Anisotropic magnetization-direction dependence of the band structure in the perovskite oxide $La_{0.6}Sr_{0.4}MnO_3$

°(B)**Noboru Okamoto**[1], **Le Duc Anh**[1,2], **Kento Takeshima**[1], **Tatsuya Matou**[1], **Masaaki Tanaka**[1,3], **and Shinobu Ohya**[1,2,3]
[1]*Department of Electrical Engineering and Information Systems, The University of Tokyo*
[2]*Institute of Engineering Innovation, Graduate School of Engineering, The University of Tokyo*
[3]*Center for Spintronics Research Network, Graduate School of Engineering, The University of Tokyo*
E-mail: noboru_okamoto@cryst.t.u-tokyo.ac.jp

For efficient gate-electric-field control of the magnetization direction of ferromagnetic (FM) thin films, it is required to understand the carrier-energy dependence of the magnetic anisotropy (MA). Tunneling anisotropic magnetoresistance (TAMR), which reflects the density of states (DOS) of FM thin films, is specifically suitable for this purpose. Because the magnetization-direction dependence of DOS is directly related to MA in FM materials, by measuring TAMR for various magnetic-field directions at various bias voltages, one can obtain the energy-resolved map of the MA of FM thin films.

In this study, we investigate the energy-dependence of the MA of the perovskite oxide $La_{0.6}Sr_{0.4}MnO_3$ (LSMO), which is a promising spintronic material due to its half-metallic band structure [1], high Curie temperature (~ 370 K), and colossal magnetoresistance [2]. The used tunnel device structure consists of LSMO (40 unit cell (uc))/ $LaAlO_3$ (LAO, 4 uc) grown on a Nb-doped (0.5 wt%) $SrTiO_3$(001) (Nb:STO) substrate by molecular beam epitaxy (Fig. 1(a)). For our tunneling transport measurements, a 50-nm thick Au film was deposited on top of the sample, and mesa diodes with the size of 600×700 μm^2 were formed. The bias polarity was defined so that electrons flow from Nb:STO to LSMO in positive V. We measured the change in the tunneling conductance $\Delta dI/dV$ (%) with V ranging from –0.5 to +0.5 V while applying a magnetic field (=1 T) at an angle θ from the [100] axis in the plane (Fig. 1(b)). Here, the Fermi level E_F corresponds to V=0. By analyzing the data in Fig. 1(b), we find that there are a two-fold symmetry component $C_{2[010]}$ along the [010] axis, a weak four-fold symmetry component $C_{4<110>}$ along the <110> axes, and a two-fold symmetry component $C_{2[110]}$ along the [110] axis (Fig. 1(c)). $C_{2[110]}$ has not been reported before in LSMO, which indicates that it is a specific component to the interface. With decreasing V, the two-fold magnetic easy axis along the [110] direction is rotated by 90 degrees at $V\approx$ –0.2 V. We will discuss the origins of this complex MA and its relation to the band structure of LSMO.

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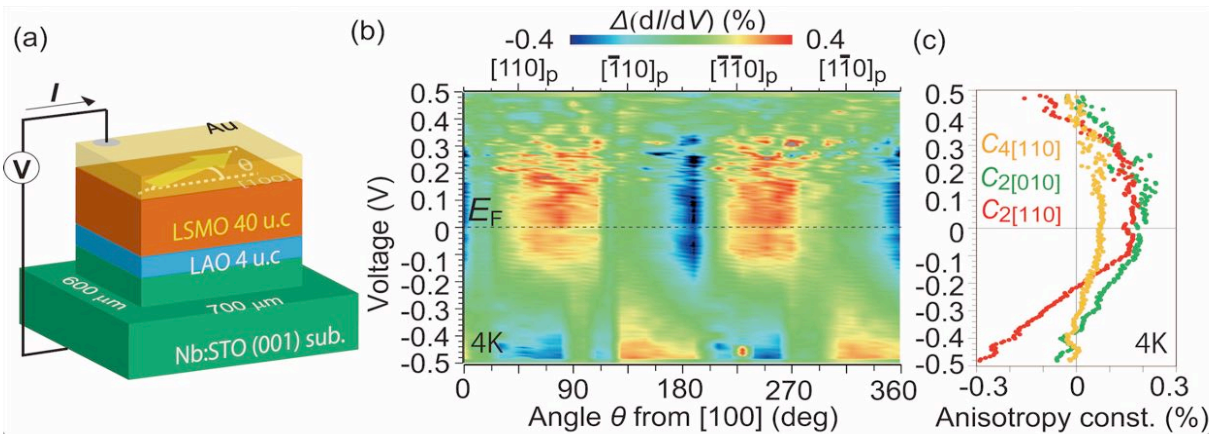

Fig. 1. (a) Device structure used for our measurements. The direction of the magnetic field with respect to the in-plane [100] axis is defined as θ. (b) Change in dI/dV from averaged dI/dV over θ when the magnetic field is 1 T, measured at 4 K. (c) Three MA components deduced from the data in Fig 1(b).