強磁性ペロブスカイト酸化物ヘテロ界面における特異な磁気異方性
Peculiar magnetic anisotropy at ferromagnetic perovskite heterointerfaces

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Control of magnetic anisotropy (MA) is crucial for low-power magnetization reversal in magnetic thin films, which is important for next generation spintronics device applications. From the perspectives of energy efficiency and scalability, gate-voltage control of the MA via modulation of the carrier density and thus, the Fermi level, is highly desirable. For efficient control of MA and for developing materials that are suitable for the MA control, it is necessary to understand the MA of magnetic thin films over a wide energy range (or the change in the Fermi level); however, there are few studies from this point of view. In ferromagnetic (FM) materials, the MA energy is related to the magnetization-direction dependence of the density of states (DOS) via the spin orbit interaction. Tunneling anisotropic magnetoresistance (TAMR) is a phenomenon observed in tunnel diodes composed of ferromagnetic (FM) layer/ tunnel barrier/ nonmagnetic (NM) electrode. TAMR is defined as the change of the tunnel resistance or conductance dI/dV, which is proportional to the DOS of the electrodes, when rotating the magnetization of the FM layer. Thus, TAMR is useful to understand the magnetic-field direction dependence of the DOS. By measuring TAMR at various bias voltages, one can obtain a high-resolution carrier-energy-resolved map of MA of the FM layer. Recently, using TAMR, we have found that the symmetry of the MA is controlled by the quantum size effect in a ferromagnetic semiconductor quantum well [1], which is very promising for MA control using quantization of carriers in ferromagnetic materials.

An equally important aspect of TAMR is that it reflects the DOS at the tunneling interface of the FM layer, and thus it provides a sensitive probe of the interfacial magnetic properties. Thin film interfaces present both problems and opportunities for exploring new functional devices. As a good example, the “dead layer” at the interface of the perovskite oxide $La_{1-x}Sr_xMnO_3$ (LSMO, the Sr content x = 0.3–0.4), which is one of the most promising oxide materials due to its intriguing magnetic and electrical properties such as the colossal magnetoresistance, half-metallic band structure, and high Curie temperature (~370 K), is a serious problem for its device applications. For the formation of the dead layer, various possible origins have been proposed, such as intermixing of atoms, oxygen vacancies, lattice distortion, and MnO_6 oxygen octahedral rotations, which induce orbital, charge, and spin reconstruction at the interfaces of LSMO. These studies on dead layers, however, suggest new ways for controlling the interfacial properties at an atomic level, which are not available in the bulk. To this end, the characterization of the interfacial magnetic properties is highly demanded, but it is difficult with conventional magnetometry because the interfacial properties are usually concealed by the dominant signals from the bulk.

In our study, using TAMR measurements for a LSMO/$LaAlO_3$(LAO)/Nb:$SrTiO_3$ heterostructure grown by molecular beam epitaxy, we have successfully obtained a high-resolution map of the MA spectrum of LSMO for the first time [2]. In addition to the biaxial MA along <110> and the uniaxial MA along [100], which originate from bulk LSMO, we found a peculiar uniaxial MA along the [110], which is attributed to the LSMO/LAO interface. The symmetry axis of this interface MA rotates by 90° at an energy of 0.2 eV below E_F of LSMO, which is attributed to the transition from the e_g band (>–0.2 eV) to the t_{2g} band (<–0.2 eV). These findings hint an efficient way to control the magnetization at the LSMO thin film interfaces, as well as confirm the rich of hidden properties at thin film interfaces that can be revealed only by interface-sensitive probes. More recently, we have found similar change of the symmetry of MA using TAMR by applying a bias voltage to an LSMO-based magnetic tunnel junction (MTJ), suggesting that the TAMR measurement is a simple but highly sensitive method for characterizing the interfacial magnetic properties of MTJs, which is important for developing more energy-efficient spintronics devices [3].

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References

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