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RAPID COMMUNICATION

$Pr_{0.67}Ca_{0.33}MnO_3/YBa_2Cu_3O_7$ thin film bilayers grown by pulsed laser ablation deposition

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Abstract. We have grown superconducting thin films of $YBa_2Cu_3O_7$ (Y-123) on $Pr_{0.67}Ca_{0.33}MnO_3$ (PCMO) buffer layers and PCMO overlayers on Y-123 thin films using pulsed laser ablation deposition. For both sets of films below 50 K, the Y-123 layer is superconducting and the zero-field cooled PCMO layer is insulating. The application of a magnetic field of 8 T results in an insulator–metal transition in the PCMO layer. This field-induced conducting state is stable in zero magnetic field at low temperature. The PCMO layer can be returned to an insulating state by annealing above 100 K. This opens the way for the construction of devices incorporating these oxide materials in which the electronic properties of key components such as the substrate or the barrier layer can be switched in a controlled way by the application of a magnetic field.

There are a number of perovskite oxide systems which exhibit interesting behaviour of which perhaps the most studied are the high temperature superconductors (HTS). Research aimed at shedding light on the underlying physics of these compounds and evaluating the potential of these materials for use in applications has included the preparation of thin films [1]. An important component of this work has been investigating the compatibility of HTS materials with a wide range of other compounds including other non-superconducting perovskites which could be used as either substrates or interlayers in various structures [2]. These non-superconducting materials have been evaluated for their chemical and structural properties as well as for their different magnetic and electronic properties which may prove useful in understanding the mechanism of HTS, or which could be exploited in devices.

One group of compounds which have until now received little attention in connection with HTS are the doped perovskites with the general formula $Ln_{1-x}A_xMnO_3$ (Ln = La, or rare earth and A = Ca, Ba, Sr, or Pb). These materials are currently of great interest due to the negative giant magnetoresistance (GMR) exhibited by some of these compounds [3–7].

In the case of $Pr_{1-x}Ca_xMnO_3$ ($0.3 \leq x \leq 0.45$), evidence for a spatial charge ordering of the Mn^{3+}/Mn^{4+} lattice is seen at 250 K. A transition to an antiferromagnetically ordered state occurs at around 160–170 K. In zero magnetic field the resistivity of these materials increases with decreasing temperature. Fitting the temperature dependence of the resistivity data suggests that conduction occurs via an activated process which probably involves polarons. At low temperature these materials are insulators. Below the charge ordering temperature the application of a sufficiently high magnetic field induces a transition from either a paramagnetic or antiferromagnetic into a ferromagnetically ordered state. This transition is accompanied by a decrease in the resistivity of the material and at low temperature this results in a field induced insulator–metal transition [8–10].

We have recently reported on the growth of $Pr_{0.67}Ca_{0.33}MnO_3$ (PCMO) thin films using pulsed laser ablation deposition. Below 50 K, the application of a magnetic field of 8 T resulted in an insulator–metal transition with a fall in the resistivity of at least six orders of magnitude [11].

In this paper we report on the growth of $YBa_2Cu_3O_7/Pr_{0.67}Ca_{0.33}MnO_3$ bilayers. PCMO has been grown as a buffer layer on a conventional substrate and then partially covered with an Y-123 overlayer. PCMO has also been grown on top of Y-123 films. We demonstrate that the PCMO is compatible with this cuprate superconductor and that the resistivity of the PCMO can be reversibly switched between an insulating and a conducting state, whilst the $YBa_2Cu_3O_7$ (Y-123) remains in the superconducting state. This opens up the way for the production of more complicated structures containing these oxide materials in which the electrical resistivity of key components such as the substrate or the barrier layer can be controlled by the application of a magnetic field.

The Y-123 and PCMO targets were prepared by a

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standard solid state reaction technique using 3N oxides and carbonates. The thin films were grown by pulsed laser ablation deposition. In a first set of experiments, thin films of $Pr_{0.67}Ca_{0.33}MnO_3$ with a thickness of 1400 Å were deposited on (100) $LaAlO_3$ and (100) MgO substrates. Y-123 films with a thickness of 300 Å were then deposited over half the area of the PCMO. In a second set of experiments, thin films of $YBa_2Cu_3O_7$ with a thickness of 300 Å were deposited on (100) MgO substrates, then $Pr_{0.67}Ca_{0.33}MnO_3$ layers with a thickness of 300 Å were deposited over half the area of the Y-123 film. During the growths the substrate temperature was held at 700–750 °C. Depositions were carried out in 0.1–0.3 mbar atmosphere of flowing oxygen. The films were cooled to room temperature under one atmosphere of flowing oxygen. No post growth annealing was performed.

