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In-Plane Transport of Doped Manganite Trilayers

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ABSTRACT

We have synthesized and characterized doped manganite trilayers composed of $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) and $La_{0.7}Ca_{0.3}MnO_3$ (LCMO). Because of the isostructural nature of the Sr and Ca doped manganites, trilayers exhibit good epitaxy as observed in X-ray diffraction. Magnetization measurements reveal magnetization values consistent with bulk values. In-plane transport of these trilayers reveals anisotropic magnetoresistance and high field negative magnetoresistance attributed to the suppression of spin fluctuations at high fields.

INTRODUCTION

Colossal magnetoresistance (CMR) materials consist of a group of doped perovskite manganites of chemical composition $A_{1-x}B_xMnO_3$ (where A = trivalent rare earth and B = divalent alkaline earth). While the phase diagram of the doped manganites is rather complicated and includes ferromagnetic, antiferromagnetic, and paramagnetic phases, insulating and metallic phases and charge ordered phases, the subclass of materials that exhibit a transition from a ferromagnetic metallic phase to a paramagnetic insulating one are known as CMR materials. They exhibit large changes in resistance under an applied magnetic field and thus have been the subject of extensive research due to their possible application in computer read/write heads and storage devices. Magnetoresistance (MR) values as high as 80% in LCMO at ~200K and 35% in LSMO at ~330K have been observed under high magnetic fields (~5 Tesla).

Many groups have studied CMR and CMR-based devices in the hopes of obtaining large magnetoresistances at low fields and at room temperature. Some research groups have focused on fabricating CMR-based magnetic tunnel junctions to this end. Initial studies of CMR tunnel junctions have shown junction magnetoresistance (JMR) behavior on field scales as low as ~50 Oe [1,2]. Subsequent studies have shown JMR values as high as 100% at 13K [3,4]. However, JMR decreases rapidly with increasing temperature and vanishes by room temperature. In magnetic tunnel junctions, the interface quality, tunnel barrier quality, surface/interface roughness, ferromagnetic electrode quality, magnetic domain walls as well as the intrinsic behavior of ferromagnetic surfaces/interfaces greatly affect the JMR. It has greatly complicated the interpretation of transport data and may contribute to the premature suppression of spin polarized tunneling to temperatures below the Curie temperature of the CMR electrodes. More recently, near room temperature operation of CMR-based tunnel junctions has also been observed by Obata et al. [5]. To minimize interface disorder, Goodenough's group incorporated a tunnel barrier of $(La_{0.85}Sr_{0.15})MnO_3$ between $La_{0.7}Sr_{0.3}MnO_3$ electrodes and obtained JMRs at temperatures as high as 295K [6].

Our approach has been to study magnetotransport in trilayers and tunnel devices composed of isostructural materials of $La_{1-x}Sr_xMnO_3$ and $La_{1-y}Ca_yMnO_3$ where good epitaxy can be obtained. In this paper, we present the synthesis and characterization of doped manganite trilayers of $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) and $La_{0.7}Ca_{0.3}MnO_3$ (LCMO). The layers can grow coherently on one another by only changing one species (Sr -> Ca). Such structures have minimal lattice mismatch strain at the interfaces and therefore optimal interface quality.

EXPERIMENTAL SETUP

The epitaxial CMR thin film trilayers were deposited in a pulsed laser deposition (PLD) system with a KrF excimer laser (248nm) operating at 10 Hz with an energy density of ~3 J/cm^2 for LSMO and LCMO. The films were deposited on (001) $SrTiO_3$ (STO) substrates. In this paper, we will describe the orientation of the manganites in terms of the pseudocubic lattice parameters $a'_{bulk}= b'_{bulk}= c'_{bulk}=$ 3.87Å. These lattice parameters are rotated 45 degrees from the rhombohedral, nearly cubic lattice parameters $a_{bulk} \approx b_{bulk} \approx c_{bulk} \approx$ 5.48Å. STO substrates place the overlying LSMO films under tensile strain. We grew trilayers with 350 to 1000Å thick LSMO electrodes and 20 to 100Å thick LCMO barrier layers.

