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Superconductivity and Magnetism in $Nd_{0.5}Sr_{0.5}MnO_3/YBa_2Cu_3O_7$ Superlattices

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We report the synthesis and characterization of $Nd_{0.5}Sr_{0.5}MnO_3$/$YBa_2Cu_3O_7$ superlattices. X-ray diffraction studies show that the superlattices are [001] oriented. We observe that the magnetic ground state of $Nd_{0.5}Sr_{0.5}MnO_3$ system in a multilayered structure is strongly dependent on the substrate.

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1. Introduction

The possibility of various applications and the appearance of new interesting physics make the experimental and theoretical study of magnetic/superconducting hybrid structures a popular topic. Interfaces between two dissimilar materials have always in this respect been very interesting. Hole doped manganite $Nd_{1-x}Sr_xMnO_3$ exhibit a rich phase diagram as a function of x [1], where metallic state below T_C becomes unstable and goes to an insulating state. This is due to the real space ordering of Mn^{3+} and Mn^{4+} ions in different sublattices. The ground state of the bulk single crystal $Nd_{0.5}Sr_{0.5}MnO_3$ (NSMO) shows antiferromagnetic ordering (charge ordered state) with Néel temperature T_N of about 140 K.

The transport and magnetic properties of single NSMO films depend significantly on the strain effect [2, 3] imposed on NSMO film by the substrate, therefore one can expect additional strain effect on NSMO films in multilayered structure imposed by $YBa_2Cu_3O_7$ (YBCO) films.

In this report we present the structural, transport, and magnetic properties of NSMO thin films and NSMO/YBCO superlattices deposited on (110) $NdGaO_3$ and (100) $[(LaAlO_3)_{0.28}(SrTaAlO_6)_{0.72}]$ (LSAT) substrates.

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2. Experimental

The NSMO films and NSMO/YBCO superlattices were fabricated on (100) $NdGaO_3$ and (100) $[(LaAlO_3)_{0.3}(Sr_2TaAlO_6)_{0.7}]$ substrates by multitarget high pressure dc sputtering [4]. The targets with nominal composition of $Nd_{0.5}Sr_{0.5}MnO_3$ and $YBa_2Cu_3O_7$ were used for deposition. Deposition was performed at 770°C with oxygen pressure of 3 mbar. The thickness of each layer was controlled by the sputtering time of respective targets. The crystallographic structure of the samples was analyzed by X-ray diffraction. The dc magnetizations were measured with SQUID magnetometer in the temperature range of 5–300 K in the magnetic field up to 1 kOe. Microstructural properties of the samples were examined using a transmission electron microscope (TEM JEOL 2000EX). Resistance versus temperature measurements were performed with a four-probe method.

3. Results and discussion

We have deposited NSMO thin films and [NSMO 16u.c./YBCO nu.c.]$_{16}$ superlattices, where n = 1–8, 10 unit cells thick YBCO layers on (110) $NdGaO_3$ and (100) LSAT substrates. Figure 1 shows representative low-angle (a) and high--angle (b) X-ray data for superlattice [NSMO 16u.c./YBCO 1u.c.]$_{16}$. The low-angle spectrum exhibits multilayers peaks with low intensity, resulting from the chemical modulation of the mutilayer, with small size oscillations (the Kiessig fringes). In the high-angle spectrum, a well-defined (002) Bragg peak and superlattice satellite peaks up to 4th order are seen.

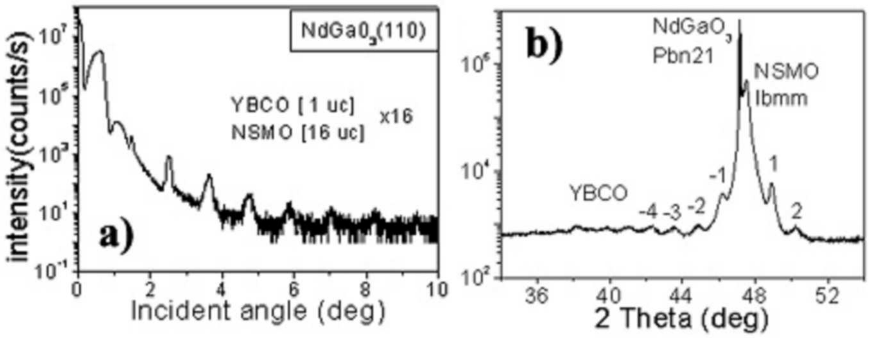

Fig. 1. Low-angle (a) and high-angle (b) X-ray pattern for [NSMO 16u.c./ YBCO 1u.c.]$_{16}$ superlattice.