The structure of the as-deposited layers were examined by x-ray diffraction. X-ray measurements in the normal Bragg geometry show textured growth for both layers. The spectra for the PCMO layer contains only the $(0\,0\,2l)$ reflections with the lattice parameter $c = 7.55 \pm 0.05$ Å. The spectra of the Y-123 layers also showed a c axis orientation with a c-axis lattice parameter of 11.7 ± 0.05 Å.

Contacts were made to both the PCMO and the Y-123 layers allowing the temperature and magnetic field dependence of the electrical resistance of each layer to be measured separately using a standard dc four-probe technique. Data were collected between 4 and 300 K in magnetic fields of up to 8 T. The field was applied parallel to the substrate surface and the direction of current flow.

Resistance versus temperature curves taken in zero magnetic field are shown in figure 1. In zero field the resistivity of the PCMO film increases with decreasing temperature. Below 80 K the resistance of the sample exceeds 10^8 Ω indicating the zero-field cooled PCMO layer is an insulator at low temperatures. The resistivity of the Y-123 layer grown on MgO substrate shows metallic behaviour with a superconducting transition onset temperature of 92 K. The films show zero resistance below 90 K. The resistivity of the Y-123 layer grown on the PCMO initially increases with decreasing temperature, then begins to fall rapidly around 90 K with zero resistance at around 50 K. This may be due to some inter-diffusion of Pr into the Y-123 structure, a possibility which is currently being investigated.

After zero-field cooling to 5 K, the samples were cycled in a magnetic field of 8 T. Figure 2 shows the resistivity versus field curve for an overlayer of PCMO during field cycling. At this temperature the application of an applied field of around ≈5.5 T produces a switching between an insulating and a conducting state in the $Pr_{0.67}Ca_{0.33}MnO_3$ layer. The resistivity of this layer falls by at least six orders of magnitude. At 5 K, this conducting state is metastable and the PCMO film remains conducting even after the field is removed. Currents of up to 100 mA were passed into the PCMO, through the PCMO/Y-123 interface and out through the Y-123 superconductor, highlighting the conducting nature of both the PCMO and the interface. Figure 3 shows the increase in resistivity versus elapsed time at fixed temperature for a thin film $Pr_{0.67}Ca_{0.33}MnO_3$ grown over Y-123. For each curve, the sample was first cycled in a field of 8 T at 5 K, then warmed in zero field to the temperature shown, at which point the increase in resistivity was noted. In the figure the resistivity at a time t is normalized to the initial value of the resistivity at $t = 0$ s. At 5 K the resistivity increases by only 2% over a period of one hour. As expected the relaxation rate back into the insulating state increases with increasing temperature.

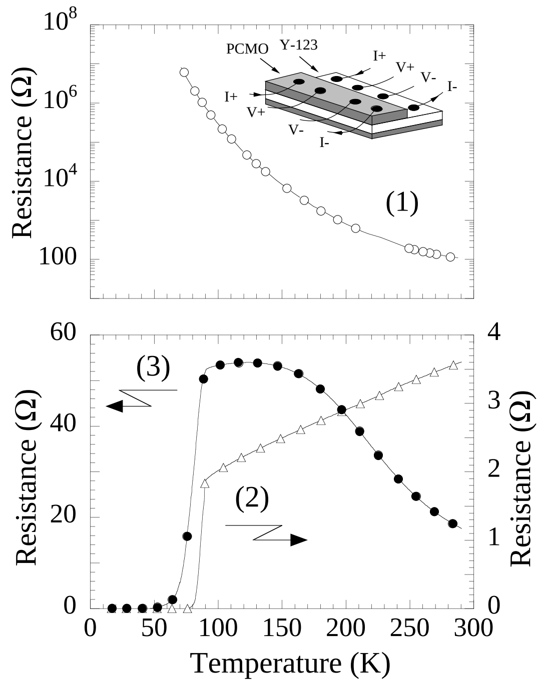

Figure 1. Resistance versus temperature curves for thin film of (1) $Pr_{0.67}Ca_{0.33}MnO_3$ grown over Y-123, (2) $YBa_2Cu_3O_7$ grown on MgO and (3) $YBa_2Cu_3O_7$ grown over the top of a $Pr_{0.67}Ca_{0.33}MnO_3$ layer. The insert shows the experimental geometry used for measurements (1) and (2).

