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Structural and Electric / Magnetic Properties of [$CaFeO_3$/$REMO_3$] (RE=La, Bi, M=Fe, $Fe_{0.8}Mn_{0.2}$) Superlattices Grown on $SrTiO_3$ (001) by Pulsed Laser Deposition Method

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Abstract: Multiferroic materials, which show simultaneously ferroelectric and magnetic ordering, exhibit unusual physical properties and potential as new device applications. In this report we investigated the induced ferromagnetic properties at the interfaces of [$CaFeO_3$ (CFO)/$LaFeO_3$ (LFO), CFO/$BiFeO_3$ (BFO), and CFO/$BiFe_{0.8}Mn_{0.2}O_3$ (BFMO)] superlattices (SLs) prepared by pulsed laser deposition method with a KrF excimer laser. RHEED patterns, atomic force microscopy images and X-ray diffraction results showed that high-quality SLs with smooth surfaces were prepared successfully. *M-H* curve measurement results showed that the Curie temperature of [CFO/LFO], [CFO/BFO] and [CFO/BFMO] SLs was 520 K, 620 K and 450 K respectively, which was higher than room temperature. The values of saturation magnetization in these SLs were several times larger than those in the bulk materials, indicating that the ferromagnetic property in these SLs was caused by the superexchange interaction around the interfaces, rather than the magnetic properties in bulk materials.

1. Introduction

Multiferroic materials with the coexistence of at least two ferroic orders (for example ferroelectric, anti-/ferromagnetic, and ferroelastic) have recently intensively studied as perspective materials for information technology and data storage applications[1]. Basically, multiferroic materials can be divided into two types: single-phase[2] and composite[3]. However the selection of single-phase multiferroic materials is really limited. And more urgent problems to be resolved are the low coupling interaction between the different order parameters and the low transition temperature[4]. On the contrary, multiferroic composites provide us more freedom in material design. The cross interaction between the phases can produce remarkable magnetoelectric (ME) effect[3,5]. Therefore the purpose of this study is to investigate the induced ferromagnetic properties at the interfaces of $CaFeO_3$ (CFO)/$LaFeO_3$ (LFO), CFO/$BiFeO_3$ (BFO), and CFO/ $BiFe_{0.8}Mn_{0.2}O_3$ (BFMO) superlattices (SLs).

2. Experimental

CFO series SLs were grown on $SrTiO_3$ (100) substrates by pulsed laser deposition (PLD) method using a KrF excimer laser (λ=248 nm). The CFO series SLs were fabricated by stacking [CFO (7 units)/$REMO_3$ (7 units)] (RE=La, Bi, M=Fe, $Fe_{0.8}Mn_{0.2}$) for 14 times. The details about the depositions were described in the published paper[6]. It should be noted that in order to control the film thickness in superlattice growth accurately, the growth rate of each material was calibrated by trial deposition of several units of corresponding material.

All the samples were characterized by reflection high energy electron diffraction (RHEED), atomic force microscopy (AFM), X-ray diffraction (XRD, Bruker D8 Discover). The magnetic properties of *M-H* curves were measured by a physical property measurement system (PPMS, Quantum Design).

3. Results and Discussion

Fig. 1 shows the corresponding (a-c) RHEED patterns and (d-f) AFM surface morphology images of CFO/LFO, CFO/BFO and CFO/BFMO SLs after their depositions. Streak RHEED patterns for all the SLs indicated the smooth surfaces after the depositions, which were confirmed by the step-terrace surfaces in AFM images.

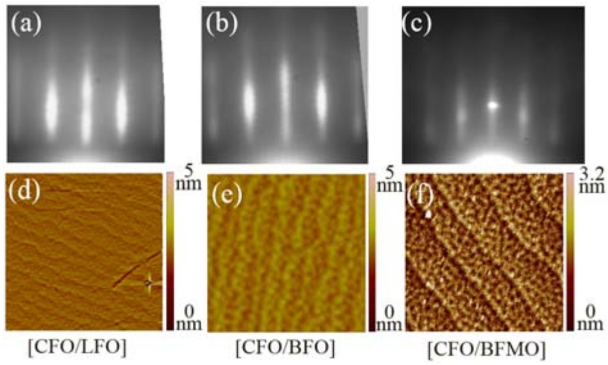

Fig. 1. (a-c) RHEED patterns (top figures) and (d-f) AFM surface morphologies (bottom figures) of [CFO/LFO], [CFO/BFO] and [CFO/BFMO] SLs after depositions. The e-beam direction in RHEED was along $SrTiO_3$ [100] direction. The scanned size of all AFM images was 5×5 μm^2.

