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THE INFLUENCE OF PARTIAL PRESSURE OF SPUTTERING GASES ON THE ELECTRICAL RESISTANCE OF Bi:2201 THIN FILMS

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ABSTRACT: $Bi_{2.1}Sr_{1.9}CuO_y$ superconducting thin films(Bi:2201) were deposited onto heated single crystal (100) MgO substrates by using an inverted cylindrical DC magnetron sputtering under a sputtering pressure of 1 mbar. The sputtering gas was a mixture with the ratio of O_2/ Ar in the range 0.3/0.7 to 0.4/0.6.The partial pressure of oxygen plays an important role regarding the behavior of normal state resistivity function of temperature.

KEYWORDS: Bi:2201 thin film, DC magnetron sputtering, electrical resistance.

1. INTRODUCTION

Deposited as epitaxial thin films, Bi:2201 is a good opportunity for fundamental studies and applications of copper oxide superconductors. However , it is difficult to prepare high quality thin films for this use. There are several reports about the epitaxial growth of Bi:2201 thin films by magnetron sputtering using Pb-doped [1] and La doped [2] planar target. This technique was used to prepare high quality superconducting $Bi_2Sr_2Cu_2O_{6+d}$ (Bi-2201) thin films. Some deviations of the Sr stoichiometry or of both Bi and Sr are suggested to be necessary to obtain a superconducting 2201 phase [3,4].

The evolution of the resistivity of single layer Bi:2201 thin films was studied at various oxygen concentration obtained after successive annealing treatments or by using different concentration of oxygen in sputtering gas [5-7].

In this paper, we will report our studies on deposition and structural properties of c-axis films deposited on MgO substrates using inverted cylindrical magnetron sputtering.

2. EXPERIMENTAL

The inverted cylindrical magnetron resolves three important issues for thin film growth by cathode sputtering: low resputtering effect, high growth rate and film homogeneity. The sputtering gas was a mixture of O_2 and Ar with the following ratio:0.4/0.6(Sample F9); 0.35/0.65(sample F10); 0.3/0.7(Sample F4).The deposition pressure was 1mbar for all samples.

The sputtering was carried out in DC mode with a power of 25W.Before each deposition the target was presputtered for 30 minute. Substrate temperature was kept at 700^0C,an optimized temperature regarding to the epitaxial and compositional properties of the films, for all depositions in this study. The deposition time was 1.5 h leading to the thin film thickness of approximately 120nm. After deposition, the films were annealed at 500^0C in an oxygen atmosphere (1 mbar) for 30 min. XRD patterns of all thin films show a c-axis orientation revealed by the presence of peaks associated to (00l) planes. The films are chemically patterned and equipped with silver sputtered contacts pads. The temperature dependence of the in-plane resistivity is measured by using a standard four probe DC method.

3. RESULTS AND DISCUSSION

Figure 1 shows the temperature dependence of electrical resistance R_{ab} for three thin film sample (F9,F10 and F4) obtained for f_{O2}=0.4;0.35 and 0.3 oxygen concentration, respectively, in sputtering gas.

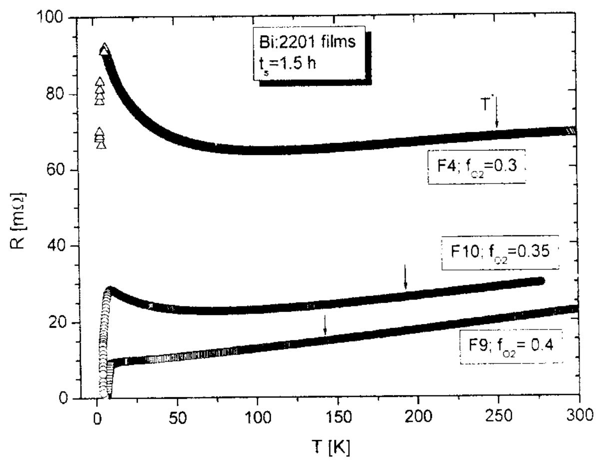

Figure 1*. Electrical resistance as a function of temperature for Bi:2201 thin film samples obtained at various oxygen concentration f_{O2} for sputtering gas.*

Near the room temperature, electrical resistance increases by decreasing oxygen content in the sputtering gases and the critical transition temperature in superconducting state decreases from T_c = 10.6 K to 4.5 K with decreasing f_{O2} from 0.4 to 0.35. The R(T) dependence for sample F9 (f_{O2}=0.4) corresponds to optimally doped regime and shows a T-linear behavior above T^*=148 K. The temperature T^* below which R(T) deviates from "metallic" behavior was attributed to the pseudogap opening [8]. The effect of decreasing oxygen content in sputterig gas is that R(T) deviates from the linear behavior at high temperatures T^*=192 K and 250K for f_{O2}=0.35 and 0.3 respectively. This result agrees by the decrease of carrier concentration by decreasing f_{O2}. As a result, before the superconducting transition, an upturn in electrical resistance and the decrease of T_c suggest an underdoped system(film F4 and F10). The origin for the increase of electrical resistance may be in the localisation of mobile carriers because of the disorder in the crystal potential induced by oxygen carriers. The R(T) dependence for the above insulating behavior may be explained by the thermal activated or hopping type of conduction.

