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Fabrication and properties of high-T_c ramp junctions with manganite barriers

M.Q. Huang *, Z.G. Ivanov, P.V. Komissinski, T. Claeson

Department of Microelectronics and Nanoscience, Chalmers University of Technology and Göteborg University, S-412 96 Göteborg, Sweden

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Abstract

We report on fabrication and characterization of $YBa_2Cu_3O_{7-\delta}$ (YBCO) ramp junctions with a barrier of doped manganite, $La_{0.67}Sr_{0.33}MnO_3$ (LSMO). Multilayers of YBCO and LSMO are epitaxially grown on (100) $SrTiO_3$ substrates by on-axis pulsed laser ablation. The resistance and current–voltage characteristics of the ramp junctions have been measured as a function of barrier thickness, in the range of 10–30 nm, and of temperature. Junctions with 20 nm thick barriers had RSJ-like current–voltage characteristics with a small excess current. The critical current density and normal state resistance of the junctions at 4.2 K were 5×10^3 A/cm^2 and 300 Ω, respectively.

Keywords: YBCO ramp junction; Manganite; Multilayer

1. Introduction

Recently, doped manganites have attracted much attention on account of their colossal magnetoresistance (CMR) [1,2]. Most studies were on spin-dependent tunneling between two ferromagnetic (FM) films across an insulator (I), while only a few reports were focused on the tunneling between oxide superconductors (S) separated by a manganite barrier [3–5]. A superconducting current through 200–500 nm thick $La_{0.7}Ca_{0.3}MnO_x$ (LCMO) barriers was reported in *c*-axis trilayer junctions of $YBa_2Cu_3O_{7-\delta}/La_{0.7}$-$Ca_{0.3}MnO_x/YBa_2Cu_3O_{7-\delta}$ (YBCO/LCMO/YBCO) at 9 K [4,5]. However, in other YBCO/LCMO/YBCO junctions, with a barrier thickness of 80–130 nm, no superconducting current was observed even at 4.2 K [3]. The results are contradictory and reflect the complexity of the epitaxial growth of the superconductive and manganite perovskites. In addition, the supercurrent transport through the LSMO/YBCO interface in these junctions is hindered by the short coherence length in the *c*-direction of YBCO. Ramp type junctions allow the study of the Josephson effect in the *a*–*b* plane of the superconductor [6]. We will report on the fabrication and properties of YBCO ramp junctions with thin barriers of LSMO. A prerequisite for epitaxial growth

* Corresponding author. Fax: +46-31-772-3224; E-mail: huang@fy.chalmers.se

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of such structures is the small lattice mismatch of 2% in the a–b planes of YBCO and LSMO and the similar growth conditions at elevated temperatures, 700°C–800°C, in oxygen environment. We deposited YBCO/LSMO/YBCO multilayers by on-axis pulsed laser ablation and fabricated YBCO ramp-type Josephson junctions by using $La_{0.67}Sr_{0.33}MnO_3$ as a barrier material. The surface smoothness of the ramps in the YBCO bottom electrode was studied by AFM and correlated with junction transport properties. The resistance and current–voltage characteristics of the junctions were measured at different temperatures.

2. Experimental details

Four-layer structures consisting of a base YBCO superconducting electrode, 150 nm thick, and a complex insulator, PBCO (50 nm)/STO (50 nm)/PBCO (50 nm), were deposited on (100)$SrTiO_3$ substrates by on-axis pulsed laser deposition at 800°C in 0.25 mbar oxygen pressure. The laser energy density was 1.2 J/cm^2 at a pulse frequency of 10 Hz. The films were cooled rapidly to 500°C at the pressure specified above, treated at 500°C in oxygen atmospheric pressure during 30 min and slowly cooled to 380°C for 30 min at the rate of 1°C/min. In order to optimize the deposition conditions of LSMO, YBCO/LSMO/YBCO multilayers were separately deposited on STO substrates at oxygen pressures of 0.2 mbar and temperature 740°C.

The ramps were etched by an Ar ion beam under an angle of 45° normal to the substrate plane while the substrate was rotated. An ion energy of 300 eV and ion beam current density of 0.2 mA/cm^2 were used for the ramp etch. The ramp layout was defined by a mask of hard baked S 1813 photoresist. After resist removal by an O_2 plasma, the ramps were cleaned, in sequence, by an Ar ion beam with ion energy of 100 eV and beam current density of 0.1 mA/cm^2 for 30 min, and by a low energy Ar/O_2 plasma. The substrates were then heated again to the deposition temperature in 0.4 mbar oxygen and held for 30 min to recrystallize the ramp surface. The $La_{0.67}Sr_{0.33}MnO_3$ barrier was epitaxially deposited and covered in situ with the top YBCO electrode. The deposition conditions of the LSMO and the top electrode were different from that of the bottom electrode. A deposition temperature of 740°C and oxygen pressure of 0.2 mbar were applied to avoid an interdiffusion at the interface. The thickness of barriers was chosen to be in the range of 10–30 nm. A 200 nm thick Au film was deposited and contact pads were defined by ion milling. The top electrode was patterned by Ar ion milling under an angle of 45°. The texture of the multilayer YBCO/LSMO/YBCO was analyzed by X-ray diffraction θ–2θ scan and ω scans. The temperature dependence of the resistance and current–voltage characteristics of junctions were measured by using a four-point method.

