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Fabrication and Magnetic property of Co/Pt/*r*-Cr_2O_3 Multilayer

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Abstract: We report the crystal structures and magnetic properties of *r*-plane oriented $[Pt/Co]_3/Pt/Cr_2O_3$ multilayers fabricated by DC-RF magnetron sputtering method. From the 2θ-θ profile, the film peaks appeared at a lower angle than that of the substrate peaks in 2θ. The lattice spacing of *r*-plane was 0.363 nm. This value is in agreement with that of the bulk, indicating that the film was grown without stress from the substrate. From the reciprocal space mapping, both the substrate and film peaks were visible for (2 -2 0 10) plane, while no peaks were observed for the (2 -2 0 8) plane. The magnetic property of the multilayer was investigated from magnetic field (*H*) dependences of the in-plane and out-of-plane magnetizations (*M*). The magnetic moments of in-plane and out-of-plane were 0.30 μ_B and 1.53 μ_B respectively per a cobalt ion at 5 K. These values are smaller than that of bulk, suggesting that the Co film may be thinner than we expected or may have island structure.

1. Introduction

In order to realize the magnetization swtching by an application of an electric field, we fabricate the multilayer of ferromagnetic (FM) metal and antiferromagnetic (AFM) showing magnetoelectric (ME) effect. FM metal and Cr_2O_3 multilayers have drawn much attention recently because the magnetic moment in FM metal can be reversed with the applied electrical field [1][2]. The origin of the reversal is the exchange bias field (H_{EB}) applied to the FM metal because of the magnetic coupling between spins in FM metal and Cr spins at the interface.

As the magnitude of H_{EB} is proportional to the magnitude of spins at the top most surface of AFM (S_{AF}), large S_{AF} is required for large H_{EB}[3]. However, the net magnetic moment is zero on the top surface of the pseudo-perovskite structure of AFM materials. On the other hand, all Cr spins on the *r*-surface of Cr_2O_3 single crystal definitely show the two-dimensional (2D) FM ordering even though the surface shows step-terrace structure as shown in Fig. 1. Such the FM structure at the surface has the potential to obtain a large value of the H_{EB}[4]. Therefore we fabricate FM metal and *r*-oriented Cr_2O_3 multilayers.

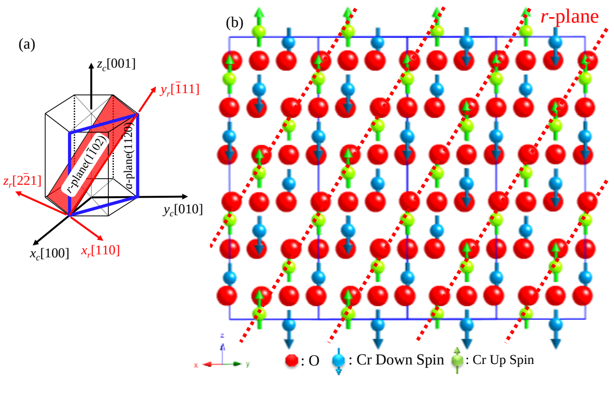

Fig.1. Crystal structure of Cr_2O_3.
(a) Sketches of crystal planes. *r*- and *a*-planes are shown as a red and blue planes respectively. (b) View from [1 1 -2 0] direction (vertical to the *a*-plane). *r*-plane is indicated by red dashed line. Large and small circles indicate the O and Cr ions. The arrows indicate the direction of Cr spins. *r*-oriented Cr_2O_3 surface shows 2D FM order of Cr spins.

2. Experimental

The $[Pt/Co]_3/Pt/r$-Cr_2O_3 multilayers were grown on Al_2O_3 (1 -1 0 2) substrate. The substrate was ultrasonically cleaned in acetone and ethanol. The cleaned Al_2O_3(1 -1 0 2) substrate were annealed at 1050ºC for 12h in air[5]. The Cr_2O_3 thin films were grown by the off-axis DC-RF magnetron sputtering method using a 2-inch Cr metal target with an RF power of 80W and a DC current of 0.04A. The substrate temperature was 580 ºC. O_2 and Ar gases were flown with the rate of 8 and 2 ccm respectively at 0.20 Pa during the sputtering. The deposition time was 240 min, estimating the film thickness at 200 nm. After the deposition, the film was cooled down to the room temperature in O_2 at 0.1 MPa. FM metal and Pt were deposited by on-axis RF magnetron sputtering method using 2-inch Co and Pt metal target with an RF power of 80W. The deposition times were 29 sec and 47sec for Pt and Co, estimating the average thickness at 0.5 and 1.0 nm, respectively. The surface morphology of the films was evaluated by scanning probe microscopy (SPM; SII Nanotechnology NanoNavi Station, dynamic force mode). The crystal structure of the Cr_2O_3 thin films was evaluated by X-ray diffraction (XRD; Bruker D8 Discover) analysis, and 2θ-θ scan was used to analyze the out-of-plane structure. Detailed analyses were carried out by reciprocal space mapping (RSM). The magnetic measurements were performed with a superconducting quantum interference device (SQUID; QUANTUM DESING, VSM Mode).

3. Results and Discussion

Fig. 2 shows the 2θ-θ XRD spectrum of the *r*-oriented Cr_2O_3 film grown on Al_2O_3 substrate. The film peaks appeared at a lower angle than that of the substrate peaks in 2θ. Pt and Co film peaks appeared between (1 -1 0 2) and (2 -2 0 4) of Cr_2O_3 peaks. The lattice spacing of *r*-plane was 0.363 nm. This values is in agreement with lattice spacing of 0.364 nm for the bulk, indicating that the film was grown without stress from the substrate.