The observed modulation wavelength is in agreement within 7% with the expected values. This is confirmed by transmission electron microscopy (TEM) cross-section image studies. The lattice fringe and selected area electron diffraction patterns (the inset) obtained at an interface between NSMO and YBCO layers are presented indicating sharp interfaces (Fig. 2).

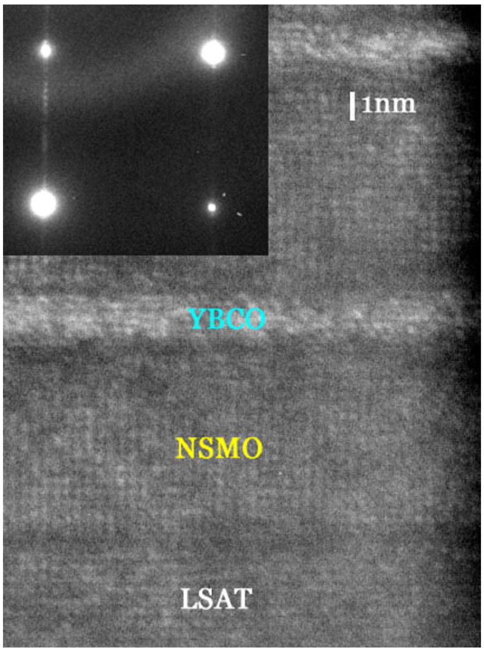

Fig. 2. TEM cross-section image and the selected area of electron diffraction patterns (inset) for [NSMO 16u.c./YBCO 1u.c.]$_{16}$, superlattice deposited at LSAT (100) substrate.

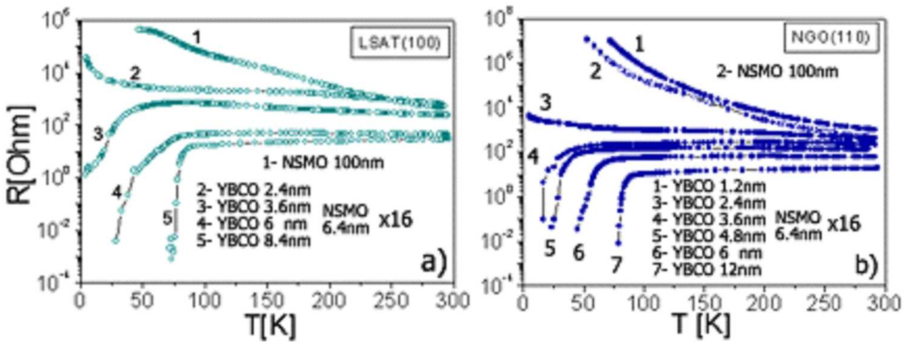

Fig. 3. The resistance, $R(T)$, as a function of temperature for single $Nd_{0.5}Sr_{0.5}MnO_3$ film and [NSMO 16u.c./YBCO nu.c.]$_{16}$ superlattices deposited at LSAT (a) and $NdGaO_3$ (b) substrates, respectively.

In Fig. 3a,b the resistance $R(T)$ as a function of temperature for single $Nd_{0.5}Sr_{0.5}MnO_3$ film and NSMO/YBCO superlattices deposited on $NdGaO_3$ and LSAT substrates are shown. A kink on $R(T)$ curves is seen for NSMO films deposited on both substrates at about 140 K. This observation presumably is related to a phase transition from a paramagnetic to antiferromagnetic state.

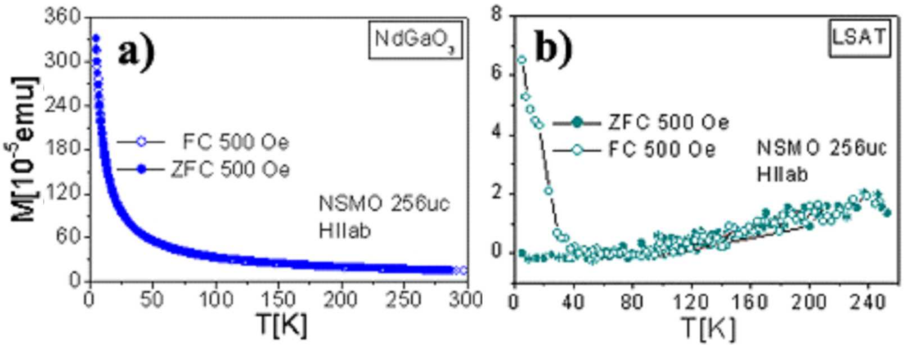

Fig. 4. Magnetic moment versus temperature for single NSMO films, deposited on (110)$NdGaO_3$ (a) and (100) LSAT (b) substrates. Magnetic field was applied in plane.

