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Negative and positive magnetoresistance in thick films of (Bi-2223)_{0.95}(LSMO)_{0.05}/LaAlO_3 composites

O. Paredes^a, O. Morán^b, D. Fuchs^c and E. Baca^d

^aCentro de Investigaciones en Materiales, Facultad de Ingeniería, Universidad de Nariño, Ciudad Universitaria Torobajo, Pasto, Colombia.
^bLaboratorio de Materiales Cerámicos y Vitreos, Departamento de Física, Universidad Nacional de Colombia, Sede Medellín, A.A. 568, Medellín, Colombia.
^cKarlsruhe Institute of Technology, Institut für Festkörperphysik, P.O.Box 3640, Karlsruhe, Germany.
^dGrupo de Ingeniería de Nuevos Materiales, Departamento de Física, Universidad del Valle, A.A. 25360 Cali, Colombia.

E-mail: eval.baca@correounivalle.edu.co

We have investigated the structural, electric transport, magnetoresistance, and magnetic properties of nominal (Bi-2223)_{0.95} (LSMO)_{0.05} thick films ground on (001)LaAlO_3 (LAO) substrates. Bi-2223 is the Bi_{2}Pb_{1-y}Sr_{2}Ca_{2}Cu_{3}O_{6+y} superconducting ceramic and La_{0.7}Sr_{0.3}MnO_{3} (LSMO) is a manganite. The X-ray diffraction patterns (XRD) of the composites exhibited most of the reflections parallel to the [00ℓ] direction suggesting a highly oriented growth along the c-axis of LSMO, Bi-2212 and Bi-2223 layers and the preferred orientation with the crystal c-axis being perpendicular to the plane of the LAO substrate. Electric and magnetic measurements shown the presence of ferromagnetic and superconducting phases at room temperature and below to 54 K respectively. Diamagnetic and ferromagnetic hysteresis loop at 5 K and 100 K under in-plane and out-of-plane regimens and negative to positive magnetoresistance crossover into (Bi-2223)_{0.95}(LSMO)_{0.05} composite at 84 K was also observed.

Keywords: Superconducting ceramics; manganites; magnetoresistance.

We investigamos las propiedades de transporte eléctrico, magnetoresistencia, y magnéticas de películas gruesas de las compositas (Bi-2223)_{0.95} (LSMO)_{0.05}/(001) LAO. Los patrones de difracción del análisis de rayos-X mostraron reflexiones paralelas a las direcciones [00ℓ] lo cual indica que los compuestos de la composita crecieron orientados altamente en la dirección perpendicular al plano del sustrato (001) LAO. Las medidas de transporte eléctrico y magnético mostraron la presencia de las fases ferromagnética y superconductora respectivamente por encima y por debajo de 54 K. Se presentan los lazos de histéresis diamagnético a 5 K y ferromagnético a 100 K medidos cuando el campo magnético es aplicado paralelo y perpendicular al plano del substrato. En las medidas de magnetotransporte a 84 K se observa un punto de cruce ente la magnetoresistencia positiva y negativa.

Descriptores: Cerámicas superconductoras; manganitas; magnetoresistencia.

1. Introduction

Superconductivity (SC) and ferromagnetism (FM) represent antagonistic orderings, a lot of work has been dedictate to reveal the possible coexistence and interplay in SC/FM heterostructures and composites being an active area of theoretical and experimental research for last few years [1-6]. These studies have been showed strong approximation effects, which can be exhibit coexistance between superconducting and ferromagnetic phases, strong magnetic anisotropy, and also crossover of negative/positive magnetoresistance [1-7]. All these effects and properties are a supply of rich physical information, where the antagonism between SC and FM is understandable from microscopic theory. Using first principles, SC requires an attractive interaction between electron pairs with antiparallel spins for the formation of Cooper pairs, but the same electrons can be participating in magnetic ordering which demand a parallel alignment of electron spins through an exchange interaction. If in a SC/FM heterostructure or composite the exchange field of FM exceeds the superconducting energy gap then the superconductivity suppression can occur due to paramagnetic effect [1-8]. However, in SC/FM heterostructures or composites both superconductivity and ferromagnetism can coexist because of proximity effect and generate mutual interactions between superconducting and ferromagnetic materials. Now, the literature report great account of information about these subjects join with approximation effect models [1-5,9]. As advance in this study, we present the preparation technique, and electrical and magnetic characterization of (Bi-2223)_{0.95}(LSMO)_{0.05} composites ground in form of thick films on (100) LaAlO_3 substrates.