3. Results and discussion

The critical temperature of the YBCO films was 88–90 K with a transition width less than 0.5 K. The ramps were characterized by AFM. Ramps with roughness of less than 8 nm and angles of 26° were obtained under the above specified conditions.

In order to minimize the interdiffusion between LSMO and YBCO at elevated temperature the deposition processes for LSMO and YBCO films were optimized. With an oxygen pressure of 0.2 mbar, the temperature of the substrate during the deposition of the barrier and the counter electrode was about 60°C lower than that during the deposition of the bottom electrode. To test the film quality under these conditions, a test sample of a YBCO/LSMO/YBCO multilayer was grown on an STO substrate. YBCO and LSMO films were epitaxially grown with a pure c-axis alignment as indicated by the X-ray diffraction θ–2θ scan pattern and by rocking curves shown in Fig. 1.

Ramp-type junctions with different thicknesses of the LSMO barriers were studied. Junctions with 30 nm LSMO barriers had no superconducting current at 4.2 K. The temperature dependence of the resistance is shown in Fig. 2 by curve (a). A drop in the R–T curve at 90 K indicates the transition of the YBCO electrodes into the superconducting state. At this temperature, a single LSMO film should be in a metallic state and a resistance of a few ohms should be measured. However, in our case we observe an

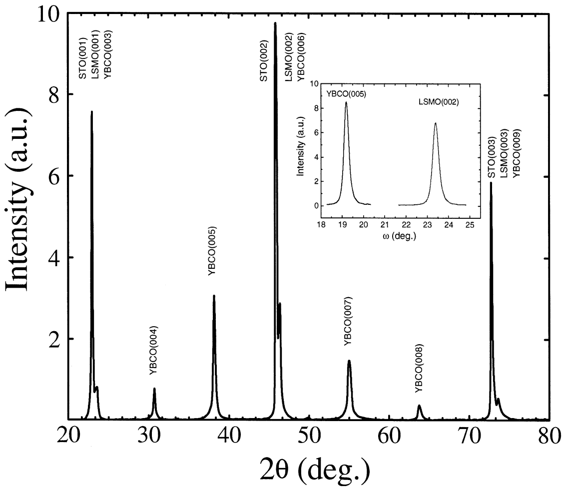

Fig. 1. X-ray diffraction pattern of a YBCO/LSMO/YBCO multilayer deposited on an STO substrate. The inset shows the rocking curves of LSMO (002) and YBCO (005) reflections.

increase in the resistance that can be related to the interface between YBCO/LSMO or to oxygen depletion of the LSMO/YBCO films. The inset shows the I–V curve of the junction at 4.2 K. The normal resistance of the junction was 330 Ω at 4.2 K. Junctions with LSMO barrier thicknesses of about 10 nm had a large superconducting current with flux-flow type I–V characteristics. This probably indicates the existence of shorts in the barrier. When the barrier thickness was 20 nm, the junction had a temperature dependence of the resistance as shown by curve (b) in Fig. 2. Fig. 3 shows (a) the I–V characteristics and (b) their dV/dI–V curves for an 8-μm wide junction with a 20-nm thick barrier at different temperatures. Additional conductivity is observed at high bias voltage in I–V curves at low temperature, while the conductivity is constant with bias voltage at 46 K. Subgap structures were seen in the dV/dI–V curves, and their locations are independent of temperature. A critical current density of the junction is 5.0×10^3 A/cm^2 at 4.2 K. The normal resistance of 300 Ω was determined at a voltage of about 100 mV. This means that the char-

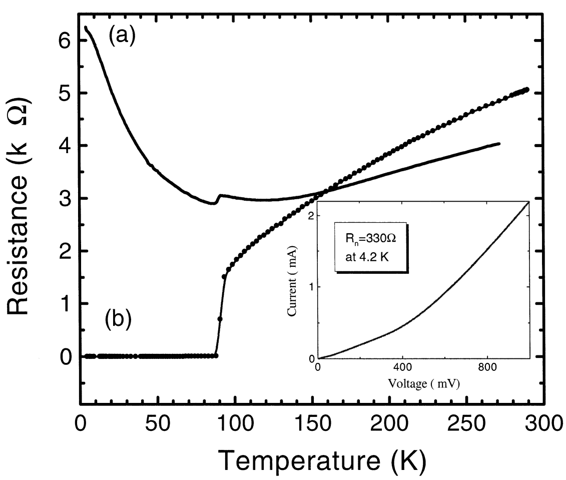

Fig. 2. The temperature dependence of the resistance of YBCO ramp-type junctions with (a) 30-, and (b) 20-nm thick LSMO barriers. The inset shows the $I-V$ curve of the junction in (a) at 4.2 K.