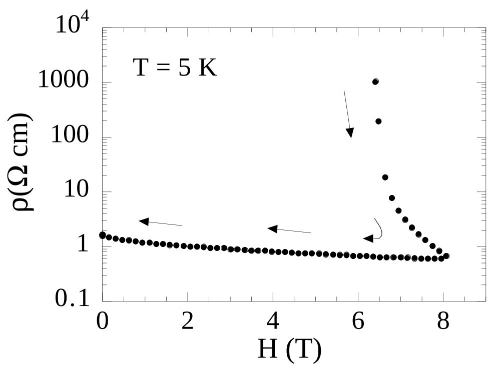

Figure 2. Resistivity versus magnetic field curve collected at a temperature of 5 K for a thin film of $Pr_{0.67}Ca_{0.33}MnO_3$ grown on top of an Y-123 thin film. The measurement was performed after cooling the sample from 300 K in zero magnetic field.

As well as switching between an insulating and a conducting state it is possible to change the degree of conductivity of the PCMO layer at low temperature by altering the field history of the sample. To demonstrate this, a thin film of $Pr_{0.67}Ca_{0.33}MnO_3$ was zero-field cooled.

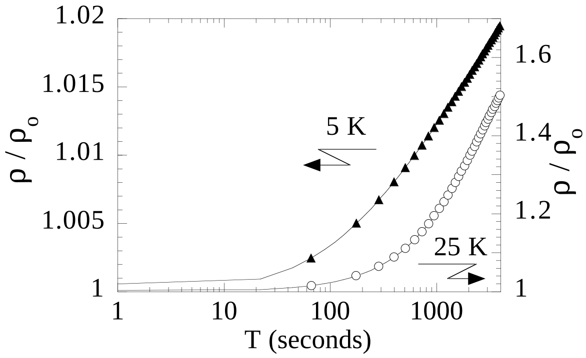

Figure 3. Change in resistance as a function of time for a $Pr_{0.67}Ca_{0.33}MnO_3$ thin film grown on Y-123. For each curve the sample was zero-field cooled to 5 K then cycled in a field of 8 T. The sample was then warmed in zero magnetic field to the temperature shown, at which time the increase in resistivity was monitored. A significant increase in the value of the resistance is seen only at temperatures above 30 K.

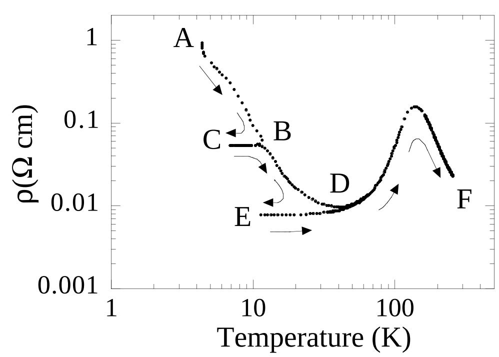

Figure 4. Resistivity versus temperature curve for a thin film of $Pr_{0.67}Ca_{0.33}MnO_3$ grown of $LaAlO_3$. The sample was zero-field cooled to 5 K. A field of 8 T was then applied and the data were collected during the subsequent field warming and cooling sequence A–B–C–D–E–F as indicated.

A field of 8 T was then applied and resistivity versus temperature data were collected during the field warming and cooling sequence A–B–C–D–E–F as indicated in figure 4. The resistivity at low temperature shows significant field history dependence. For the $Pr_{0.67}Ca_{0.33}MnO_3$ film used here, it would be possible to select resistivity values of between ≈1 and ≈0.01 Ω cm.

The results reported here suggest that this class of materials have potential for use in device applications. For example, it should be possible to grow multilayer structures such as SNS/SIS junctions, which include PCMO as the barrier layer, where the resistivity of the barrier can be switched in a controlled way from an insulating to a conducting state by application of a magnetic field. Once established the metastable nature of the conducting state allows the PCMO layer to remain conducting in zero field, provided the structure is maintained at low temperatures. The resistivity of the barrier layer could be varied by cycling in field or switched back to the insulating state by warming the structure in zero field.

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