Microscopic Origin and Role of Uncompensated Antiferromagnetic Spins in Mn-Ir Based Exchange Biased Bilayers

The exchange bias of ferromagnetic (FM) / antiferromagnetic (AFM) bilayers, characterized by a horizontally shifted magnetization hysteresis loop, is an indispensable physical phenomenon for the realization of high-density magnetic storage devices, such as hard disk drives (HDDs) and magnetic random access memories (MRAMs). A strong exchange biasing property is required to achieve a high storage density. While the microscopic mechanism of the exchange bias has been the subject of extensive studies for the last 50 years, it is not yet completely understood. The information required to clarify the mechanism is the asymmetry of a spin structure in a bilayer system, which is obviously required to provide exchange anisotropy, against the reversal of a practical external magnetic field. As the only candidate that mediates the spin motion from the FM layer to the AFM layer during the magnetic field reversal, uncompensated AFM spins might play a key role in the magnetization of the AFM layer and likely be a clue for investigating the asymmetric spin structure formed in the AFM layer. X-ray magnetic circular dichroism (XMCD) in a *transmission mode* is a powerful tool for detecting the uncompensated AFM spins at the buried interface because of its element selectivity and excellent sensitivity. We thus investigated the microscopic origin [1] and role of the exchange anisotropy [2] of the uncompensated AFM spins by XMCD spectroscopy at beamline **BL25SU** for Mn-Ir based exchange biased bilayers, which are widely used for the application of HDDs and MRAMs nowadays.

The AFM layer thickness (d_{AF}) dependences of (a) X-ray absorption spectra (XAS) and (b) XMCD spectra at Mn $L_{2,3}$-edges were measured for $Mn_{73}Ir_{27}$ / $Co_{70}Fe_{30}$ bilayers. The X-ray beam was incident on the sample surface at an angle of 30°. A magnetic field of +14 kOe was applied along the axis rising 20° from the sample surface. As d_{AF} increases, the resonant absorption magnitude at the respective *L*-edge naturally increases (Fig. 1(a)), depending on the effective volume of Mn absorption. On the other hand, the XMCD magnitude at the respective resonant peak does not markedly change (Fig. 1(b)), indicating that uncompensated Mn moments resulting in an XMCD signal do not exist homogeneously in the entire Mn-Ir layer. From an inverse-proportion of the normalized XMCD magnitude by resonant absorption against d_{AF} (not shown), it was confirmed that the uncompensated Mn moments are localized at the interface of less than a few monolayers between the FM and AFM layers. The FM layer material greatly affects the uncompensated Mn moments and changes the sign and magnitude of the XMCD signal. Furthermore, no MCD signal is observed on the spectrum, when the FM layer is detached from the Mn-Ir layer. We thus

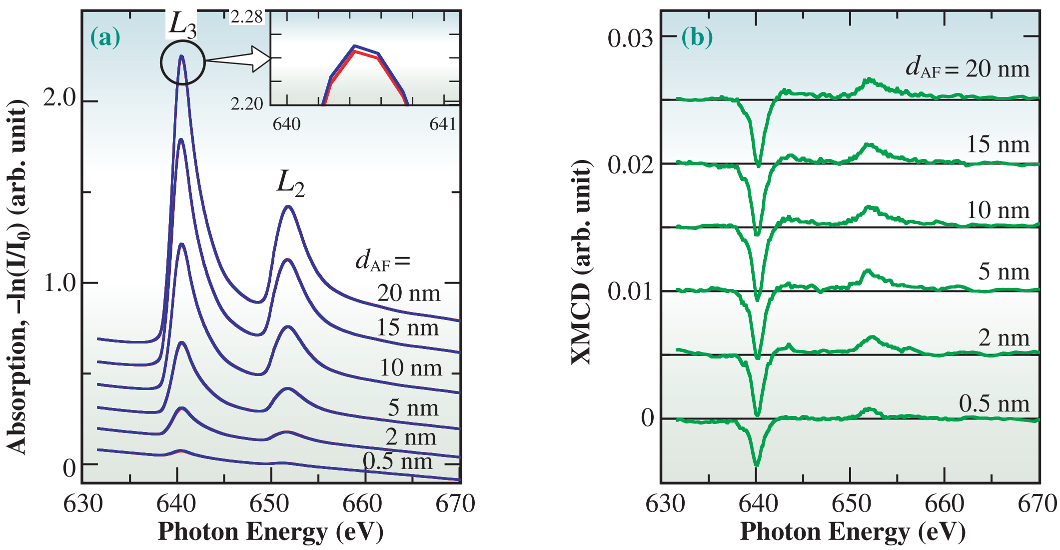

Fig. 1. **(a)** XAS and **(b)** XMCD spectra at Mn $L_{2,3}$-edges in Mn-Ir(d_{AF})/$Co_{70}Fe_{30}$(2.5 nm) bilayers. The spectra are vertically shifted to be distinguished from each other. Thin horizontal lines accompanied by the XMCD spectra indicate base (XMCD = 0) lines.

conclude that the uncompensated AFM spins are induced exactly at the interface through the exchange interaction between the FM and AFM layers, as illustrated in Fig. 2.

