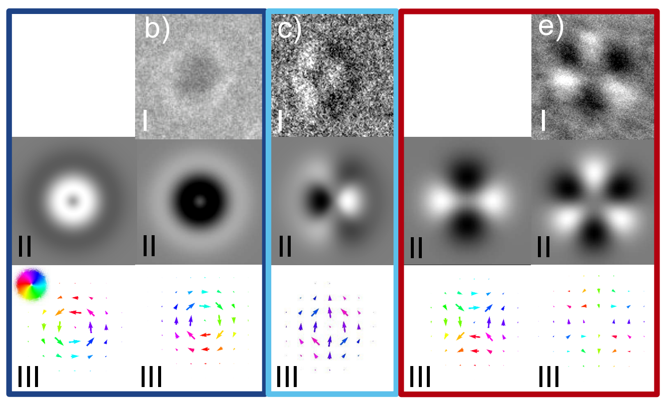

Fig.2 *Zoomed-in spin objects (I), simulated LTEM contrast (II), and theoretical spin textures (III) of counterclockwise (a) and clockwise Bloch skyrmions (b), type-2 bubbles (c), first-order antiskyrmion (d), and second-order antiskyrmion (e).*

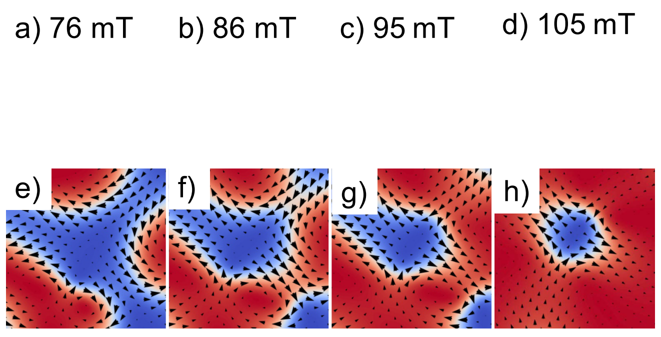

Fig.3 *Experimental (a-d) and simulated (e-h) nucleation process of an antiskyrmion.*

Spin wave dispersions measured using VNA

Propagating spin-wave spectroscopy (PSWS) is an established technique for probing material's spin-wave properties using a vector network analyzer (see insert Fig. 5e). Figure 5(a,b) shows RF transmission S_{21} spectra measured on CoFeB 30 nm layer using a pair of 500 nm wide stripline antennas. PSWS experiment can be used to extract the spin-wave dispersion relations by measuring the spin-wave phase over multiple propagation distances. Fig. 5(c) shows 11 phase measurements for gap sizes from 900 (the lowest line) to 2900 nm (the steepest line) with a step of 200 nm. Fig. 5(d) shows fits at representative frequencies, where the slope of the fit is equal to the kk-vector at that frequency. This approach can be carried out for all frequencies and also at different magnetic fields to extract full dispersion relations, as presented in Fig. 5(e). The black lines are fits using the dipole-exchange model with the resulting parameters shown inside of Fig. 5(e).

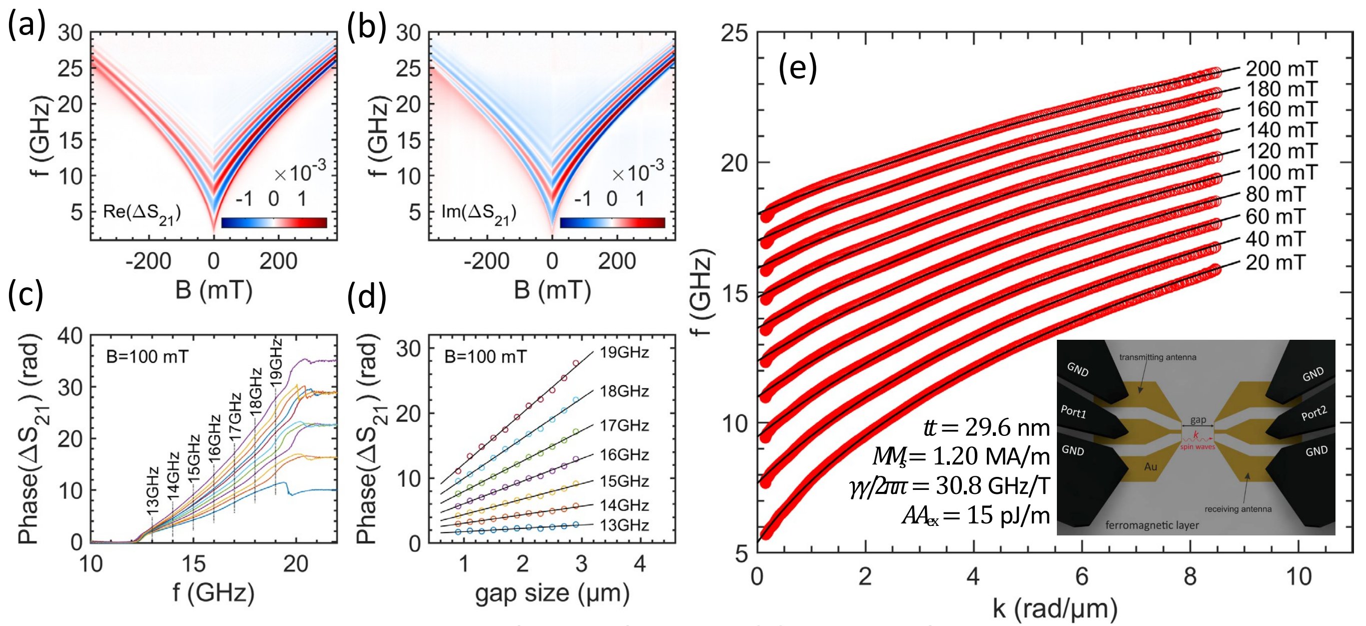

Fig.5 *PSWS experiment on CoFeB 30 nm layer with extracted dispersion relations.*

