Conductivity Fluctuation of $YBa_2Cu_3O_{7-\delta}$/Sr_2YSbO_6/$SrTiO_3$ Thin Films

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Thermal fluctuations in the electric conductivity of $YBa_2Cu_3O_{7-\delta}$ superconducting thin films grown on Sr_2YSbO_6 novel substrate materials in the film form were experimentally studied. $YBa_2Cu_3O_{7-\delta}$ films were grown by using a *dc*-technique on Sr_2YSbO_6 substrates, which were produced by *rf* magnetron sputtering. X-ray diffraction analysis evidenced that the Sr_2YSbO_6 films grow on conventional $SrTiO_3$ substrates in a preferential orientation along the (100) planes direction with lattice parameter a=4,43(2) Å. The $YBa_2Cu_3O_{7-\delta}$ thin films, grown on Sr_2YSbO_6 films, exhibit an oriented growth in the (001) crystallographic direction, with lattice constant c=11,65(9) Å. Morphological characterizations were performed by means atomic force microscopy. Experiments of electrical resistivity show that the $YBa_2Cu_3O_{7-\delta}$ films present a normal-superconducting transition with critical temperature T_c=82,33 K. Fluctuation analysis for the $YBa_2Cu_3O_{7-\delta}$ thin films were performed by utilizing the concept of logarithmic derivative of the conductivity excess. Above the critical temperature T_c we experimentally determine the occurrence of Gaussian 3D, 2D and fractal fluctuation regimes. A genuinely critical region identified by the exponent λ_{CR}=0,35 were obtained close to T_c. This critical regime is effectively described by the 3D-XY model.

Keywords: Fluctuation conductivity; New materials; Substrates; Superconducting films

I. INTRODUCTION

There are currently immense research interests in perovskite oxide materials containing rare-earth metals. Because of their varied structure, composition, physical and chemical characteristics, these materials have attracted intense research activities in many applied and fundamental areas of solid state science and advanced materials research. Earlier investigations in 1950s and 1960s [1] identified a large group of materials, which have the basic perovskite ABO_3 structure, or a small distortion of that structure. These complex perovskite oxides generally have the formula $A_2BB'O_6$ or $A_3B_2B'O_9$ and result from the ordering of B and B' cations on the octahedral site of the primitive perovskite unit cell. Due to the increased flexibility in lattice parameter, complex perovskite oxides have been extensively investigated in recent years as new substrate materials for films of high T_c superconductors [2], which are based on the perovskite structure.

In view of the above promising characteristics of complex cubic perovskites, we have synthesized a new ceramic substrate material Sr_2YSbO_6 (SYSO). In order to obtain SYSO samples with more ordering degree when compared with the bulk samples, we produce films of this material on conventional $SrTiO_3$ (STO) single-crystals. There are experimental evidences that the substrate material improves some the characteristics of the high temperature superconducting thin films [3]; for this reason we grow $YBa_2Cu_3O_{7-\delta}$ (YBCO) superconducting films on SYSO novel material substrates in the film form.

One characteristic and relevant effect of the cuprate high temperature oxides, concern to the thermal fluctuations near the normal-superconducting transition. These effects are enhanced in these materials due the very short coherence length, high critical temperature and strong planar anisotropy [4]. The aim of this work is to analyze the contribution of the thermal fluctuations on the electric conductivity near T_c for YBCO/SYSO/STO films and compare with the recognized behaviour of this fluctuation contribution for YBCO/STO superconducting thin films [5]. We find three Gaussian fluctuation regimes by means the utilization of the Kouvel-Fisher analysis method. The correlation lengths of these regions of evanishing Cooper-pairs were obtained along the crystallographic c axis by applying the Ginzburg-Landau theory concepts. The scaling theory analysis permitted to determine one genuinely critical region which gives information about the degree of anisotropy of the superconductor and the symmetry of the order parameter.