The appearance of superconducting transition in multilayered structure is observed for the samples with YBCO layer thickness equal or larger than 3 unit cells. A similar behavior has been observed in other NSMO/YBCO superlattices [5]. This is in contrast to the measurements on LSMO/YBCO superlattices [6], where the transition to superconducting state is observed for the samples with at last 2 unit cell thick YBCO layers. The zero net magnetic moment is observed for a single NSMO film on $NdGaO_3$ substrate as shown in Fig. 4, whereas a weak ferromagnetic moment is seen at low temperatures for film deposited on LSAT substrate. The difference in magnetic ground state of NSMO films deposited on different substrates is presumably a result of different degree of (lattice) tetragonal distortion [2, 3] of NSMO films imposed by the substrates and YBCO layers.

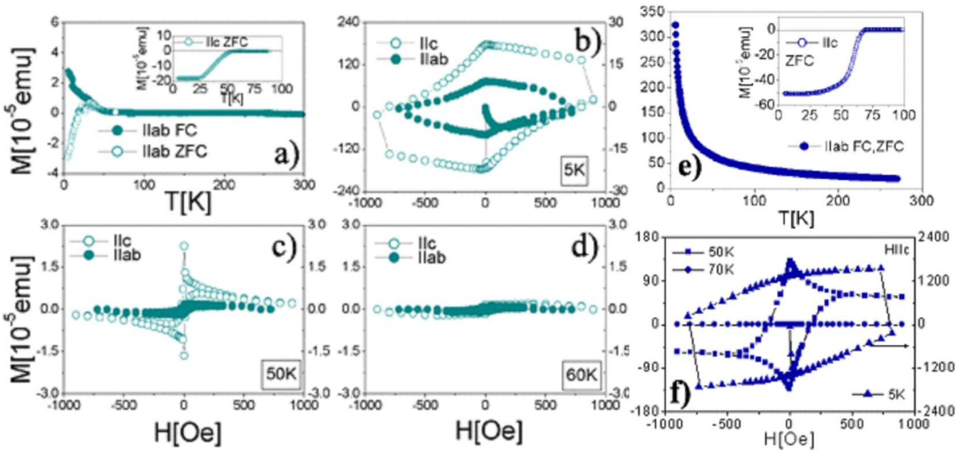

Fig. 5. (a) ZFC and FC magnetic moment for [NSMO 16u.c./YBCO 7u.c.]$_{16}$ superlattice deposited at LSAT substrate, inset — ZFC magnetic moment, (b–d) $M-H$ hysteresis loops, (e) ZFC and FC magnetic moment of [NSMO 16u.c./YBCO 10u.c.]$_{16}$ superlattice deposited at $NdGaO_3$ substrate, inset — ZFC magnetic moment vs. temperature, (f) hysteresis loops measured below and above superconducting transition.

Figure 5a shows zero-field-cooled (ZFC) and field-cooled (FC) $M(T)$ curves. $M(H)$ hysteresis loops measured for [NSMO 16u.c./YBCO 7u.c.]$_{16}$ superlattice deposited at LSAT substrate are presented in Fig. 5b–d. The weak ferromagnetic moment is seen below $T = 40$ K, similar to the observation for the single NSMO film deposited on the same substrate. Presented in Fig. 5e–d $M(T)$ and $M(H)$ curves for the [NSMO 16u.c./YBCO 10u.c.]$_{16}$ superlattice demonstrate a zero net magnetic moment (the paramagnetic substrate contribution has been subtracted).

These observations indicate the existence of the antiferromagnetic ground state in the NSMO layers in a multilayered structure. Measurements of $M(H)$ of NSMO/YBCO superlattices on LSAT substrates in FC mode (not shown) demonstrate a shift of the hysteresis loop along H axis (exchange bias). Such behavior suggests the charge transfer of holes from YBCO layers to NSMO layers similar to the observation on LSMO/YBCO superlattices [6].

In summary, we have fabricated $Nd_{0.5}Sr_{0.5}MnO_3$/YBCO superlattices of a high structural quality. The magnetic moment measurements show a weak ferromagnetic order of NSMO system in the multilayered structure deposited at LSAT substrates. The zero net magnetic moment is observed for NSMO system in the multilayered structure deposited at $NdGaO_3$ substrates.

Acknowledgments

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