Structured yttrium ion garnets for magnonics

Magnonic crystals are magnetic structures with periodic spatial variations of the magnetic properties. This leads to spin wave (SW) band gaps and selective SW propagation. $Y_3Fe_5O_{12}$ (YIG) is the ideal material used in SW studies due to an extremely low Gilbert damping parameter (< 10^{-4}).

Sinusoidal structures with an amplitude of 8 nm and a periodicity of 200 – 300 nm were patterned on $Gd_3Ga_5O_{12}$(111) substrates by focused ion beam milling by the collaborators in Brno. In Augsburg, a heat treatment of the substrates was carried out leading to the recrystallization of the substrate surface. The heat treatment results in rather irregular pattern for the 200 nm and 250 nm periodic structures, while the 300 nm periodic structures remained rather unchanged with a slight decrease in amplitude by around 1-2 nm.

20 – 100 nm thick YIG films were grown by pulsed laser deposition. An atomic force microscopy topography image and the corresponding profile line of the 100 nm thick film grown on structures with a 200 nm periodicity are displayed in Fig. 4. The YIG film grows following the pattern of the substrate surface and shows a smooth morphology. From Fig. 4, a modulation amplitude of around 4 nm is extracted, which is half of the initial amplitude patterned on the substrate.

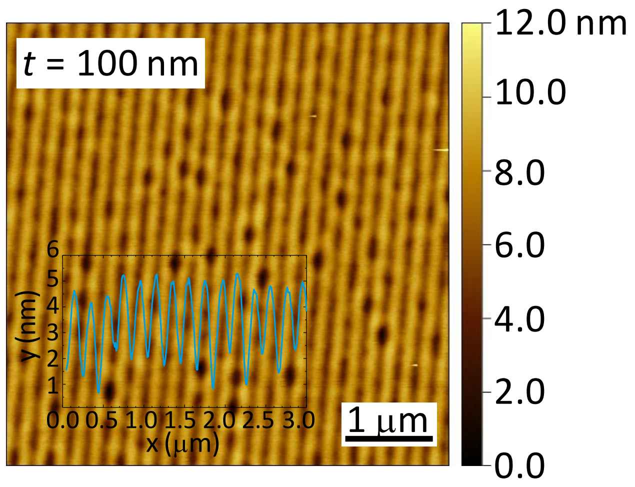

Fig. 4 AFM topography image and line profile of patterned YIG(100 nm)/GGG.

Spin wave propagation in corrugated waveguides

Curvature-induced effects allow us to tailor the static and dynamic response of magnetic nanostructures with an unprecedented degree of freedom. By controlling the local curvature of the system, a local effective magnetic field can be tailored with excellent fidelity,

giving us a direct mean of control over the local static and dynamic response of the magnetic system. In order to control the local curvature, we have used focused electron beam induced deposition of silicon dioxide to prepare a substrate with sinusoidal morphology. Magnetic thin films grown on this pre-structured substrate exhibit dominant uniaxial anisotropy perpendicular to the corrugation direction.

This curvature-induced effective field is strong enough to overcome the shape anisotropy of long and narrow magnonic waveguides and to stabilize the magnetization perpendicularly to their long axis. We show, by Brillouin light scattering microscopy, that it is possible to propagate spin waves in narrow corrugated magnonic waveguides in the favorable Damon-Eshbach geometry without using any external magnetic field.

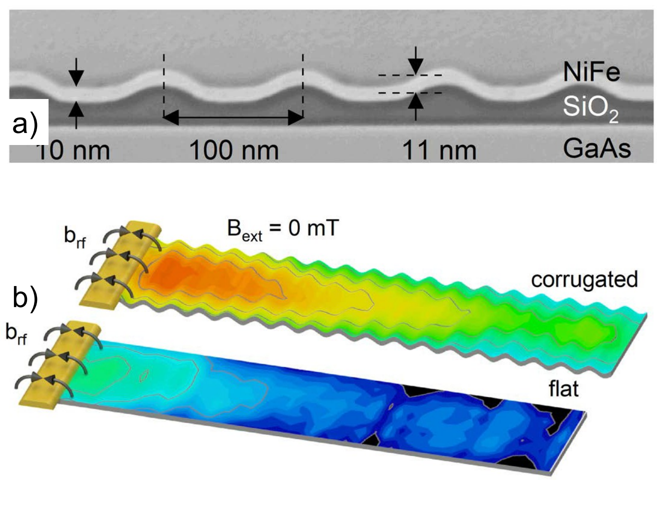

Fig. 6 a) STEM image of the structure prepared with 6,000 scans of the e-beam. b) Sketch of the BLS experiment. Both corrugated and flat waveguides are measured in zero magnetic field. Due to the corrugation of the magnonic waveguide, the magnetization vector lies perpendicular to the long axis of the waveguide. In the flat waveguide, due to the shape anisotropy of the waveguide, the magnetization is aligned parallel to the long axis.

Bayerische Staatskanzlei

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