II. EXPERIMENTAL SETUP

SYSO has been prepared by a solid-state reaction process. Stoichiometric ratios of the precursor powders SrO, Y_2O_3 and SbO_2 (purity 99.99%) were finely ground and thoroughly mixed. The precursor powder was pressed into a disc and the material was calcined at 1100 ^oC for 200 h in ambient atmosphere. With nickel-filtered CuK_α radiation (λ=1.5406 Å) of a SIEMENS D5000 diffract meter, X-ray diffraction (XRD) spectra were taken of this calcined powder, which showed a multiple-phase structure. The XRD pattern of the sintered material showed a single-phase structure. Thick films of SYSO were produced by using the known rf-magnetron sputtering technique. The target utilized was a stoichiometric polycrystalline sintered pallet of SYSO (25,4 mm diameter, 3,0 mm thickness). The temperature at a conventional STO substrate was 800 ^oC, the oxygen pressure was 2 mbar, the applied rf-magnetron has a power of 70 Watt and the distance target-substrate was 26 mm. After analyzed the structural, morphological and compositional quality of SYSO films, a high-pressure (3,5 mbar) dc-sputtering technique [8] was used to grow YBCO superconducting thin films (300 nm thickness) over the SYSO/STO substrates. The chemical stability and the crystallographic parameter coupling of the YBCO/SYSO/STO films were analyzed from XRD experiments. Morphological characterization of samples was systematically performed from atomic force microscopy (AFM). Transport properties were examined by performing the conventional four-probe DC electrical resistivity measurements.

III. STRUCTURAL AND MORPHOLOGICAL RESULTS

The microscopic structure of target, SYSO/STO film and YBCO/SYSO/STO superconducting films was analyzed by X-ray diffraction. Fig. 1 shows X-ray diffraction pattern of the SYSO polycrystalline target. This pattern consists of strong peaks which are characteristics of a primitive cubic perovskite plus a few weak line reflections arising from the super-lattice. No evidence for a distortion from the cubic symmetry is observed in the XRD spectrum. In the SYSO composition, Sr^{+2} with the largest ionic radius (1,13 Å) occupies position A of the complex cubic perovskite, Y^{+3} (ionic radius 0,93 Å) and Sb^{+5} (ionic radius 2,45 Å) cations occupy the B and B' positions. Due to the ordering of B and B' on the octahedral site of the ABO_3 unit cell, there is a doubling in the lattice parameter on the basic cubic perovskite unit cell. Thus, the whole XRD pattern of SYSO can be indexed in a $A_2BB'O_6$ cubic cell with the cell edge $a = 2a_p$, where a_p represents the cell lattice of the cubic perovskite.

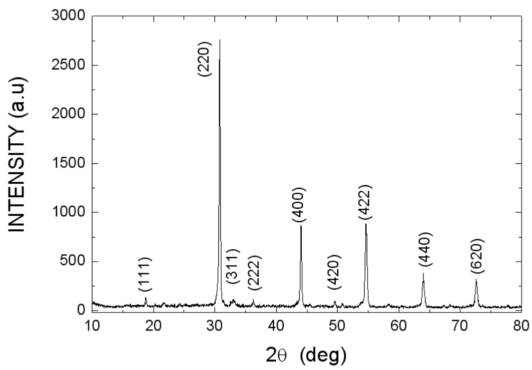

FIG. 1: Diffraction pattern of SYSO polycrystalline target.

The XRD spectrum of SYSO is similar to $A_2BB'O_6$-type complex cubic perovskite oxides reported in the JCPDS (Joint Committee on Powder Diffraction Standards) files, as judged by the similarity in d spacing and intensity ratios. The presence of the superstructure reflection lines (111) and (311) in the XRD spectrum of SYSO is the signature of an ordered complex cubic perovskite structure. In a substitutional solid solution BB', there is a random arrangement of B and B' on equivalent lattice positions in the crystal structure. It upon stable heat treatment, the random solid solution rearranges into a structure in which B and B' occupy the same set of positions but in a regular way, such a structure is described as superstructure. In the superstructure, the position occupied by B and B' are no longer equivalent and this feature is exhibited in the XRD spectrum of the material by the presence of superstructure reflection lines.

Figure 2 shows the diffraction pattern of YBCO/SYSO/STO. We can see the typical peaks (200) and (300) of the STO single crystal. Other peaks corresponding to the YBCO, oriented along the [00λ] direction, with lattice parameter c = 11,65(1) Å were identified and the (400) peak of SYSO is observed. Clearly the SYSO films growth with a preferential orientation along the (100) planes direction with crystallographic parameter a=4,43(2) Å, which is closely compatible with the target value. This result is a strong evidence of the chemical stability at the interface between these materials, e. g., there is no chemical reaction between SYSO and YBCO films.