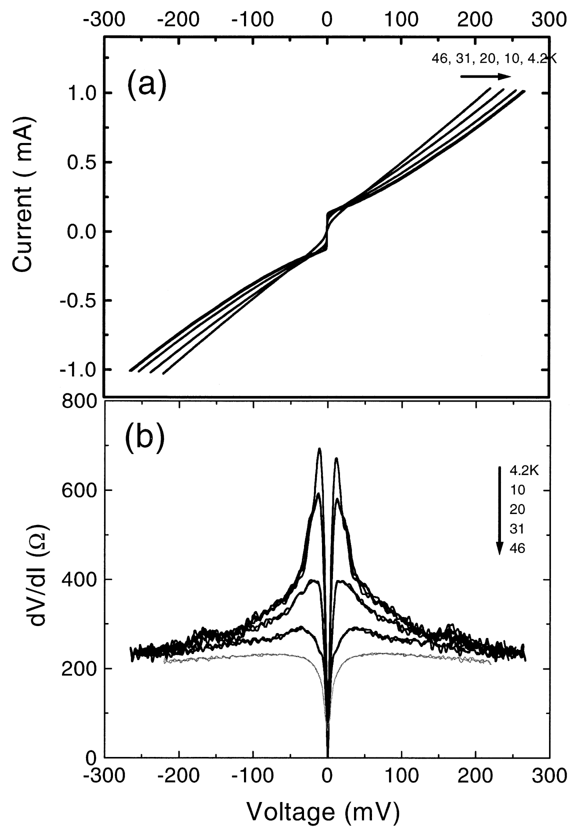

Fig. 3. (a) The $I-V$ curves and (b) $dV/dI-V$ curves of a YBCO ramp-type junction with a 20 nm thick LSMO barrier at different temperatures.

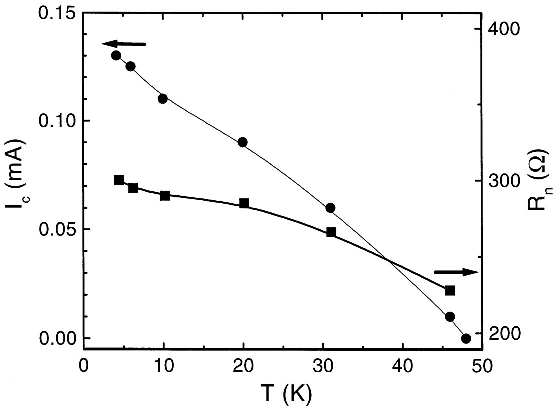

Fig. 4. The temperature dependence of critical current and normal resistance of an 8-μm wide ramp junction with a 20-nm thick barrier. (The lines are used only to guide the eyes.)

acteristic voltage of the junction is about 40 mV. The temperature dependences of the critical current and the normal resistance of the junction are depicted in Fig. 4.

Comparing the parameters of junctions with different barrier thicknesses, an interface resistance of 240 Ω was estimated for these junctions. It means that the junction properties are dominated by the S/FM interfaces. Even if the interface resistance were subtracted from the total resistance of the junctions, the calculated value of the barrier resistivity at 4.2 K was 0.36 Ω cm and this is still about two orders of magnitude higher than the usual value in bulk materials. A high resistance was reported in *c*-axis trilayer junctions with LCMO barriers by Bari et al. [3]. So far, we cannot figure out whether the higher resistance is due to an interface diffusion or is an intrinsic effect of the LSMO barrier. An oxygen depletion at the interface and inside the barrier may be a possible origin for the high resistivity. A further investigation is in progress.

4. Conclusion

In summary, we have deposited YBCO/LSMO/YBCO multilayers by on-axis pulsed laser ablation and fabricated YBCO ramp-type Josephson junctions with LSMO barriers on STO substrates. The temperature dependence of the resistance and *I–V* characteristics of the junctions were measured. The thickness of the LSMO barrier has obvious effects on the properties of the junctions. A superconducting current and too high normal resistance were observed in some junctions, but the origin of the high normal resistance is unknown at the moment.

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