2. Experimental

Powders of LSMO were obtained via the Pechini method and the nominal Bi-2223 by solid state reaction technique. Thick (Bi-2223)_{0.95}(LSMO)_{0.05} films were deposited by melting-
quenching- annealing (MQA) on (001) LaAlO$_3$ substrates, mixing 95% of Bi-2223 powders, 5% of LSMO powders mixing with acetone to assure an uniform composite paint. The (100)LaAlO$_3$ were coated with the composite paint, melted at 1050°C, quenched up to room temperature at 175°C/min, and finally annealed at 840°C for 48 hours and quenching again to room temperature. More details of the samples preparation are presented in the Ref. (O. Paredes et al., Physica C to be published). XRD was performed on the samples. For the electric, magnetic and magnetoresistance characterization a PPMS system was used in the temperature range between 2 K and 400 K.

3. Results and discussion

X-ray diffraction patterns of the film are presented in the Fig. 1 between 20 values of 20° and 100°. There only exist (00l) peaks attributed to Bi-2212, Bi-2223, and LSMO besides (00l) peaks of the LAO substrate implying that the film is c-axis oriented. XRD patterns between 20 values from 20° and 40° no showed here the basic peaks of the Bi-2212, Bi-2223 phases. Exactly, the peak around to 28.886° is used to calculate Bi-2223 phase purity obtaining a value of 66% and 44% of Bi-2212 phase [10]. The positions of peaks were used to obtain the respective lattice parameter c for LSMO compound, Bi-2212 and Bi-2223 phases that correspond to 0.360 nm, 3.02 nm and 3.60 nm respectively in according compound, Bi-2212 and Bi-2223 phases that correspond to used to obtain the respective lattice parameter c and 44% of Bi-2212 phase [10]. The positions of peaks were used to obtain the respective lattice parameter c for LSMO compound, Bi-2212 and Bi-2223 phases that correspond to 0.360 nm, 3.02 nm and 3.60 nm respectively in according with literature report. The average grain size was calculated by Scherrer’s equation using the LSMO and Bi-system XRD lines obtaining the ~35 nm and ~38 nm values respectively.

Figure 2 exhibits the temperature dependence of resistivity at 0 T and 2 T, and its magnetoresistance for thick (Bi-2223)$_{0.95}$(LSMO)$_{0.05}$ film composite. The bulk Bi-2223, and Bi-2212 resistivity at room temperature is approximately two orders of magnitude smaller than nominal (Bi-2223)$_{0.95}$(LSMO)$_{0.05}$ composite, which is indicative that the carrier concentration into composite decreases as percentage of LSMO is 5%. At 53 K and 0 T the composite is superconducting with an onset at 100 K associated to Bi-2223 and Bi-2212 phases. The decreasing of T$_C$ in the (Bi-2223)$_{0.95}$(LSMO)$_{0.05}$ composite is due to the injection of the polarized spins from LSMO into superconducting grains at the grain boundaries, breaking the Cooper pairs and decreasing its concentration. At 2 T, occurs the typical behavior of decreasing T$_C$ for superconducting materials, and increasing of T$_{Curie}$ in the FM materials, but with the cross-over effect at 86 K from negative to positive magnetoresistance MR. Behavior of MR [$\rho(5T) - \rho(0)$]/$\rho(5T)$ as a function of temperature is plotted in the same Figure 2, where the negative MR (MR) and positive MR (MR$^+$) are clearly observed above and below ~86 K respectively. MR is associated with the small amount of LSMO in the composite, while MR$^+$ corresponds to superconducting matrix, which is approximately one order of magnitude larger than MR due to its large superconducting diamagnetic signal. Note the abrupt transition of MR to MR$^+$ around of 86 K. MR$^+$ is a natural response of a superconducting material under an applied magnetic field, which is exhibited by the increasing of resistivity into superconducting transition region (T$_C$<T<T$_{onset}$), decreasing the critical temperature and superconducting current density. Between 86 K and 400 K, MR showed itself two minimums at 100 K that correspond to the superconducting onset and 375 K where the metal-insulator transition of ferromagnetic material occurs. Minimum at 100 K can be associated to interaction between great concentration of polarized carriers of LSMO and paraconducting carriers into superconducting transition region. In this region the Bi-Systems amalgamate normal carriers and Cooper pairs highly sensible to temperature and electric and magnetic fields. Minimum at 375 K, metal-insulator transition, is typical in a pure polycrystalline manganite.

