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Fabrication of Cr_2O_3/Fe_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ Films on Sapphire Substrate by Sputtering Method

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Abstract: We report the Cr_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ films grown on *r*-plane sapphire substrate using DC-RF magnetron sputtering method. These films are evaluated by scanning probe microscopy and x-ray diffraction analysis. From surface image, the grains of Cr_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ film are coalesced, otherwise trenches appeared between grains in Cr_2O_3 film. The step-terrace structure is obtained in both films as well. The step height is consistent with one unit step normal to the *r*-plane. The lattice spacing (2-204) of Cr_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ films are 0.362 and 0.363 nm.

1. Introduction

In order to realize the magnetization reversal by an application of an electric field, we fabricate the multilayer of ferromagnetic (FM) metal and antiferromagnetic (AFM) with magnetoelectric (ME) effect. FM metal and Cr_2O_3 multilayers have been paid much attention recently because the magnetic moment in FM metal could be reversed with the applied electrical field[1, 2].

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 structures as shown in Fig. 1(b), see dashed lines. Such the FM / Cr_2O_3 multilayer structure has the potential to obtain a large value of an exchange bias field (H_{EB}) in a magnetization curve of FM metal[4].

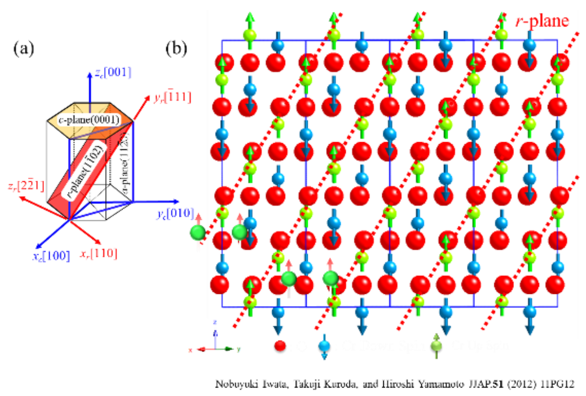

Fig. 1 Crystal structure of Cr_2O_3:(a) Schematic view of crystal planes. The *r*-and *a*-planes are shown as a red and blue planes respectively. (b) Two dimensional (2D) crystal structure along the [11-20] direction (normal to the *a*-plane). The *r*-plane is indicated by red dashed line. Large and small circles indicate the O and Cr ions. The arrows indicate the direction of Cr spins. The *r*-oriented Cr_2O_3surface shows 2D FM order of Cr spins.

However, *r*-plane oriented Cr_2O_3 film has deep trenches between grains due to the large lattice mismatch, approximately 4%, and the lowest surface energy. By the way it is reported that Fe_2O_3 film epitaxially grows by step-flow manner on *c*-plane of sapphire substrate with clear step-terraces structure even though the lattice mismatch is larger than that of Cr_2O_3[5]. It is because of lack of twin grain growth in Fe_2O_3. We expect that such the growth fashion of Fe_2O_3 could help the growth of Cr_2O_3 to reduce the trenches. Therefore we fabricated Cr_2O_3/Fe_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ film on *r*-plane sapphire substrate in order to eliminate the trenches.

2. Experimental

The *r*-plane sapphire substrate was ultrasonically cleaned in acetone and ethanol. The cleaned substrate was annealed at 1050ºC for 12h in air. The $(Cr_{1-x}Fe_x)_2O_3$ films were deposited by the off-axis DC-RF magnetron sputtering method. The 2-inch Cr and Fe metal targets were set at off-axis ant on-axis respectively against the substrate surface. The RF power of 80W was introduced, and the DC current 0.04A was additionally input to the Cr metal target. The substrate temperature was 580ºC. The introduced O_2/Ar volumes in ccm unit during sputtering were 2/8, and the sputtering pressures were 0.3Pa. The deposition time was 120 min, the film thickness of which was approximately 200 nm. Oxygen was introduced up to 0.1 MPa after the deposition, and temperature was cool down to room temperature. The surface morphology of the film was evaluated by scanning probe microscopy. The crystal structure of the films was evaluated by x-ray diffraction(XRD : Bruker D8 Discover)

