

Hall effect in a $\text{GdBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{La}_{0.75}\text{Sr}_{0.25}\text{MnO}_3$ perovskite bilayer

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Abstract

We present results on the Hall coefficient R_H in the normal state for a $\text{GdBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{La}_{0.75}\text{Sr}_{0.25}\text{MnO}_3$ bilayer and a $\text{La}_{0.75}\text{Sr}_{0.25}\text{MnO}_3$ film grown by dc magnetron sputtering on (1 0 0) SrTiO_3 . We find that the electric transport on the bilayer can be qualitatively described using a simple parallel layers model. The $\text{GdBa}_2\text{Cu}_3\text{O}_{7-\delta}$ layer presents a carrier density approximately equal to that reported for $7 - \delta = 6.85$ oxygen doping. Also we observe an unexpected presence of two Hall resistivity regimes, effects that may be associated with the internal magnetic field induced on the superconducting layer by the ferromagnetic layer.

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An important issue that remains unsolved in the physics of high-temperature superconductor/ferromagnetic manganite superlattices is the microscopic origin of the changes on the physical properties of the materials that arise when they are put in close contact [1]. Recently [2,3], evidence has been found for an antiferromagnetic (AF) phase at the interfaces in superconducting/ferromagnetic $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}/\text{La}_{0.66}\text{Ca}_{0.33}\text{MnO}_3$ (YBCO/LCMO) perovskite superlattices. One possible microscopic origin for this effect is that holes are transferred from the High- T_c cuprate (HTC) to the manganite at the contact interface [4]. This possibility has not yet been proved, since the carrier concentration in this type of bilayer has not been studied systematically enough to separate the RBCO (R : rare earth) and manganites contribution. There exist, however, extensive investigations on RBCO thin films. Wuys et al. [5] showed that a systematic reduction of the carrier density occurs when

the oxygen content is diminished in RBCO films. Also the carrier density of manganites was investigated, the results showed a dramatic drop in the number of carriers at the ferromagnetic transition temperature [6,7].

A possible way to analyze the carrier concentration on RBCO/manganites multilayers and to check the interface influence on the resulting physical properties is by performing Hall effects measurements. The Hall resistivity of ferromagnetic materials is given by the addition of two terms, $\rho_H = R_0 H + 4R_S M$ where H is the magnetic field, M the magnetization and R_0 and R_S are the ordinary and anomalous Hall coefficients [6,7]. In a single band material R_0 depends on the carrier charge and density n , $R_0 = 1/nq$. The type of charge carriers in the material, holes or electrons, are determined by the sign of R_0 . Previous works in Hall effect on RBCO (R : rare earth) and $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ films show that both materials have hole character with positive R_0 values [5,7].

In this work, we study the normal state electronic transport properties of a $\text{GdBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (12 unit cells (u. c.) ≈ 14.4 nm)/ $\text{La}_{0.75}\text{Sr}_{0.25}\text{MnO}_3$ (30 u. c. ≈ 12 nm) (GBCO/LSMO) bilayer and we compare its behavior with GBCO and LSMO single films. The GBCO/LSMO bilayer and a 12 nm thick LSMO film were

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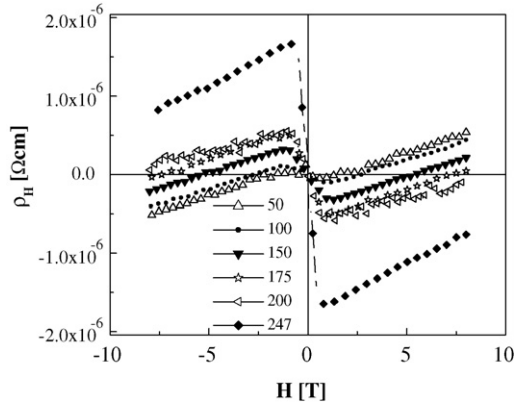


Fig. 1. Hall resistivity ρ_H of a LSMO film vs. magnetic field H at different temperatures from 50 to 250 K.

grown by sputtering as previously reported [8]. Single GBCO films grown under these same conditions typically show a T_c corresponding to an oxygen content around 6.95 [8]. Electrical resistance (ρ) versus temperature (T), and ρ_H versus magnetic field (H) measurements were performed in a temperature range of 50–300 K, and in magnetic fields between -8 and 8 T. The samples were patterned by wet chemical etching. In all experiments the magnetic field was applied perpendicular to the film surface.

