Crystallinity dependence of spin-orbit torque in electrically-conductive RuO_2

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Spin-orbit (SO) torque generated by the spin Hall effect (SHE) or Rashba-Edelstein effect (REE) is expected to effectively perform magnetization switching in an adjacent ferromagnet [1]. To increase conversion efficiency or functionality, recently there has been interest in synthesizing SO materials such as oxides. CuO_X was successfully observed to have finite spin torque efficiency through oxidation from pure Cu, which has negligible SO interaction interestingly [2]. However, the mechanism for this generation in oxides is still controversial. Basically, a finite SO interaction could generate the SO torque via the SHE or the REE, and gives different types of spin relaxation in different crystallinities in the materials [3].

To unveil the systematic mechanism of the SO torque generation in SO oxides, we have studied polycrystalline and epitaxial electrically-conductive RuO_2 based on the above background by means of spin-torque ferromagnetic resonance in this study. First of all, we deposited two kinds of 10 nm-thick RuO_2 film onto Al_2O_3(11-02) and Si/SiO_2 substrates by using reactive magnetron RF sputtering with a pure Ru target with 0.06 Pa-oxygen partial pressure. The substrate temperature was increased to 400 ℃ during sputtering for epitaxial RuO_2. After the deposition, we checked the crystallinity as shown in Figs. (a), (b), and (c) by means of reflection high-energy electron diffraction (RHEED) and X-ray diffraction (XRD), and deposited Co(5nm)/AlO_X(2nm) in-situ onto the RuO_2 layer. Finally, we prepared devices for ST-FMR measurement by photo-lithography and Ar-ion milling.

In the measurement, we surprisingly found an enhancement of the spin-torque efficiency ξ_{ST} in the epitaxial RuO_2 ($\xi_{ST} = 14.3 \pm 2.0$ %) compared with the polycrystalline film ($\xi_{ST} = 10.2 \pm 1.7$ %). We discuss the detailed mechanism for the enhancement in this meeting.

[1] L. Liu *et al.*, Science **336** (2012) 555. [2] H. An *et al.*, Nat Commun. **7** (2016) 13069.

[3] J. Ryu *et al.*, Phys. Rev. Lett **116** (2016) 256802.

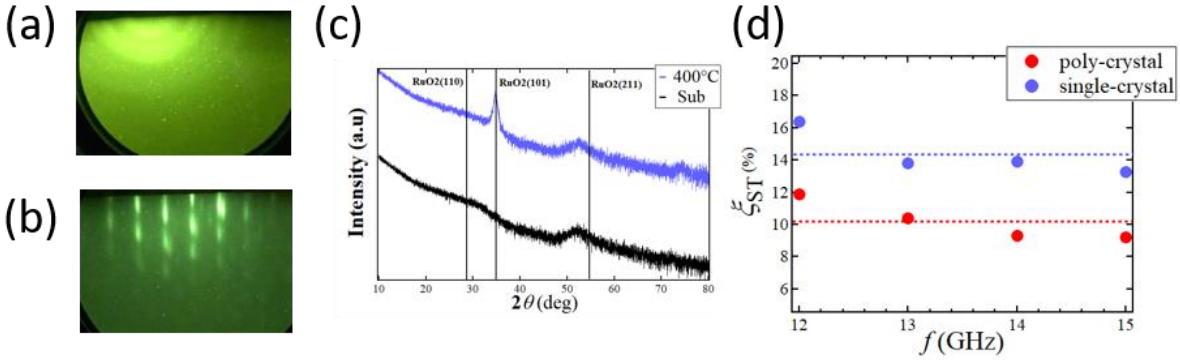

Fig. (a) Ring pattern for polycrystalline RuO_2, and (b) Streak pattern for epitaxial RuO_2, respectively.

(c) XRD peaks of epitaxial RuO_2 deposited at 400 ℃, and Al_2O_3(11-02) substrate as a reference.

(d) Spin torque efficiencies of polycrystalline and epitaxial RuO_2.