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Perpendicular magnetic anisotropy at Fe/Au(111) interface studied by synchrotron-radiation-based spectroscopies

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When ferromagnetic transition metals (TMs) are deposited on surfaces with large spin-orbit coupling or topologically insulating properties, novel properties such as perpendicular magnetic anisotropy (PMA) emerge at the interfaces, which are derived from the Rashba-type spin-orbit coupling effects through interfacial symmetry breaking. The interfacial magnetic proximity can be a novel technology for developing and enhancing spin-orbit-related functionalities. Therefore, hybrid structures combining different spin-orbit coupling strengths yield a magnetic cooperative effect as enhancements of the interfacial orbital magnetic moments, resulting in a large PMA. The spin-orbit coupling between the ferromagnetic 3d TMs Fe or Co and the more-than-half $4d$-$5d$ heavy TM elements of non-ferromagnetic materials such as Pd and Pt have been utilized for PMA through the proximity at the interfaces [1]. In the case of Au, the $5d$ states are mostly occupied. The relationship between the Rashba-type spin-orbit interaction in Au(111), mainly originating from the $6p$ Shockley surface states [2], and PMA in $3d$ TMs has not been explicitly clarified. Here, we address the Fe/Au(111) interfaces using a magnetic Fe layer and non-magnetic Au because the proximity between a large Rashba-type spin-orbit coupling constant on the Au surface and the spins in the Fe layer results in interfacial PMA.

X-ray magnetic circular dichroism (XMCD) measurements were conducted using BL-7A at the Photon Factory. A magnetic field of ± 1.2 T was applied along the incident polarized beam by switching the magnetic field directions. The total electron yield mode was adopted. The X-ray absorption spectroscopy (XAS) and XMCD spectra were obtained after normalization with respect to the incident photon intensities. The geometry between sample surface normal and incident beam directions are changed by changing the sample position from normal incidence to oblique incidence of 60°. All XAS and XMCD measurements were performed at 80 K using liquid N_2.

Figure 1 shows the XAS and XMCD of Fe L-edges with angular dependence taken at 80 K. Clear metallic line shapes are detected even at a 3-ML thickness. In the normal incident case, the spin ($m_{\rm s}^{\perp}$) and orbital magnetic moments ($m_{\rm orb}^{\perp}$) along the normal direction in the relation $m_{\rm orb}^{\theta} = m_{\rm orb}^{\perp} + (m_{\rm orb}^{\parallel} - m_{\rm orb}^{\perp})\sin^2\theta$ [3]. Because of the d orbital states, the angular dependence is expressed as a function of $\sin^2\theta$. The oblique incident geometry case includes half of the in-plane component for $m_{\rm orb}^{\parallel}$. By adopting the XMCD sum rules, $m_{\rm orb}^{\perp}$ and $m_{\rm orb}^{\parallel}$ are determined to be 0.10 and 0.09 $\mu_{\rm B}$, respectively. The value of $m_{\rm orb}^{\perp}$ is enhanced through the interfacial proximity with Au. The value of m_s is 1.71 $\mu_{\rm B}$, and a negligible value of the magnetic dipole moment $m_{\rm T}$ is deduced using the Fe $3d$ hole number of 6.9, estimated from the density functional theory (DFT) calculation. Angle-resolved photoemission spectroscopy (ARPES) images are also shown in Fig. 1. Clear Rashba-type surface states appear in Au(111) surface. By deposition the 3-ML-thick Fe, broad band dispersions originate from Fe $3d$ states appear which is consistent with the DFT calculations.

The enhancement of $m_{\rm orb}^{\perp}$ at the interface is also characterized by the synchrotron-radiation based Mossbauer spectroscopy. The details of ARPES are also reported in ref. [4].

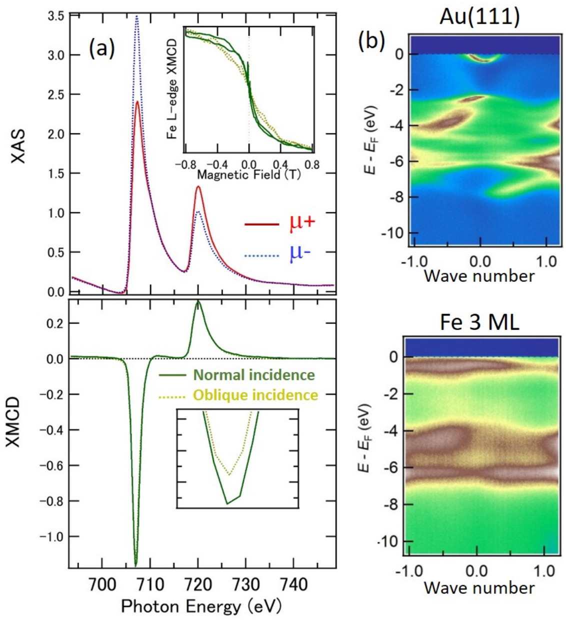

Fig. 1, XAS and XMCD of Fe L-edges in 3-ML-thick Fe on Au(111). (a) XAS in normal incidence and XMCD in both normal and oblique incidence cases. Insets show the M-H curves at Fe L_3 edge and expanded view around L_3-edge. (b) ARPES of Au(111) surface and 3-ML-thick Fe deposited surface.

[1]J. Okabayashi *et al.*, Sci. Rep. **8**, 8303 (2018).
[2]S. LaShell *et al*,, Phys. Rev. Lett. **77**, 3419 (1996).
[3]P. Ohresser *et al*,, Phys. Rev. B **64**, 104429 (2001).
[4]J. Okabayashi *et al.*, Phys. Rev. B **103**, 104435 (2021).
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