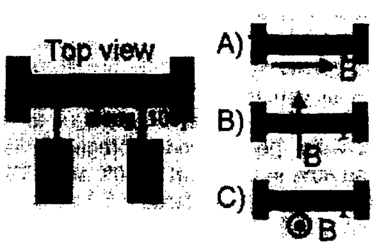

Figure 1. Schematic of resistivity bar for in-plane transport measurements (left). The magnetic field was applied in three different orientations (right): (A) in-plane and parallel to the current, (B) in-plane and perpendicular to the current, and (C) out of plane.

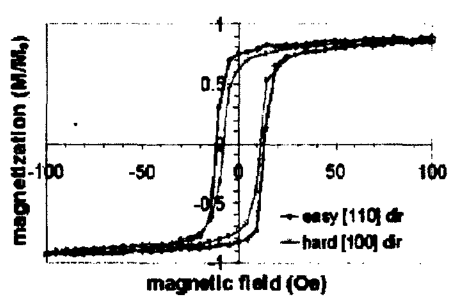

Figure 2. Vibrating sample magnetometer magnetization data for a LSMO trilayer film on a (001) STO substrate showing an easy [110] direction and a hard [100] direction.

X-ray diffraction of the trilayers was performed on a Scintag, Inc. theta-theta diffractometer to verify the epitaxy of the films. A vibrating sample magnetometer and a superconducting quantum interference device (SQUID) magnetometer were used to take magnetization measurements.

In-plane transport measurements were taken in a physical property measurement system. The trilayer films were patterned into resistivity bars using argon ion milling. The current was applied along the [100] direction, and the resistivity was measured with three possible orientations between the current and the magnetic field (Figure 1).

RESULTS AND DISCUSSION

X-ray diffraction 2θ measurements of the trilayer films only showed distinct peaks corresponding to the (001) orientation of LSMO films and the STO substrates, demonstrating the epitaxy of the trilayers.

Magnetization measurements taken with a SQUID magnetometer show that LSMO has a Curie temperature T_C of ~350K, while LCMO has a T_C of ~250K. The magnetic behavior of the trilayer films was similar to that of LSMO single layer films, with a decrease in magnetization and coercive field with increasing temperature. As shown in our previous work, in (001)-oriented LSMO films, the magnetocrystalline anisotropy gives rise to an in-plane easy direction along [110] and equivalent directions, and the hard directions are [100] and [010] [7]. As expected, the trilayer films show the same easy and hard directions (Figure 2). Moreover, the trilayer magnetization values are consistent with bulk values.

In-plane transport measurements were taken by first sweeping the magnetic field from high positive field to high negative field and then back to high positive field. All measurements show a negative, linear MR at high fields, which is attributed to

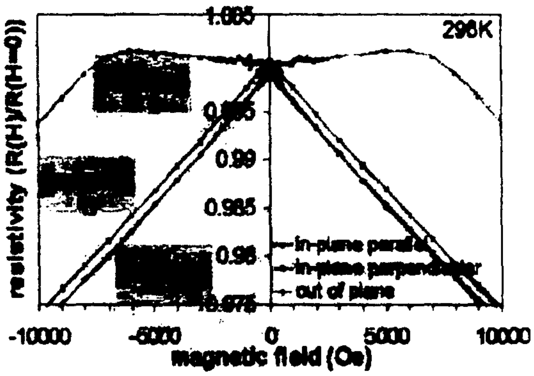

Figure 3. In-plane transport measurements at room temperature taken in the configurations A, B and C as marked.

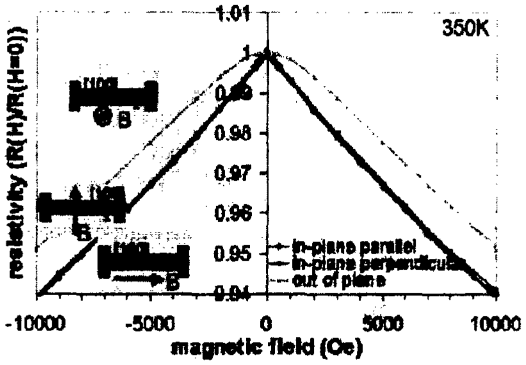

Figure 4. In-plane transport measurements at 350K taken in the configurations A, B and C as marked.

the suppression of spin fluctuations at high magnetic fields (CMR). The MR in the out-of-plane orientation (configuration C) is shifted due to demagnetization effects as seen in Figure 3. The curve exhibits demagnetization effects around 5kOe as well as irreversibility at ~1.5kOe. The irreversibility corresponds to the domain wall motion that is observed in the magnetization loops.

