Planar homogeneity of the electrical properties of YBa$_2$Cu$_3$O$_7$/La$_{0.7}$Sr$_{0.3}$MnO$_3$ bi-layers

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Abstract. The YBa$_2$Cu$_3$O$_7$/La$_{0.7}$Sr$_{0.3}$MnO$_3$ (YBCO/LSMO) microstructures represent model systems for investigating the interplay between two fundamental condensed-matter phenomena – superconductivity and ferromagnetism. Such microstructures make it possible to realize new types of devices for superconductor spintronics. In this work, the planar homogeneity of the electrical properties of YBCO/LSMO microstructures was investigated because of its importance for application in complex devices.

1. Introduction
Combining superconducting (SC) and ferromagnetic (FM) materials in joint heterostructures leads to a variety of effects due to various coupling mechanisms across the interface [1-4]. The ferromagnet/superconductor heterostructures are model systems for studying the interplay between two fundamental condensed-matter phenomena – superconductivity and ferromagnetism. The unique physical characteristics of such structures open possibilities for a great number of applications, such as magnetic sensors, magnetic recording and spintronic devices.

The high-temperature superconducting (HTS) material YBa$_2$Cu$_3$O$_7$ (YBCO, $T_c$ ~ 90 K) and the ferromagnetic (FM) material La$_{0.7}$Sr$_{0.3}$MnO$_3$ ($T_{Curie}$ ~ 350 K) are relatively well studied in view of creating HTS/FM YBa$_2$Cu$_3$O$_7$/La$_{0.7}$Sr$_{0.3}$MnO$_3$ (YBCO/LSMO) heterostructures. However, growing high-quality heterostructures of multicomponent materials, such as YBCO and LSMO, is not a trivial problem, as a minor difference in the technological conditions along the substrate can lead to a significant worsening of the quality and the planar homogeneity of the structure.

In this paper we report studies on the planar homogeneity of the electrical properties of YBCO/LSMO microstructures bearing in mind their importance for applications more complex devices.

2. Experimental
RF and DC magnetron sputtering techniques were used for growing bi-layers of ferromagnetic (FM) manganite La$_{0.7}$Sr$_{0.3}$MnO$_3$ and high temperature superconducting (HTS) YBa$_2$Cu$_3$O$_7$ thin films on

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SrTiO$_3$ (100) single crystal substrates. First, the FM LSMO thin film (with thickness $t_F \sim 30$ nm) was deposited by RF magnetron sputtering on a 10×10 mm$^2$ STO substrate. Then, the HTS YBCO thin film with the thickness $t_{SC} \sim 70$ nm was grown on top of the LSMO film using DC magnetron sputtering equipment. The growing procedure and growing conditions of the HTS YBCO and FM LSMO films and sandwiches were close to those used in the case of LaAlO$_3$ substrate [5, 6].

Afterwards, 28 microstrip motives of width 10 $\mu$m and length 5 $\mu$m were formed by photolithography and Ar ion beam etching on the 10×10 mm$^2$ SrTiO$_3$ substrate. The superconducting properties of the microstrips located in different areas of the substrate were investigated using four probe DC measurements.

3. Results and discussion

The single LSMO films deposited on the STO substrates were in FM state at room temperature. This was confirmed by the response of suspendent samples to the strongly inhomogeneous magnetic field of a permanent magnet. The temperature dependence of the resistance of an as-prepared LSMO/STO sample is shown in figure 1. It is typical for ferromagnetic manganite films of good quality. The insulator–metal transition temperature of the film is $T_{IM} \sim 320$ K, which means that the Curie temperature $T_{Curie}$ of the sample is greater than 320 K.

The critical temperature $T_c$ of the YBCO film in as-prepared YBCO/LSMO/STO bi-layers, measured using the four-probe method, was about 85 K (figure 2). The temperature dependence of the resistance $R$ of these bi-layers was nearly linear at $T > T_c$ due to the electrical shunting of the LSMO film by the YBCO one (which has a significantly lower $R$ and a linear temperature dependence of the resistance).

The YBCO/LSMO/STO bi-layers prepared were patterned using photolithography and Ar ion beam etching. The configuration (chip – figures 3 and 4) contained the current carrying microstrips, the narrow microstrip lines and the square shaped contact areas being used for measurement of the voltage drop in four probe measurements. Visual examination of the optical microscopy image of the chip showed its good quality and absence of large scale defects.

The temperature dependences of the resistance of the microstrips at different planar locations in the substrate are shown in figures 5-7. The selection of microstrips at the corner, at the edge and in the middle of chip was made randomly. The electrical characteristics of the microstrips (figure 5) located in the central area of substrate were close to those of the as prepared YBCO/LSMO/STO bi-layer (figure 2). They demonstrated a nearly linear temperature dependence of the resistance $R$ and a
superconducting transition temperature $T_c \sim 85$ K. Such microstrips are suitable for further focused ion beam machining in order to use them in more complex devices.

**Figure 3.** Fragment of the structures implemented.

**Figure 4.** Details of a microstrip in the structures implemented.

**Figure 5.** Temperature dependence of the resistance of a microstrip located in the central part of the substrate.

**Figure 6.** Temperature dependence of the resistance of a microstrip located at the edge of the substrate.

The resistance of the microstrip at the edge of the substrate was higher possibly due to the higher resistance of the YBCO component (figure 6). The electrical shunting capability of such YBCO layer is not sufficient to “transform” the temperature dependence of the resistance to a linear one, as is the case of as prepared bi-layers or of microstrips in the central area of the substrate. In spite of this, the microstrips demonstrate a sharp superconducting transition.

Microstrips at the corners of the chip were less or more degraded – some of them even fully, demonstrating a lower value of the critical temperature or absence of a superconducting transition (figure 7). Differences in the technological conditions (especially in what concerns the temperature regime) at the corner of the substrate in comparison with those in the middle of the substrate during the processes of growing and etching the bi-layer may cause such a degradation of the microstrips in the corner area.

**Figure 7.** Temperature dependence of the resistance of a microstrip, placed at the corner of the substrate.
Conclusions
In this paper, the planar homogeneity was investigated of the electrical properties of YBCO/LSMO microstructures. The analysis of the temperature dependence of the microstrip resistances in different areas of the sample revealed that the sample is practically homogeneous, although a certain inhomogeneity of the electrical parameters is only observed close to the corners of the structures. Thus, the planar homogeneity of the structures prepared is sufficient for the study of more complex superconductor/ferromagnet/superconductor microstructures.

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