Average and Local DMI obtained from quantitative MFM of domains and skyrmions in thin films with interfacial DMI

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High resolution magnetic force microscopy (MFM) is a versatile tool to image domains and skyrmions embedded in seed- and oxidation-protection layers such as a sample of $Si/Pt/[Ir_{1nm}/Co_{0.6nm}/Pt_{1nm}]_{\times 5}/Pt$. Calibrating the response of the MFM tip allows the deconvolution of the MFM frequency shift images to obtain all components of the stray field, and to match it by candidate model magnetization structures.

We use of measured domain patterns obtained after different demagnetization processes to determine the average Dzyloshinskii-Moriya interaction (DMI) from a minimization of the systems magnetic energy taking into account the specific multilayer structure and the domain wall energy reduced by the DMI. The DMI value of (1.97 ± 0.02) mJ/m^2 is comparable to that found in a similar system by Moreau-Luchaire et al. [1]. Isolated skyrmions could be observed in zero field after saturation. (a) and (b) display MFM images obtained in -1.1 and -5.3 mT, respectively. The magnetic background contrast visible in image (b) corresponds to a variation of the thickness of the Co layers by ±1ML (c). According to theoretical work by Yang et al. [2] DMI values of up to can occur for 2ML of Co on Pt.

Using the calibrated response of the MFM tip to the magnetic field, all vector components of the stray field of the measured skyrmions can be extracted from the MFM frequency shift data (d). We find the counter-clock wise orientations of the skyrmion spin profile lead to an amplification of the field emanating from the skyrmion compared to clock-wise spin-profiles.

Local D, K_u, and A values at the location of the skyrmions can be obtained from fits of the simulated MFM images of skyrmion model magnetization structures to the MFM images of the skyrmions. We find D values in the range of 3.35 to 3.5 mJ/m^2 for all four skyrmions analyzed here, considerably higher than the average value of 1.97 mJ/m^2 obtained from the domain size analysis. The high values at the location of the skyrmions are however compatible with theoretical expectations [2] for a Co layer thickness of 2ML. Panels (e), (f), and (g) show zoomed images of the measured skyrmions, simulated images, and difference images, respectively for the top (top row) and bottom (bottom row) of the two skyrmions of Fig. (a).