In the in-plane perpendicular orientation of the current and field (configuration B), a positive MR is seen at low fields that crosses over to negative MR at higher

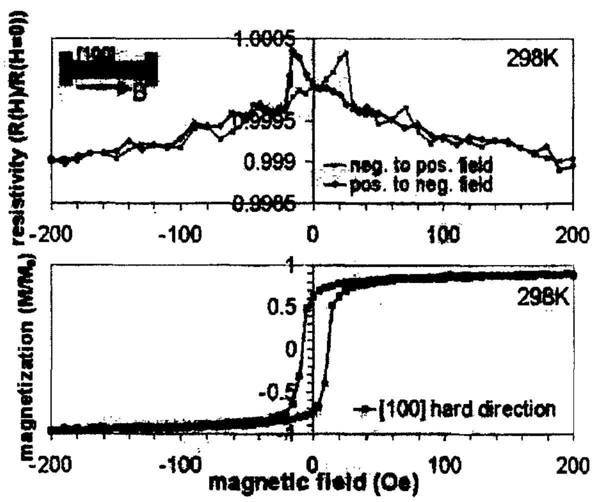

Figure 5. Low field in-plane transport measurements for the in-plane parallel field configuration (A) (top) and magnetization measurements (bottom) taken at room temperature.

fields. The field at which the crossover occurs does not correspond to the shape effect of the transport bar [8,9]. In fact, the field corresponds to the magnetic anisotropy field of the film. In the in-plane parallel orientation (configuration A), the MR exhibits a linear dependence with a superlinear deviation at low fields and an irreversibility corresponding to the coercive field. The MRs in the in-plane parallel and in-plane perpendicular orientations are shifted with respect to one another due to anisotropic magnetoresistance (AMR). AMR occurs when the resistance depends on the orientation between the magnetization and the current. In LSMO, the resistance is less when the magnetization is parallel to the current versus perpendicular to the current [10]. However, the AMR disappears for transport measurements taken just below the T_C of LSMO as the magnetization has decreased almost to zero (Figure 4).

In the in-plane parallel orientation (A), as soon as the magnetic field is decreased to below the anisotropy field, the magnetic moments rotate away from the applied field direction of [001] into the magnetically easy [110] directions. The magnetization is no longer pointing parallel to the current, and the MR increases, hence a superlinear deviation (Figure 5). However, for the in-plane perpendicular orientation (B), the magnetic moments start out pointing perpendicular to the current and then rotate to the easy diagonal directions. Since they are pointing more along the current in decreasing magnetic field, the MR drops, and hence we observe the sublinear deviation or a crossover from negative to positive MR (Figure 6). Moreover, we see that the hysteretic behavior of the low field MR in the in-plane configurations (see Figure 5,6) corresponds to the coercive fields of the magnetization loops and thus to domain wall motion.

Since LCMO is an insulator, we suspect that most of the current travels through the LSMO layers, and indeed our transport measurements of trilayers are similar to those of LSMO thin films [10,11].

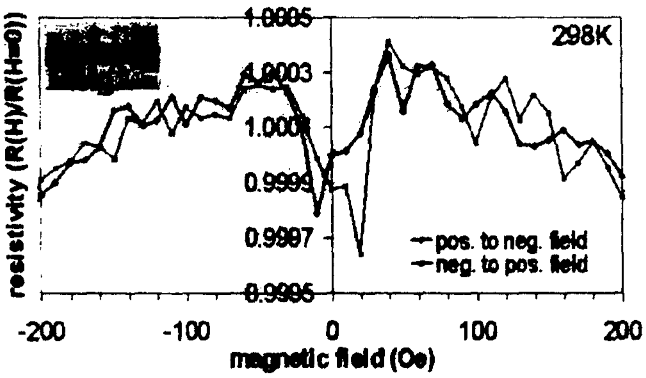

Figure 6. Low field in-plane transport for the in-plane perpendicular configuration (B) taken at room temperature.

CONCLUSIONS

We have synthesized and characterized doped manganite trilayers composed of LSMO and LCMO. Given the isostructural nature of the trilayer, with the substitution of the alkaline earth dopant, there is minimal disorder at the interfaces of the layers, and therefore, we are able to obtain trilayers with good epitaxy. In-plane transport measurements reveal the main MR effects to be CMR and anisotropic MR.

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