Atomic Layer Resolved Measurements of Fe/MgO with Perpendicular Magnetic Anisotropy by Synchrotron Mössbauer Spectroscopy

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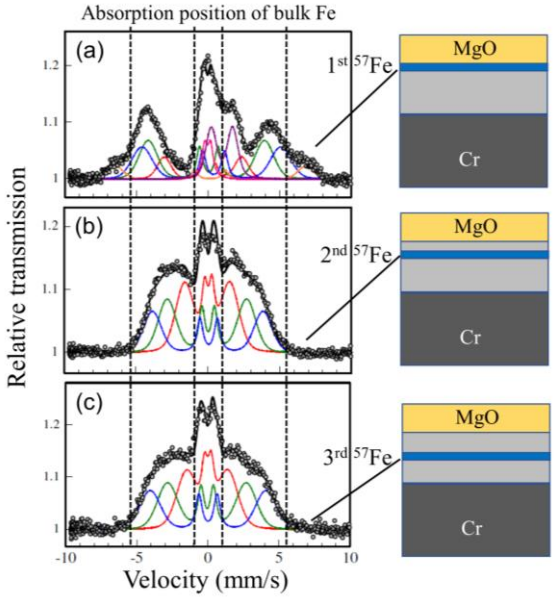
The discovery of perpendicular magnetic anisotropy (PMA) at the interface of ferromagnetic ultra-thin films and MgO [1] has stimulated a vast interest in developing high-density magnetic random-access memory. Whilst attempts have been made to understand the origin of interfacial PMA, difficulties in distinguishing contributions from the interface and bulk layers has hampered the understanding of such phenomena. In this study, we have investigated for the first time the electronic and magnetic properties of PMA in Fe ultra-thin films on MgO in an atomic-layer resolved fashion by employing depth-resolved synchrotron Mössbauer spectroscopy [2] to get an insight into the physical mechanism of interfacial PMA.

Samples investigated in this study had a stacking structure of Cr(20nm)/Fe(0.58nm~5ML)/MgO(2nm), which were deposited on MgO(001) substrates by molecular beam epitaxy (MBE). These Fe ultra-thin films consisting of 0.48 nm(~0.43 ML)-thick ^{56}Fe and 0.1 nm(~0.7 ML)-thick ^{57}Fe were grown by evaporating two separate sources of ^{56}Fe(99.94%) and ^{57}Fe(95.93%). The ^{57}Fe probing layer was embedded at different depths from the Fe/MgO interface, within the 1st, 2nd, and 3rd atomic layer respectively. Film preparation conditions were optimized to achieve PMA, which was confirmed using a SQUID magnetometer. Mössbauer experiments were performed at the BL11XU section of SPring-8 using π-polarized ^{57}Fe Mössbauer γ-rays (14.4 keV). Figures (a), (b), and (c) show the Mössbauer spectra of the 1st, 2nd, and 3rd AL samples, respectively. Peak positions of bulk Fe are also shown by the dash lines. Three prominent magnetic components (bule, green, red) with hyperfine fields smaller than bulk Fe are observed in each sample. The intensities of these 3 components were found to change with the embedded depth of the ^{57}Fe probing layer. Additionally, a minor magnetic component (orange) with a hyperfine field larger than that of bulk Fe and the non-magnetic component (purple) was found in the 1st AL sample. The details of depth-resolved properties at the Fe/MgO interface and its relation to interfacial PMA will be discussed with the aid of theoretical calculations.



[1] S. Ikeda *et al.*, Nat. Mater. **9,** 721–724 (2010); [2] T. Mitsui *et al.*, Phys. Rev. Lett. **125**, 236806 (2020)