3. Results and Discussion

Figure 2 shows the surface images of (a) Cr_2O_3 and (b) $(Cr_{1-x}Fe_x)_2O_3$ film. The grains were coalesced, otherwise trenches appeared between grains in Cr_2O_3 film. The grain size was larger and depth of the trenches was deeper in the $(Cr_{1-x}Fe_x)_2O_3$ film, comparing the results of Cr_2O_3 film. It is expected that the optimized growth temperature of Fe_2O_3 might be higher than that of Cr_2O_3. However, the step height was approximately 0.35 nm, the value of which is consistence with a unit step, from the results of line profile in both films. The higher value of unit step is probably due to a coalescence.

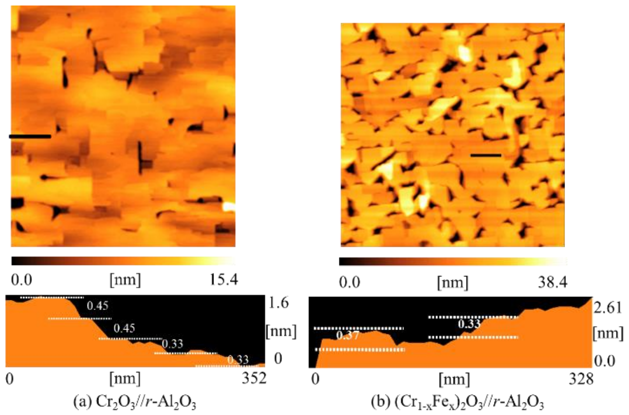

Fig. 2 Surface images and line profiles of (a) Cr_2O_3 and (b) $(Cr_{1-x}Fe_x)_2O_3$ film on r-plane sapphire. Both of Cr_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ film were coalesced, and trenches appeared between grains.

Fig. 3 shows shows the 2θ-θ XRD patterns of the Cr_2O_3 film and $(Cr_{1-x}Fe_x)_2O_3$ films. Solid black line is of Cr_2O_3 film and dashed red line is of $(Cr_{1-x}Fe_x)_2O_3$ film. The lattice spacing (2-204) of Cr_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ films was 0.362 and 0.363 nm. Those values were almost same.

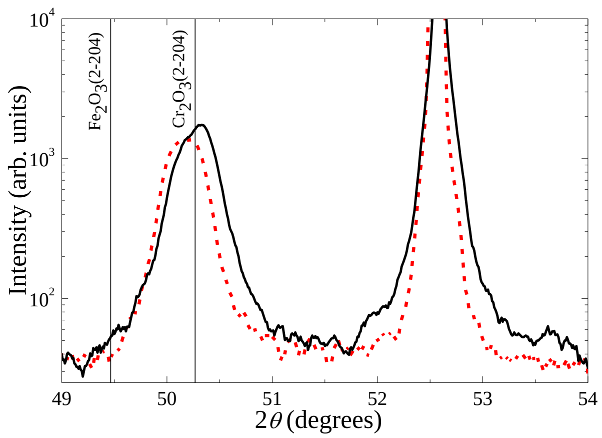

Fig. 3 2θ-θ XRD patterns of Cr_2O_3 film and $(Cr_{1-x}Fe_x)_2O_3$ films on r-Al_2O_3. : Solid and dashed lines are of Cr_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ film.

4. Summary

The Cr_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ films on r-plane sapphire substrate by DC-RF magnetron sputtering method. From the surface images of Cr_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ film, the grains were coalesced, otherwise trenches appeared between grains in Cr_2O_3 film. The grain size was larger and depth of the trenches was deeper in the $(Cr_{1-x}Fe_x)_2O_3$ film than those of Cr_2O_3 film. It seemed that the optimized growth temperature of Fe_2O_3 might be higher than that of Cr_2O_3. The step-terrace structure was obtained. The step height was approximately 0.35 nm, the value of which is consistence with a unit step, from the results of line profile of the surface in both films. The x-ray diffraction showed that the lattice spacing (2-204) of Cr_2O_3 and $(Cr_{1-x}Fe_x)_2O_3$ films was 0.362 and 0.363 nm, those value of which are same to that of bulk Cr_2O_3.

5. Reference

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