THE DZYALOSHINSKII-MORIYA INTERACTION IN MAGNETIC MULTILAYERS

Hans NEMBACH[1,2], Emilie JUE[1], Eric EDWARDS[1], Tom SILVA[1] and Justin SHAW[1]

1) Quantum Electromagnetics Division, National Institute of Standards and Technology, Boulder, Colorado 80305, USA, hans.nembach@nist.gov

2) JILA, University of Colorado, Boulder, Colorado 80309, USA

The Dzyaloshinskii-Moriya interaction (DMI) is of large interest from a scientific as well as from a technological point of view. The DMI is an anti-symmetric exchange interaction, which favors perpendicular alignment of neighboring spins [1], [2]. The DMI only exists in systems with broken inversion symmetry. It is for example responsible for the canted spin-structure in α-Fe_2O_3 (Hematite). It can also exist in magnetic multilayers, where a ferromagnet is in contact with a heavy metal, for example Pt. Interfacial DMI can be described by a three site exchange mechanism, where the coupling between two spins in the ferromagnet is mediated by an atom with large spin-orbit coupling in the adjacent material [3], [4]. It can give to chiral spin-chains, chiral domain walls and skyrmions. Nanoscale skyrmions have the potential to be utilized as bits for a novel racetrack memory [5]. Skyrmions promise high stability and they can be generated and propagated by spin-orbit torques.

The DMI can have disruptive effects for magnetic random access memory (MRAM) by reducing thermal stability and increasing the switching current [6], [7]. This is especially relevant for spin-orbit torque driven MRAM, where a heavy metal is in contact with the free layer. We have demonstrated that ferromagnetic films in contact with an oxide can also give rise to DMI. Thus, any MRAM cell with an MgO tunnel-junction can potentially be subject to detrimental effects of DMI.

We are using Brillouin Light Scattering spectroscopy (BLS) to determine the DMI in our sample systems. The DMI causes a non-reciprocal frequency-shift for Damon-Eshbach spin-waves. The sign of the frequency-shift depends on the polarity of the magnetization and the propagation direction of the spin-waves [8], [9]. We use Brillouin Light scattering spectroscopy to determine the spin-wave frequency for both field-polarities. This allows us to determine the DMI induced frequency-shift. We use M_s and g, which are determined by SQUID and ferromagnetic resonance spectroscopy (FMR), to then extract the DMI. This method does not require any modeling.

In order to gain deeper insight into the underlying physics of the interfacial DMI, we prepared different multilayer systems with DMI. We found that for a $Ni_{80}Fe_{20}$(x)/Pt sample series with x ranging from 1 nm to 13 nm the symmetric Heisenberg exchange and the DMI both show the almost identical thickness dependence [9]. This was originally predicted for magnetic oxides and for metallic spin-glasses. With another sample series we studied the role of the direct exchange coupling between CoFeB and Pt, where we inserted a Cu spacer between the two materials with a thickness x ranging from 0.2 nm to 2.0 nm. We find that the DMI and the proximity magnetization in the Pt both show a similar exponential decrease with Cu thickness, fig.1. This underlines the importance of the direct exchange for these two phenomena. Moreover, we find that the Gilbert damping is highly correlated with the magnitude of the proximity magnetization. This suggest that spin-memory loss due to the proximity magnetization strongly contributes to the total damping.

Bulk magnetic oxides are well known for the presence of DMI. We in-situ oxidized a Pt/$Co_{90}Fe_{10}$ and a Cu/$Co_{90}Fe_{10}$ sample series for different times and subsequently capped these samples to prevent further oxidation. Both sample series showed an increase in DMI with oxidation, which demonstrates unambiguously that interfacial oxide gives rise to DMI. The spectroscopic splitting factor $g^{\perp}$, which we determined by perpendicular FMR, changes with the oxidation and is correlated with the increase in the DMI. The change in $g^{\perp}$ indicates changes of the hybridization and the associated charge transfer at the oxide interface. This was also predicted by recent density functional calculations (DFT).

Hans T. Nembach
E-mail: hans.nembach@nist.gov
Tel.: +1-303-497-4966

Finally, we addressed the importance of the in-plane symmetry of the crystal lattice. So far, most of the experimental work has been done on (111) textured films exhibiting C_{3v} symmetry, for which the DMI is isotropic. We prepared by molecular beam epitaxy the Pt(110)/Fe system, which has C_{2V} symmetry. Our measurements show a two-fold symmetry for the DMI, see fig.2. The ratio for the DMI along the [-110] and the [001] agrees with DFT calculations.

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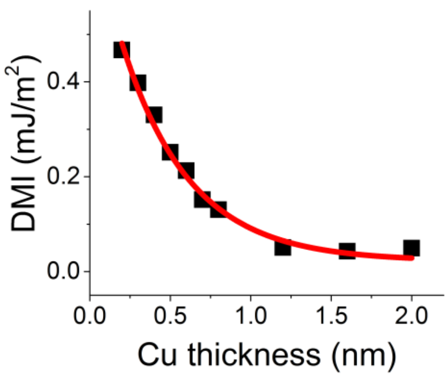

Fig. 1: Exponential decay of the DMI with Cu dusting layer thickness.

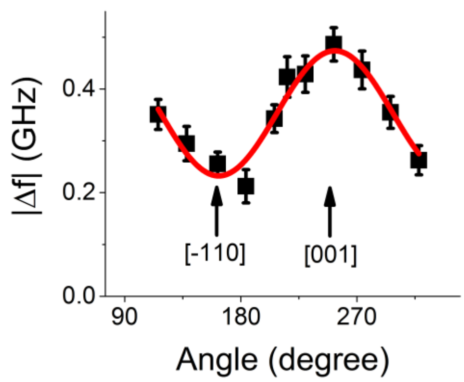

Fig. 2: Angular dependence of the DMI induced frequency-shift.