To clarify the role of uncompensated AFM spins in exchange anisotropy, the magnetization of the AFM spin was also studied. If the uncompensated AFM spins provide the asymmetric spin structure against the field reversal and dominate the exchange bias strength by themselves, a certain part of such spins should be irreversible and should result in the vertical offset of their ESMH corresponding to the exchange biasing strength. Figure 3 shows the Mn- and Co-ESMH loops of the $Mn_{73}Ir_{27}$ / $Co_{70}Fe_{30}$ bilayers, with different exchange biasing strengths (J_K). Different J_K values of (a) 0.55 erg/cm^2 and (b) 1.18 erg/cm^2 were achieved by changing the chemical ordering of the Mn-Ir layer [3]. For the accurate determination of the vertical offset of the ESMH, both the parallel and antiparallel configurations were examined. However, we cannot observe any vertical offsets of the Mn-ESMH in both bilayers, which is different from the case in a previous study [4]. That is, all the uncompensated AFM components follow the rotation of FM moments and only mediate the spin motion from the FM layer to the AFM layer in Mn-Ir based exchange biased bilayers.

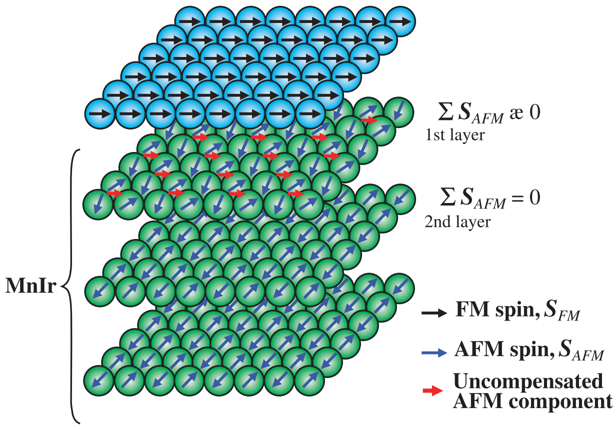

Fig. 2. Schematic illustration of uncompensated AFM moments induced at the interface.

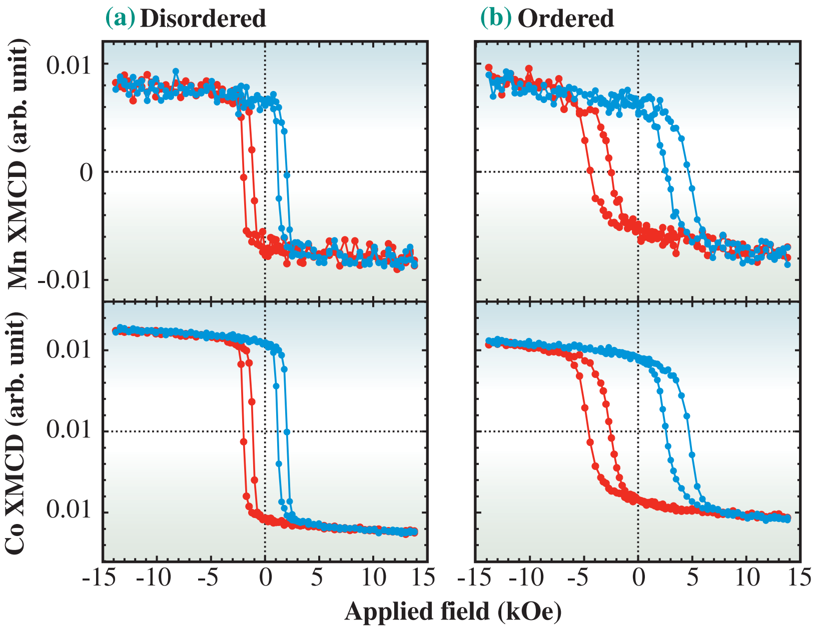

Fig. 3. Mn and Co ESMH loops of **(a)** disordered and **(b)** ordered Mn-Ir/Co-Fe bilayers. The hysteresis loops were obtained in the exchange bias direction either parallel (red) or antiparallel (blue) to the incident X-ray wave vector.

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