Fig. 1 shows ρ_H versus H for a LSMO film. The curves display at lower fields the expected anomalous Hall effect associated with the rotation of the magnetic domains, and for higher fields the expected positive linear dependence for the hole character of the carriers [6,7]. Fig. 2 shows the temperature dependence of the resistivity and the carrier density n estimated from R_0 in a single band model. We can observe a gradual increase of n_h when the temperature is lowered below the metal insulator transition in the film [6,7].

Fig. 3 shows ρ_H versus H for the GBCO/LSMO bilayer. No features resembling anomalous ρ_H of the LSMO layer are identifiable. However, the curves show two different field regimes: for fields lower or higher than ≈ 0.7 T. The magnetic field that the GBCO layer senses is the sum of two terms, $H = H_E + H_I$, where H_E is the external applied field, and H_I is the stray field of the ferromagnetic manganite. The first regime

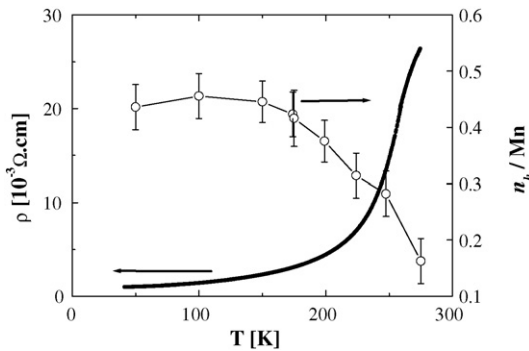


Fig. 2. Temperature dependence of the resistivity (ρ) (left scale) and of the carrier density per unit cell n_h (right scale) for a 12 nm thick LSMO film. The error bars were calculated considering the error in R_H and in the film thickness.

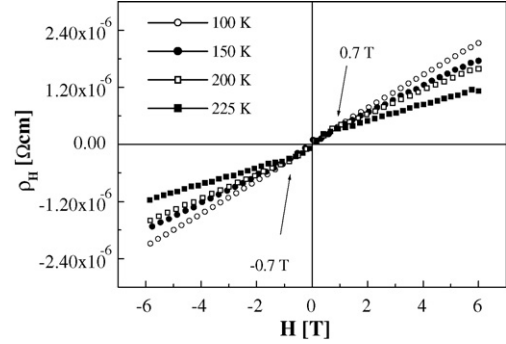


Fig. 3. Hall resistivity ρ_H vs. magnetic field H in the GBCO/LSMO bilayer at temperatures from 100 to 225 K.

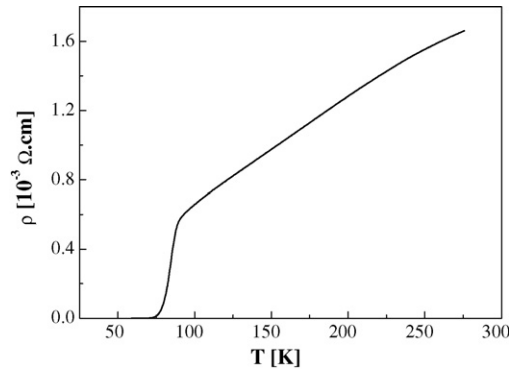


Fig. 4. Temperature dependence of the resistivity (ρ) for a GBCO/LSMO bilayer. The resistivity was calculated using the total thickness.

corresponds to a variable H_I resulting from an out of plane gradual magnetization of the LSMO layer when H_E is increased, whereas in the second regime the out of plane LSMO layer magnetization is saturated and H_I is hence constant. This hypothesis is supported by the fact that the regime change occurs approximately at the saturation H_E of the LSMO film, given the shape anisotropy ($4\pi M_S \approx 7000$ Oe). Small discrepancies from this field value could be related to changes in anisotropy given by stress [9].

Fig. 4 shows resistivity (ρ) versus T for the GBCO/LSMO bilayer. The superconducting critical temperature is around 75 K (defined by zero resistance). This value is reduced with

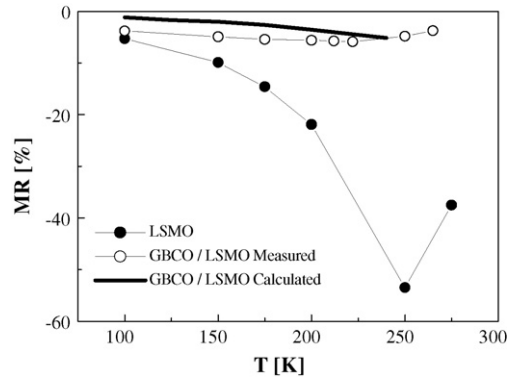


Fig. 5. Magnetoresistance ($MR = [(MR_{(8T)} - MR_{(0T)}) / MR_{(0T)}]$) vs. temperature for a LSMO film and a GBCO/LSMO bilayer. The solid line shows the estimated MR from the parallel resistor model.