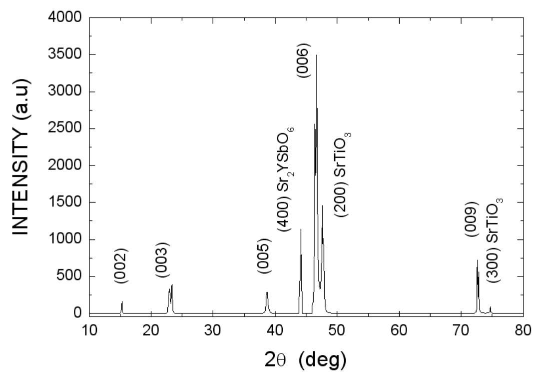

FIG. 2: Diffraction pattern of YBCO/SYSO/STO films.

AFM analysis was performed to determine the superficial characteristic of films. Fig. 3(a) show the image of SYSO/STO for 2 μm scale. We can see uniform grains with 0,1239(4) μm size.

Figure 3(b) belongs to photography of AFM for a YBCO/SYSO/STO film. At 2 μm scale, is evident that the grains are uniform and they are bigger in the films grow for more hours. This result permits to infer that the size of grain is dependent of the deposition time, so we find that the grain in films grow for one hour is 0,0891(1) μm and in films grow for three hours is 0,2485(7) μm. The wrinkled too is depend of the deposition time: in first case is 0,0068(4) μm and in

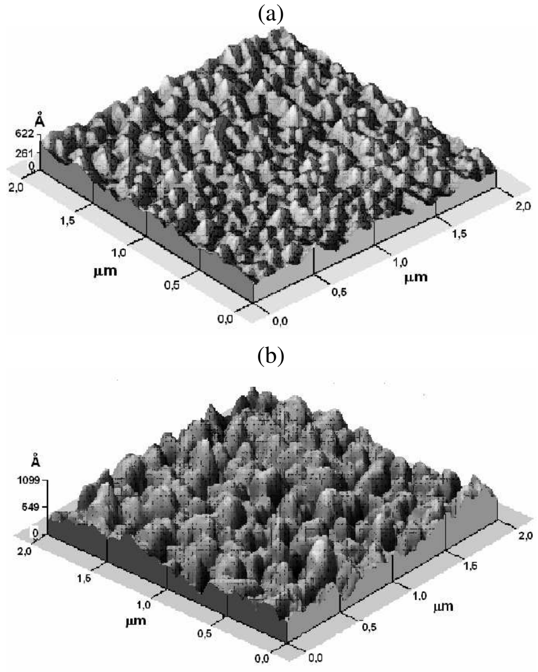

FIG. 3: AFM photograph of (a) SYSO/STO and (b) YBCO/SYSO/STO.

second is 0,0161(3). The percentage cover have the similar dependence, is 44,6997(9)% in the first case and 48,6087(5)% in the second case.

IV. FLUCTUATION ANALYSIS

The analysis of results for the fluctuation contribution on conductivity is performed by assuming that the conductivity excess is given by [4]

$$\Delta\sigma = \sigma - \sigma_R, \tag{1}$$

where σ is the measured conductivity, i.e., $\sigma=1/\rho$, and $\sigma_R=1/\rho_R$ is the regular term extrapolated from the high-temperature behavior. According to the Aslamazov-Larkin proposal [6], the fluctuation conductivity diverges as a power law of the type

$$\Delta\sigma = A\varepsilon^{-\lambda}, \tag{2}$$

where A is a constant, $\varepsilon=(T-T_c)/T_c$ is the reduced temperature and λ is the critical exponent. Analogously to the Kouvel-Fisher method of analysis of critical phenomena [4], the logarithmic temperature derivative of $\Delta\sigma$ is given by $\frac{d}{dT}\ln(\Delta\sigma)$. Then, we define the quantity

$$\chi_\sigma = -\frac{d}{dT}\ln(\Delta\sigma) = \frac{1}{\Delta\sigma}\frac{d(\Delta\sigma)}{dT}. \tag{3}$$

By substituting equation (2) in equation (3) it is obtained that

$$\frac{1}{\chi_\sigma} = \frac{1}{\lambda}[T-T_c]. \tag{4}$$

This quantity is known as the inverse of the logarithmic temperature derivative of $\Delta\sigma$. Thus, obviating more complex procedures of adjustment, simple identification of linear temperature behavior in plots of $\chi_\sigma^{-1}(T)$ allows simultaneous determination of critical temperature T_c of fluctuation regime and the corresponding critical exponent.