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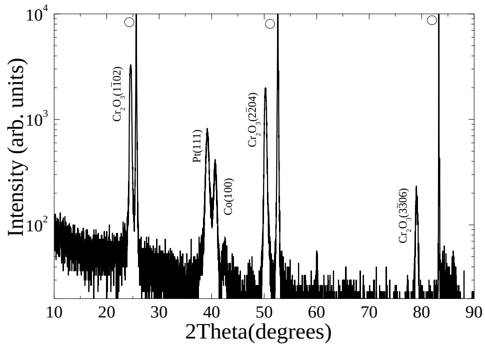

Fig.2. 2θ - θ XRD patterns.
The film peaks appeared at a lower angle than that of the substrate peaks for 2θ. Pt and Co film peaks appeared between (1 -1 0 2) and (2 -2 0 4) of Cr_2O_3 peaks.

In order to investigate the presence of the twin grains, RSMs were obtained. Fig.3. show the RSMs around the C_1(2 -2 0 10) and C'_1(2 -2 0 8) planes. Both the substrate and film peaks were visible for C_1(2 -2 0 10) plane while no peaks were observed for the C'_1 (2 -2 0 8) plane. Fig.4. show the schematic hexagonal structures. D_1(2 0 -2 8) and C_1(2 -2 0 10) peaks coexist in the single grain because of the crystal structure, while C'_1(2 -2 0 8) and C_1 (2 -2 0 10) peaks coexist only in the twin grains as the C'_1(2 -2 0 8) plane corresponds to the 60º rotated plane of D_1(2 0 -2 8) plane on the *c*-axis. Therefore the RSMs in Fig. 3 indicates the Cr_2O_3 film consists of single grain.

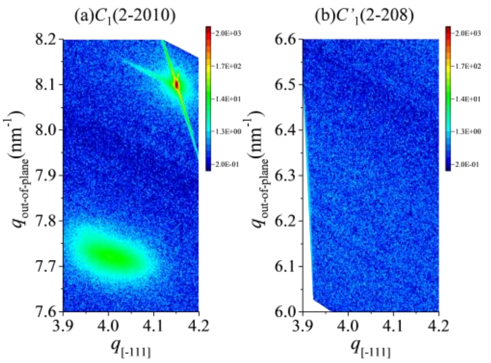

Fig.3. RSM around Al_2O_3(2 -2 0 10), Al_2O_3(2 -2 0 8).
Both the substrate and film peaks were visible for C_1(2 -2 0 10) while no peaks were observed for the C'_1(2 -2 0 8) planes.

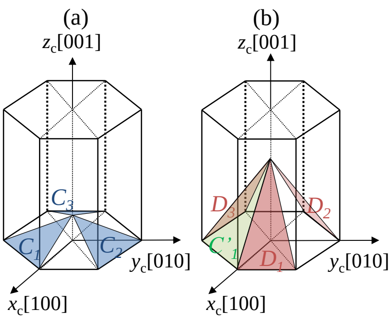

Fig.4. Schematic hexagonal structure
(a)*C*{2 -2 0 10} groups of planes satisfy Bragg's law. *C* set of C_1(2 -2 0 10), C_2(0 2 -2 10) and C_3(-2 0 2 10). (b)*D*{2 0 -2 8} groups of planes satisfy Brass's law. *D* set of D_1(2 0 -2 8), D_2(-2 2 0 8) and D_3(0 -2 2 8). C'_1(2 -2 0 8) plane corresponds to the 60º rotated plane of D_1(2 0 -2 8) plane on the *c*-axis.

Fig.5. shows the in-plane and out-of-plane magnetization as a function of the magnetic field at 5 K. Hysteresis loops were observed below 200 K. The magnetic moments of in-plane and out-of-plane were 0.30μ_B and 1.53μ_B respectively per a cobalt ion at 5K. These values are smaller than that of bulk, suggesting that the Co film may be thinner than we expected or may have island structure. Optimization is required on the deposition conditions for the Pt and Co layers.

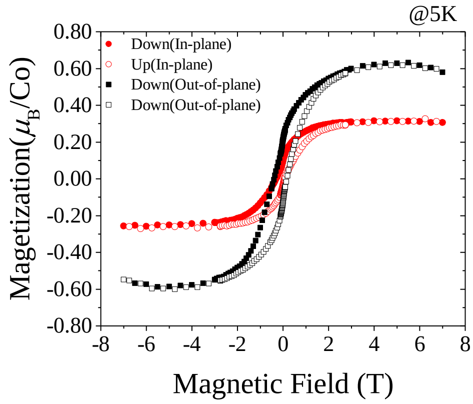

Fig.5. in-plane and out-of-plane magnetization as a function of the magnetic field at 5K.
The magnetic moments of in-plane and out-of-plane were 0.30μ_B and 1.53μ_B respectively per a cobalt ion. These values are smaller than that of bulk.

4. Summary

The $[Pt/Co]_3/Pt/r\text{-}Cr_2O_3$ multilayers were grown on Al_2O_3(1 -1 0 2) substrate using DC-RF magnetron sputtering method. The 2θ-θ profile and RSMs indicate *r*-oriented Cr_2O_3 films were grown in single grain. From the in-plane and out-of-plane magnetic property, the magnetic moments of in-plane and out-of-plane were 0.30μ_B and 1.53μ_B respectively per a cobalt ion at 5K. These values are smaller than that of bulk, suggesting that the Co film may be thinner than we expected or may have island structure. Detailed magnetic property will be discussed on improved films.

5. Reference

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