respect to the value for optimally doped films at approximately 90 K [5]. The low ρ values indicate that the current primarily flows along the GBCO layer, although the presence of negative magnetoresistance, MR, (Fig. 5) confirms that the LSMO layer contribution is not negligible. Assuming that the resistivity in the GBCO/LSMO bilayer could be represented by a simple parallel resistor model and that the LSMO layer properties are similar to those found in the pure LSMO film, we can estimate the ρ_{GBCO} and the expected MR in the bilayer. Fig. 5 shows the measured and calculated $\text{MR} = [(\rho_{(8T)} - \rho_{(0T)}) / \rho_{(0T)}]$ versus T . The results indicate that the low MR values in the bilayer are a consequence of the electrical parallel resistor behavior. The small discrepancies in the MR magnitude could be related with differences between the properties of a LSMO film and the LSMO layer in the bilayer, provided that interface disorder mechanisms like stress, roughness, charge transfer, etc. were not considered.

The carrier density in the GBCO layer could be estimated considering the parallel resistor model for the Hall coefficient in the bilayer [10], considering the hole character of both layers:

$$R_H = \frac{(t_{\text{LSMO}} + t_{\text{GBCO}})(t_{\text{LSMO}}(\sigma_{\text{LSMO}}^2/n_{\text{LSMO}}) + t_{\text{GBCO}}(\sigma_{\text{GBCO}}^2/n_{\text{GBCO}}))}{q(t_{\text{LSMO}}\sigma_{\text{LSMO}} + t_{\text{GBCO}}\sigma_{\text{GBCO}})^2} \quad (1)$$

where t_i and σ_i are the thickness and the conductivity of each layer. The data used to estimate the n_{GBCO} are the sample dimensions, R_H of the bilayer, the estimated ρ_{GBCO} from the parallel resistor model, and our measurements of ρ_{LSMO} and n_{LSMO} , as shown in Fig. 2. The results for the GBCO layer carrier density versus T are summarized in Fig. 6. The estimated n_{GBCO} agrees with the results for YBCO films with an oxygen content near 6.85 [5]. An oxygen doping deficiency is expected from the reduced T_c of the bilayer with respect to the optimally doped films. The reduction in the GBCO carrier density and T_c with respect to GBCO films can be explained by charge transfer or by stress at the interfaces [4]. The matching of the lattice parameters at the interfaces without the presence of dislocations implies that optimal oxygen doping in the GBCO layer (lattice parameters $a = 0.383$ and $b = 0.389$ nm) can only be achieved if a high orthorhombic distortion in the LSMO layer is induced. Normally, the rhombohedral LSMO layer has pseudocubic lattice parameter $a \approx 0.386$ nm that better matches with the oxygen deficient RBCO lattice parameters ($a \approx b \approx 0.386$ nm) [11].

In summary, our results show that the electrical transport in GBCO/LSMO bilayer is well described by a simple parallel resistor model. Hall resistivity measurements allowed to estimate the GBCO carrier density, which results lower than the expected values in fully oxygenated RBCO films. This

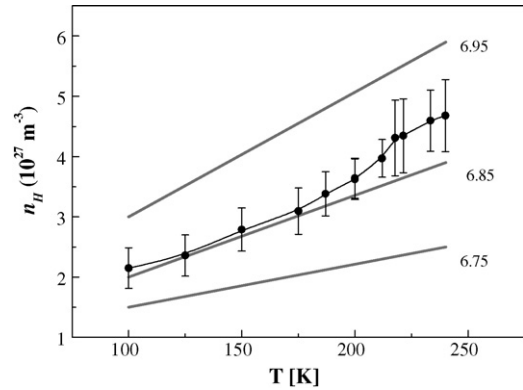


Fig. 6. Carrier density n_H vs. temperature T of the GBCO layer on the GBCO/LSMO bilayer. The error bars are estimated by error propagation in Eq. (1). Solid lines indicate the expected carrier density for the corresponding oxygen doping [5].

result agrees with the suppressed superconducting critical temperature found in the bilayer. We also found that the contribution of the internal magnetic field produced by the ferromagnetic LSMO layer on the GBCO cannot be neglected.

Acknowledgments

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