For the activation energy E_a = / E_F - E_c / realized by thermal excitation from Fermi energy E_F to the mobility edge E_c electrical resistance has the following temperature dependence:

$$R = R_0 \exp [E_a/(k_B T)] \quad (1)$$

Another process which explains the charge transport at low temperature is the variable -range - hopping (VRH) among the localized states near the E_F [9,10]. The VRH resistance is of the form:

$$R = R_0 \exp[(T_0/T)^{\alpha}] \quad (2)$$

with T_0 a characteristic temperature and α a constant that is determined by the precise conditions of hopping processes. By assuming that the density of states $N(E_F)$ is energy independent we obtain the case of Mott variable range hopping with α =1/3 and α =1/4 in 2D and 3D dimension respectively. A value α =1/2 in 3D was obtained for low carrier concentration for electron-electron repulsion and the presence of a soft Coulomb -gap around the Fermi level [11]. To check the validity of the activated or hopping type of conduction, the resistance data for F4 sample in the insulating region was analyzed.

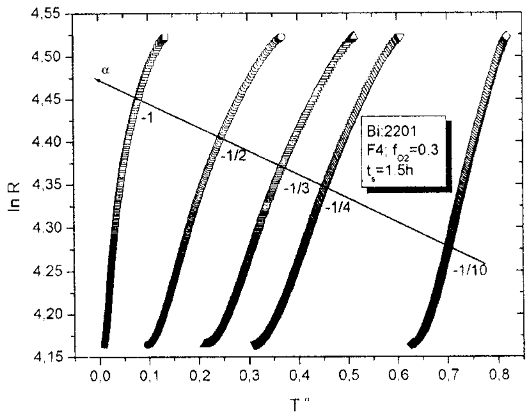

Figure 2. *The low temperature part of ln R plotted versus T^{α} for F4 film.*

From this figure is clear that only for α =-1/10 some linearity behavior is obtained. Because the limit α =-1/10 yields a good linearity than the classical hopping transport (α =-1/3,-1/4) our data are not well described in the VRH processes.

Magnetoresistivity measurements in high magnetic field and low temperatures for Bi:2201 [12]. Ba_2Cu_3Oy and $Y_{1-x}Pr_xBa_2Cu_3Oy$ [13] thin films shows that ρ_{ab} diverge as~ ln T. These results were analyzed in the relation by the possibility of stripe formation in the CuO_2 planes. To check the validity of this observation for our Bi:2201 thin films, in figure 3 the in plane electrical resistance R_{ab} was replotted versus ln(T). From these two plots, a linear behavior R(lnT) can be observed in the temperature range 8K-33K and 11K-33K for samples F10 and F4, respectively.

In presence of stripe fragmentation, charge carriers have to hop to another metallic stripe , passing the intercalating Mott insulator, also resulting in an increased resistivity. Recentely, in a model for a strong correlated electronic system in presence of non magnetic impurities was assumed a power law energy dependence of density of states. A lnT dependence for R(T) was obtained if the electron correlations lead to a singular density of states, without taking into consideration the localization effects. [14].

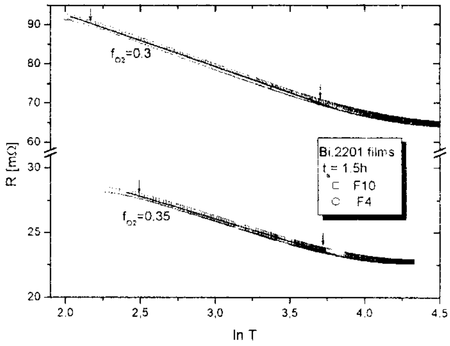

Figure 3*.Resistance versus lnT for F10 and F4-Bi:2201 thin film*

4. CONCLUSIONS

By using different partial pressure of oxygen in sputtering gas of inverted cylindrical DC magnetron sputtering, epitaxial Bi:2201 thins films were deposited onto MgO substrate.

By decreasing the partial oxygen pressure from 0.4 mbar to 0.3 mbar, the obtained thin films shows above the superconducting transition a electrical resistance which changes from metallic to insulating behavior.

The temperature dependence in the insulating region is not very good described for the thermal activated VRH processes. The linear dependence of electrical resistance as a function of ln(T) agree with the model for fragmentation and pinning of stripes in CuO_2 planes and with the model which of a non-Fermi –liquid model with a singular density of states and a randomly distributed nonmagnetic impurities.

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