For YBCO/SYSO/STO thin films we clearly discerned three regions characterized by Gaussian fluctuations, as shown in figure 4. Farthest from T_c we identified the exponent $\lambda_{2D} = 0,98 \pm 0,02$, which is an average value over several measurements. When the temperature approaches T_c from above, successive crossovers to the regimes characterized by the exponents $\lambda_{3D-2D} = 0,62 \pm 0,02$ and $\lambda_{3D} = 0,47 \pm 0,03$ were observed. According to the Aslamazov-Larkin [6] and Char-Kapitulnik theories [7], the Gaussian exponents are given by

$$\lambda = 2 - \frac{\tilde{d}}{2}, \tag{5}$$

where $\tilde{d}$ represents the dimensionality for the fluctuation spectrum. From (5) it is clear that λ_{2D} and λ_{3D} correspond to homogeneous 2D and 3D Gaussian fluctuation regimes, in agreement with previous observations in YBCO thin films [5], YBCO granular samples [4] and YBCO single crystals [8]. In the temperature region identified by λ_{3D-2D}, the fluctuation system develops in a space having fractal topology [7] with dimensionality $\tilde{d} = 2,76$. This can be explained as a crossover of the fluctuation system between 2D and 3D. By assuming that the coherence length varies as in the Ginzburg-Landau theory, $\xi_c(T) = \xi_c(0)\varepsilon^{-\frac{1}{2}}$, it is possible to determine the characteristic correlation length of the fluctuation regimes along the c crystallographic axis.

Using $\xi_c(0)$=2 Å [9], for the λ_{3D} regime $\xi_c \approx$12-15 Å, which is clearly three-dimensional when compared with the c lattice parameter of the YBCO material. By using the Lawrence-Doniach model [10] in the 3D limit, we estimate from the amplitude A in equation (2) that the coherence length perpendicular to the Cu-O planes is $\xi_c(0) = 1,14 \pm 0,02$. These values are in good agreement with other estimations [5].

A fourth power-law regime in $\chi_\sigma^{-1}(T)$ was identified closely above the critical temperature, which is characterized by $\lambda_{CR} = 0,35 \pm 0,02$. This behaviour is due to genuine critical fluctuations and the theoretical value predicted by Lobb [11] is $\lambda_{CR} = 0,33$. In this 3D-XY model, the critical exponent is given by $\lambda_{CR} = \nu(2+z-d+\eta) \cong \frac{1}{3}$, where $\nu \cong 2/3$ is the coherence length critical exponent, $z \cong d/2$ is the dynamical critical exponent, $d = 3$ represents the dimensionality of

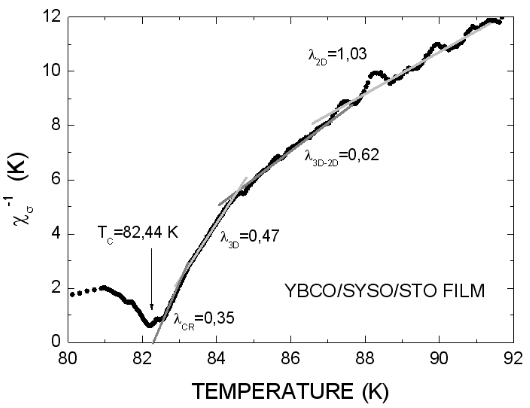

FIG. 4: Fluctuation regimes in plot of the inverse of logarithmic temperature derivative for YBCO/SYSO/STO thin films.

the system and $\eta \approx 0$ describes the exponent of the order parameter correlation function. The value of z defined above corresponds to the dynamic universality class of the *Model E*, in the classification of the full dynamical scaling theory of Hohenberg and Halperin [12-13].

V. CONCLUSION

Films of SYSO substrate perovskite was produced and characterized. X-ray diffraction revealed that this material belongs to the complex cubic perovskite family and show the oriented growth of the film along the c crystallographic axis. The lattice parameters were determined by the X-ray diffraction patterns. Highly orientated along c-lattice axis YBCO/SYSO/STO films were systematically growth and analyzed by X-ray diffraction and AFM. Crystallographic analysis revealed that there chemical stability at the interface between SYSO and YBCO materials. The AFM results showed the uniform and granular character of films and permitted to determine the corresponding grain sizes. The analysis of fluctuation conductivity shows the occurrence of homogeneous 2D and 3D Gaussian regimes above T_c. Additionally, temperature region dominated by fractal fluctuations 3D-2D was observed. Closer to T_c we observed a genuine critical regime, which is described by the 3D-XY-E universality class model, as in many investigations on fluctuation effects [4,5,8,13].

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