![Figure 1](image1.png)

**Figure 1.** XRD patterns for the the (Bi-2223)$_{0.95}$(LSMO)$_{0.05}$/LAO thick film.

![Figure 2](image2.png)

**Figure 2.** Temperature dependence of the resistivity, $\rho$(T), MR$^+$, and MR at 2 T of a (Bi-2223)$_{0.95}$(LSMO)$_{0.05}$/LAO thick film.
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Figure 3. Ferromagnetic and superconducting diamagnetic hysteresis loops of a Bi-2223)$_{0.95}$(LSMO)$_{0.05}$/LAO thick film as a function of the magnetic field applied in-plane and out-of-plane at a) 100K, and b) 5 K.

Figure 3 shows magnetic field dependence of magnetization at 100 K and 5 K when the field is applied out-of-plane and in-plane. Figure 3(a) shows the composite hysteresis loops at 100 K $> T_C$. Here a ferromagnetic-type hysteretic behavior is observed only with the presence of LSMO 5 % into composite. A smaller saturation magnetic field $\mu H_S$, also is observed, under in-plane than the out-of-plane regime, attributed to the LSMO easy-axis parallel to plane substrate. On the contrary, Fig. 3(b) shows the hysteresis loops at 5 K $< T_C$, exhibiting a superconducting diamagnetic response. Here, the ferromagnetic signal due to LSMO 5 % is inexcistent under in-plane and out-of-plane regimens indicating that superconducting diamagnetism is dominant at 100%. This behavior is very different to similar effect found in epitaxial F/AF/S and F/S/F trilayers, where F is La$_2$/3Ca$_{1/3}$MnO$_3$, AF is La$_{1/3}$Ca$_{2/3}$MnO$_3$ and S is YBa$_2$Cu$_3$O$_{7-\delta}$ [4]. In these trilayers a superconducting diamagnetic behavior out-of-plane, and a ferromagnetic behavior in-plane at 5 K $< T_C$ is present. Proximity effects in both cases play a fundamental role to explain the coexistence and interplay between magnetism and superconductivity. Data of Fig. 3(b) show also an anisotropic superconducting phase effect when the magnetic field is applied in-plane and out-of-plane.

4. Conclusions

In summary, we have been prepared and characterized structural, electrical and magnetically thick films of (Bi-2223)$_{0.95}$(LSMO)$_{0.05}$ composites onto (001) LAO substrates. Ferromagnetic and superconducting phases, as well as MR and MR$^+$ are clearly determined above and below 86 K. The composite thick films showed a rather textured growth with the crystal c-axis being perpendicular to the plane of the substrate. The presence of the superconducting and ferromagnetic phases of the constituents was demonstrated by careful electrical and magnetic measurements. A sharp crossover from negative to positive magnetoresistance was observed at $\sim$80 K in a 5 T magnetic field, and an anisotropic superconducting phase of Bi-2223 was also observed with the M-H measurements at T=5 K $< T_C$.

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