スピントロニクス材料の内殻吸収磁気円二色性分光

X-ray magnetic circular dichroism spectroscopy study of spintronic materials

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（概要）

We have found a perpendicular magnetic anisotropy of iron adatoms on a surface of the prototypical three-dimensional topological insulator Bi_2Se_3 by using X-ray magnetic circular dichroism measurements. The orbital magnetic moment of Fe is strongly enhanced at lower coverage, where angle-resolved photoemission spectroscopy shows co-existence of non-trivial topological states at the surface.

キーワード：

three-dimensional topological insulator, Dirac fermionsm, surface magnetism,

twin-helical undulator, x-ray magnetic circular dichroism (XMCD)

１．目的

Topological insulators (TIs) [1,2,3], a new class of quantum materials, have stimulated extensive theoretical and experimental research owing to their unique spin-polarized topological edge states. Such non-trivial topological surface states have been observed for several materials. Because of time-reversal symmetry (TRS), edge-state electrons are robust against non-magnetic perturbations, which is a key requirement for revolutionizing modern electronic devices. There is wide interest in magnetic doping of TIs owing to the possible breaking of TRS, since it is predicted to create several exotic topological phenomena, such as half-quantized Hall conductance, giant magneto-optical effects [4] and the quantized anomalous Hall effect [5]. In this research we studied the magnetic and electronic structures of iron (Fe) adatoms and ultra-thin films on the topological insulator Bi_2Se_3 surface.

２．方法

We conducted our experiments at the state-of-the-art twin helical undulator beamline BL23SU of SPring-8. We acquired X-ray absorption spectroscopy (XAS) spectra with a total electron yield method and applied an external magnetic field with a superconducting magnet. The Bi_2Se_3 single crystals are cleaved in-situ in ultrahigh vacuum, and the Fe deposition is conducted at room temperature. During the measurement of XAS and XMCD, the sample is cooled by helium cryostat.

３．研究成果

Figure 1(a) shows the XAS spectra at the Fe L_{23} edges for 0.013 monolayer (ML) Fe deposited on the surface of Bi_2Se_3, where the spectrum of pristine Bi_2Se_3 in the same energy range is also shown to estimate the spectral background. The blue (red) line represents the XAS spectra when the applied magnetic field is parallel (anti-parallel) to the circularly polarized X-ray vector, where there is a clear difference between the different magnetization directions, indicating the presence of magnetic moments of Fe atoms at the Bi_2Se_3 surface. Note that neither satellite nor shoulder structure on the higher energy side has been observed near the Fe L_3 (707 eV) or L_2 (720 eV) absorption peaks, confirming that the measured samples are free from oxidization, which is further supported by the absence of O 1s edges (not shown) in this experiment. The observed line shapes of XAS spectra at the Fe L_{23} edges are quite close to those of bulk bcc iron, suggesting a weak hybridization between the deposited Fe and substrate. By removing the spectral background deduced from the relevant spectrum of pristine Bi_2Se_3 in the same energy range, we have extracted the

XAS component of Fe, as shown in the normalized spectra in the inset of Fig. 1(a), where the XAS spectra show a narrowing of the L_3 and L_2 peaks with decreasing Fe coverage indicating a localization of 3d electrons at the Fe site.

Figure 1(b) shows the XMCD spectra measured for three Fe coverages, whose total XAS spectra are shown in the inset of Fig. 1(a), under a magnetic field of 8 T at 5 K. At first glance, all the spectra are almost identical to each other exhibiting two peaks at the Fe L_3 and L_2 edges with opposite signs. However, when these spectra are normalized by the intensity at the Fe L_2 edges, the XMCD amplitude at the L_3 edge significantly increases with decreasing Fe coverage.

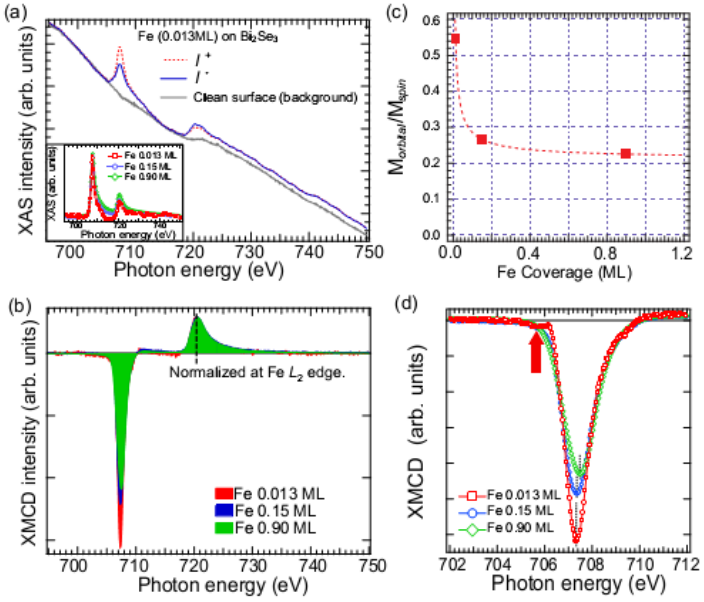

FIG. 1: (a) XAS spectra of 0.013 ML Fe/Bi_2Se_3 at Fe L_{23} edge acquired under a magnetic field of 8 T applied perpendicular to sample surface (temperature 5 K). Blue and red lines represent the spectra taken with the circular x-ray vector parallel and anti-parallel to the magnetic field. Inset shows normalized XAS spectra for different coverages of Fe on Bi_2Se_3 (background contributed by pristine Bi_2Se_3 is removed). (b) XMCD spectra at Fe L_{23} edge (normalized by the intensity of L_2 edges). (c) Ratio between orbital magnetic moment and spin magnetic moment as a function of Fe coverage deduced from sum rules. (d) Magnified XMCD spectra at Fe L_3 edge with different Fe coverages.

４．結論・考察

By applying the magneto-optical sum rules to the experimentally obtained XMCD spectra, we can deduce the orbital and spin magnetic moments of the Fe 3d states. We find that the Fe 3d orbital magnetic moment (M_{orb}) is significantly enhanced [Fig.1(c)], approximately four to seven times larger than that for bulk bcc Fe [27].

We further investigated the magnetic anisotropy of Fe on Bi2Se3. We found that the magnetization perpendicular to the surface is 25% to 30% larger than that measured for 45° tilted samples, indicating a perpendicular magnetic anisotropy.

In conclusion, we observed a giant orbital magnetic moment of Fe adatoms on the topological surface of Bi_2Se_3 through the combined methods of XAS and XMCD. And we have further found that the out-of-plane magnetic anisotropy is preferred for this system. These results provide a way to control the magnetism and quantum transport properties of magnetically doped TIs by fine-tuning the intensity of magnetic impurities on the topological surface.

５．引用(参照)文献等

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