Driving Magnetization Perpendicular by Antiferromagnetic-ferromagnetic Exchange Coupling

In the field of recording technology, the controllable perpendicular magnetization of magnetic material is of great importance because it's promising for the out-of-plane type of data storage. Generally, the approaches to establish perpendicular magnetization are based on the spin-orbital coupling which includes ferromagnetic/noble-metal multilayers and strained magnetic ultrathin films. However, a new possibility for achieving perpendicular magnetization is through exchange-coupled ferromagnetic/antiferromagnetic bilayers or multilayers. Here we have proposed a new concept for establishing perpendicular magnetization via antiferromagnteic-ferromagnetic exchange coupling. "This finding is also beyond current physics of antiferromagnteic-ferromagnetic exchange coupling, indicating that the well –known exchange bias is only one of two effects."

B.-Y. Wang
National Taiwan University, Taiwan

M.-T. Lin
National Taiwan University, Taiwan
Academia Sinica, Taiwan

Ferromagnetic/antiferromagnetic bilayers with controllable perpendicular magnetization are of great interest due to a potential achieving non-volatile memory and logic devices with high density, thermal stability, and low critical current for current-induced magnetization switching.[1] To date, common ways to establish perpendicular magnetization include building periodically alternated ferromagnetic (FM)/noble-metal multilayers,[2] or the use of strained magnetic thin films.[3] All of these approaches are based on the spin-orbital coupling at the interface or inside the volume of magnetic materials. However, a new possibility, which was recently demonstrated by our work,[4] indicates that the perpendicular magnetization can also be established by exchange coupling effect between FM layer and antiferromagnetic (AFM) layer.

In this work, a series of Fe(Py)/Mn bilayered samples were prepared in a UHV multi-functional NTU-NSRRC Nanomagnetism chamber (base pressure = 2×10^{-10} torr). The magnetic hysteresis loops of samples were in-situ measured by magneto-optical Kerr effect (MOKE). The prepared samples were also transferred to the connected photoemission electron microscopy (PEEM) endstation at beamline BL05B2 of NSRRC, Taiwan, for the magnetic domain imaging with X-ray magnetic circular dichroism (XMCD) effect. According to a detailed structural characterization,[4] the significant structural effects on the magnetic properties of Fe(Py)/Mn bilayers can be excluded.

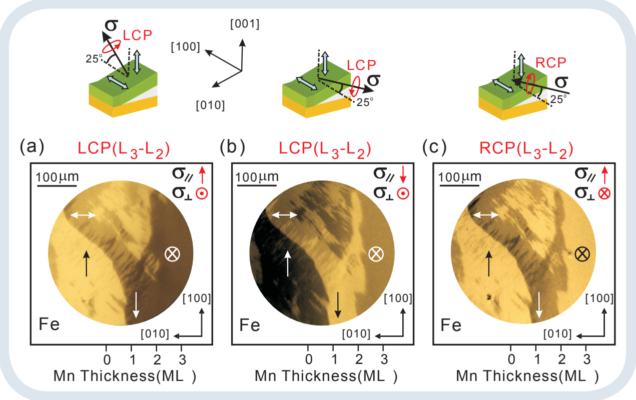

Fig. 1: (a)-(c) Magnetic domain images of a 6 ML Fe/wedged-Mn bilayer measured with different relative orientations between X-ray and samples.

Figure 1(a) shows the Fe domain image of 6 ML Fe/wedged-Mn bilayer, with incoming X-rays of left-circular polarization (LCP). The sample is further precessed 180° along the [001] direction to let the incident X-ray on the sample in Fig. 1(b), as compared with 1(a), have the same perpendicular projection of photohelicity ($\sigma_\perp$) but inverse in-plane projection of photohelicity ($\sigma_{//}$). Thus, the magnetic domains showing inverse contrast in the region of Mn film thickness (t_{Mn}) < 2 ML present the signature of in-plane anisotropy. On the other hand, we keep the same instrument configuration as in Fig. 1(b) but reverse the polarization of the incident X-ray from left to right-circular polarization (RCP), as shown in Fig. 1(c). This makes the incident X-ray of the sample in Fig. 1(c) have the same $\sigma_{//}$ but inverse $\sigma_\perp$ with that in Fig. 1(a). By comparing Fig. 1(c) with 1(a), an inverse domain contrast shown in the region of t_{Mn}> 2 ML presents the characteristics of perpendicular magnetization. Thus, a so-called spin-reorientation transition (SRT) from the in-plane to perpendicular direction was demonstrated in the 6 ML Fe/wedged-Mn bilayer with the increase of t_{Mn}.