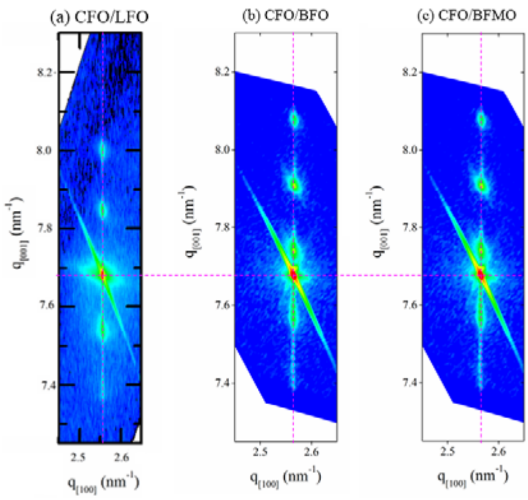

Fig. 2 Selected typical RSMs around $SrTiO_3$ (103) peaks of (a) CFO/LFO, (b) CFO/BFO and (c) CFO/BFMO SLs.

Fig. 2 shows the selected typical RSMs of CFO series SLs around $SrTiO_3$ (103) peaks. For all the CFO series SLs, Laue oscillations were observed clearly. In addition the in-plane lattice constants of all the CFO series SLs were fitted to that of $SrTiO_3$ substrate. These results proved that the cube-on cube growth of CFO series SLs with good structural and crystallinity properties was successful.

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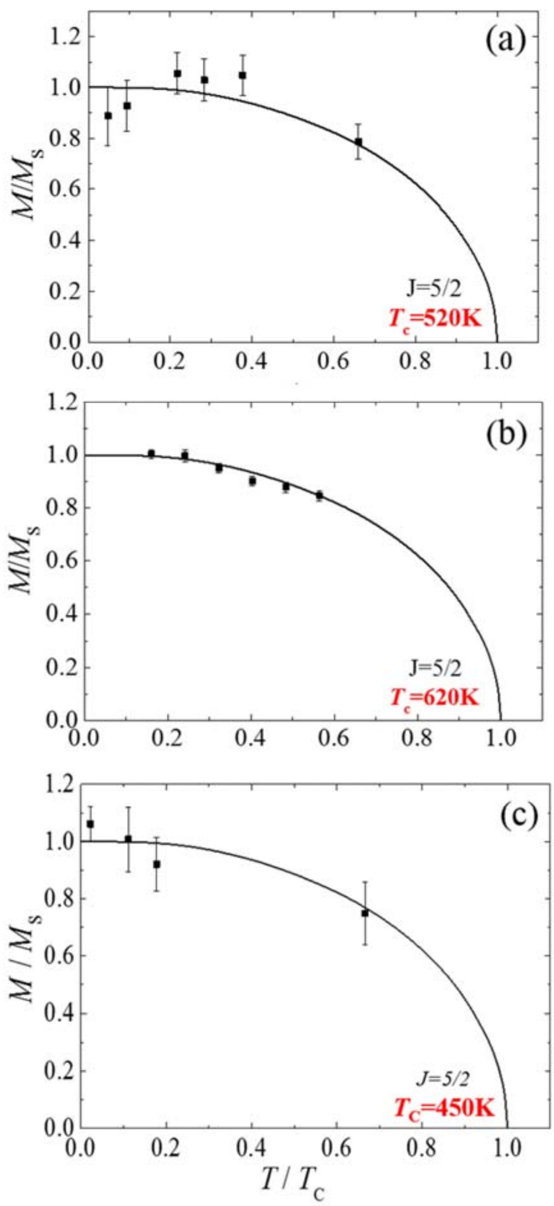

Fig. 3 Saturation magnetization of (a) CFO/LFO, (b) CFO/BFO and (c) CFO/BFMO SLs as function of temperature, together with the theoretical fitting curves for *J*=5/2 on the mean field theory.

Based on the *M-H* curves measured at different temperatures, the relationship between the saturation magnetization and the temperature could be determined. Fig. 3 shows the saturation magnetization of CFO series SLs as function of temperature. Curie temperatures (T_c) were fitted to be about 520 K (CFO/LFO), 620 K (CFO/BFO) and 450 K (CFO/BFMO), which were much higher than room temperature. Also the values of saturation magnetization in these CFO series SLs were several times larger than those in the bulk materials. Although CFO, LFO, BFO or BFMO are G-type antiferromagnetic or only very weak ferromagnetic[4,7,8], the charge transfer through the interface with an applied electric field can control the $(3d)^5$-$(3d)^4$ configuration between Fe ions, and results in ferromagnetic superexchange interaction around the interfaces according to the Kanamori-Goodenough rules[9].

4. Summary

CFO/LFO, CFO/BFO and CFO/BFMO SLs were grown on $SrTiO_3$ (100) substrates by PLD method successfully. RHEED, AFM and XRD results confirmed that the growth of CFO series SLs with good structural and crystallinity properties was achieved. The magnetic properties measured by PPMS indicates that ferromagnetic superexchange interactions exist around the interfaces in these SLs, leading to the transition temperatures higher than room temperature and the saturation magnetizations larger than those in the bulk materials. Our results also prove that the material design in composites system is a promising method towards to the better multiferroic performance.

5. Reference

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