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Preparation of $CaFeO_3/LaFeO_3$ Heterointerface Grown on $SrTiO_3(001)$ and $LaAlO_3(001)$ Substrates by Pulsed Laser Deposition Method

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Abstract: The purpose of our study is to prepare $CaFeO_3$ (CFO)/$LaFeO_3$ (LFO) hetero-structure to control a ferromagnetism induced at the interface. The CFO/LFO hetero-interface was prepared on Nb doped STO(001) and LAO(001)(pseudo cubic notation substrates by pulsed laser deposition (PLD) method. In the case of CFO/LFO growth on LAO, $Ca_{1-x}Ce_xMnO_3$ (CCMO) is deposited as a bottom electrode. Detected all RHEED patterns after depositions exhibit two dimensional streak patterns. The RHEED oscillation at the specular spot is hard to detect as the CFO film is grown. As the LFO film is deposited, the RHEED oscillation is sometimes observed. It is speculated that the CFO surface quality strongly influence the following LFO growth.

1. Introduction

In-plane ferromagnetic phase at the hetero-interface of $LaAlO_3$ (LAO) / $SrTiO_3$ (STO) is reported at room temperature [1-2] . It is well known that two-dimensional (2D) electron gas at the LAO / STO(001) interface results in superconductivity and ferromagnetic ordering, even though the both materials are nonmagnetic insulator. Concerning about the ferromagnetic ordering, it is still controversial. Meanwhile, it is reasonable to consider that using iron oxides to be stable of ferromagnetic ordering at room temperature for realistic magnetic devices. Then, we have focused on the $CaFeO_3/LaFeO_3$ hetero-interface and we expect the charge transfer through the interface with an electric field applied and/or an accumulated static electric energy depending on the grown LFO thickness. We have used STO as the substrate because of its well-known etching method to appear step-terraces structure with its stable TiO_2 surface layer. While $LaAlO_3$ substrate has less lattice mismatch with $CaFeO_3$, it was expected more smooth growth of CFO layer.

The purpose of our study is to prepare $CaFeO_3$ (CFO) / $LaFeO_3$ (LFO) hetero-structure with a function of electric controllable ferromagnetic property appeared at the interface.

2. Experimental

The CFO/LFO hetero-interface was prepared on Nb doped STO(001) and LAO(001) (pseudo cubic notation) substrates by pulsed laser deposition (PLD) method. On the LAO substrate, $Ca_{0.96}Ce_{0.04}MnO_3$ (CCMO) was inserted as a bottom electrode. In the case of CFO/LFO grown on STO, the number of units of CFO was fixed at 3, while grown on LAO, 5 units of CFO was grown. The thickness of bottom electrode, CCMO was fixed at approximately 10 nm (33units). The LFO was deposited on CFO with approximately 3 to 15 units each to change a storage static electronic energy. The grown unit number was roughly determined from the observation of the reflection high energy electron diffraction (RHEED) intensity.

All the samples were characterized by RHEED, atomic force microscopy (AFM), X-ray diffraction (XRD, PANalytical X'Pert Powder, Philips, and Bruker D8 Discover).

3. Results and Discussion

Fig. 1 shows the RHEED intensity of (a) CFO and (b) LFO grown on Nb doped STO(001) substrates. In the CFO growth, RHEED intensity of the specular spot rapidly decreased and showed three broad peaks, then deposition was stopped. The grown unit number of CFO was approximately three. In the case of LFO growth, five units LFO grew with layer by layer manner from the result of clear RHEED oscillation. However, the LFO RHEED oscillation was not always able to be obtained so clearly. LFO growth and film quality are expected to be strongly influenced by the CFO film surface. Becase three units is critical number for CFO to transfer from growth of $CaFeO_3$ to that of $Ca_2Fe_2O_5$. The surface of 3 units CFO could be composed of mixture of $CaFeO_3$ and $Ca_2Fe_2O_5$ unit cell.