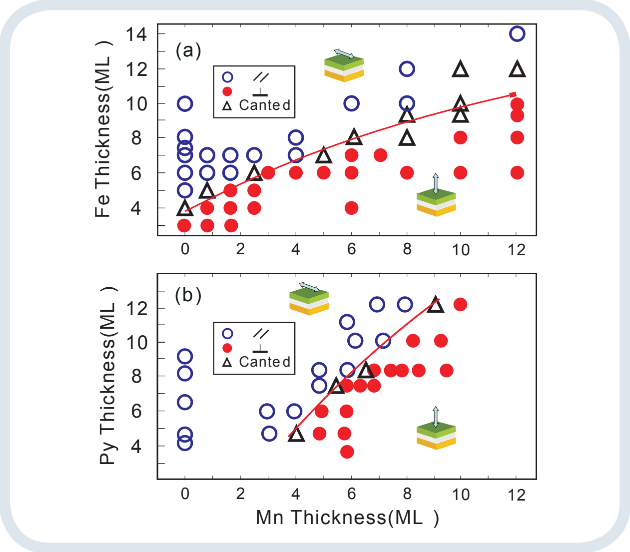

Fig. 2: Magnetic easy axis phase diagram for (a) Fe/Mn bilayers and (b) Py/Mn bilayes, measured by MOKE at 220 K. The solid lines are the SRT boundaries fitted with theoretical model.[4]

To further confirm this SRT phenomenon, we also performed the hysteresis loop measurements on a series of uniform Fe(Py)/Mn bilayers. The direction of magnetic easy axis of these films was summarized in Fig. 2. In Fig. 2(a), the range of Fe film thickness (t_{Fe}) within which perpendicular magnetization can be achieved extends from 3 ML to 8 ML, depending on t_{Mn}. A thicker Mn layer is found capable of stabilizing the perpendicular magnetization for a thicker Fe layer. The similar results were also performed in Fig. 2(b) for Py/Mn bilayers, in which the perpendicular magnetization was observed with $t_{Mn} > 4$ ML. Thus, we have demonstrated a general feature for the perpendicular magnetization of FM layers which is achieved and enhanced by increasing t_{Mn}.

To investigate the origin of the established perpendicular magnetization in both systems, the temperature-dependent experiments were performed. In Fig. 3(a), the 6 ML Fe/6 ML Mn bilayer exhibits perpendicular magnetization at low temperature. As the temperature is elevated, its magnetization switches from the perpendicular to in-plane direction with a transition temperature $T_{SRT} \sim 230$ K. This temperature-dependent SRT is also seen in 6 ML Fe/8 ML Mn at a higher $T_{SRT} \sim 245$ K. The variation of T_{SRT} is plotted as a function of t_{Mn} in Fig. 3(b), in which T_{SRT} increases monotonically from 220 K to 245 K as t_{Mn} is increased from 2 to 10 ML.

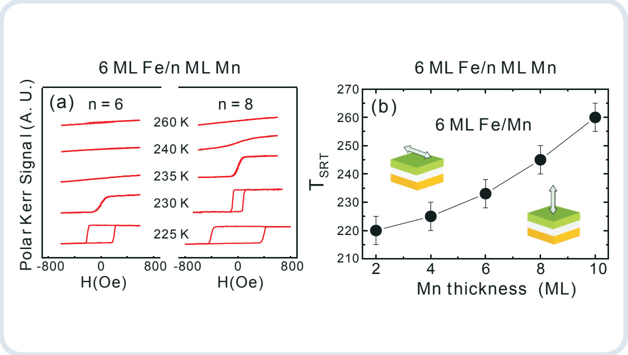

Fig. 3: (a) Temperature-dependent polar hysteresis loops of (a) 6 ML Fe/6 ML Mn and 6 ML Fe/8 ML bilayers. (b) The spin-reorientation transition temperature (T_{SRT}) for 6 ML Fe/Mn bilayers as a function of t_{Mn}.

Similar to blocking temperature (T_B), which describes the strength of "pinned" uncompensated spins in exchange bias coupled systems, T_{SRT} in this work can also be used to monitor the thermal stability of the "effective" magnetic ordering in the AFM Mn layer which is associated with the established perpendicular magnetization of Fe/Mn bilayers. Thus, the T_{SRT} monotonic increase with AFM thickness reveals the same finite-size effect tendency as found in T_B for the AFM-FM exchange bias systems.[5] Such tendency distinguishes the present coupling type from the spin-orbital coupling at interfaces that supports the conventional perpendicular interfacial anisotropy in FM/noble-metal bilayers or multilayers, because the latter case presents the maximum strength of perpendicular magnetization for noble-metal thickness with low coverage.[2]

In summary, our work demonstrates a new concept of AFM-FM exchange coupling on perpendicular magnetization, except for the well-known exchange bias field. This may lead to the perpendicular magnetization desired in the frontier recording technology.

Beamline 05B2
PEEM end station

References

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Contact E-mail

mtlin@phys.ntu.edu.tw