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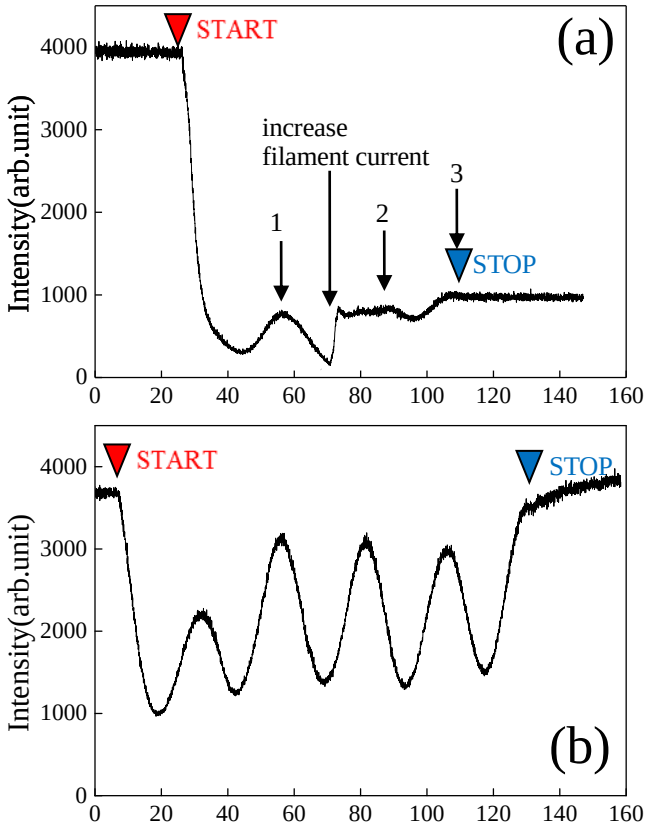

Fig. 1 RHEED Intensity of (a) CFO and (b) LFO grown on Nb doped STO(001)

Fig. 2 shows the (a-b) RHEED patterns after CFO deposition, (c-d) RHEED patterns after LFO deposition and (e-f) surface images of CFO(3units) /LFO(5units) grown on (a,c,e) Nb doped STO(001) and CFO(5units) /LFO(5units) grown on (b,d,f) LAO(001) after their depositions. All images of RHEED showed streaky pattern, indicating a smooth surfaces after the CFO/LFO depositions. The streaky patterns were consistent with results of step-terraces surface structures.

The surface treatment method of LAO substrate was not optimized to get single termination layer at this moment. Since it might affect the magnetic interactrion at the interface, the issue must be excluded.

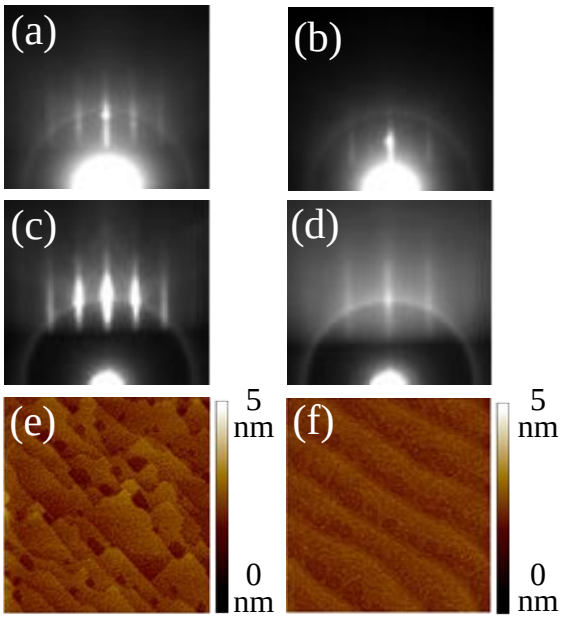

Fig. 2 (a-b) RHEED patterns after CFO deposition, (c-d) PHEED patterns after LFO deposition and (e-f) AFM surface image of CFO(3units)/LFO(5units) grown on Nb doped STO(001) and CFO(5units)/LFO(5units) grown on LAO(001). The e-beam direction in RHEED was along substrates [100] direction. The scanned size of all AFM images were 5×5 μm^2.

4. Summary

CFO/LFO heterointerfaces were prepared on Nb doped STO(001) and LAO(001) by PLD method, in the case of LAO, CCMO was inserted as a bottom electrode. RHEED intensties, RHEED patterns and AFM images indicated the layer by layer growth of CFO/LFO thin films with step-terraces structures. And RHEED intensities, RHEED patterns indicated LFO growth depended on CFO growth conditions.

Those results indicates good structure about considering applied measuring to confirm accurate results like electric properties because of its structures as we expected.

5. Reference

[1] Feng Bi, *et al*., Nat. Commun, **5**, 5019 (2014)
[2] X. Renshaw, *et al*., Science **349** (2015) 716.