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Temperature and electric-field dependencies of PBCO c-axis resistivity in YBCO/PBCO/Au structures

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The current-voltage characteristics of YBCO/PBCO/Au planar structures reflect the resistance behavior of PBCO in the c-axis direction. With increasing applied voltages the PBCO barrier shows a transition from thermally-activated hopping conductivity to an activationless-hopping regime. Variable-range hopping and weak-localization models are discussed to explain the experimental data. An account of the Lifshitz correlation in the hopping conductivity gives an satisfactory agreement with the junction resistivity for c-axis PBCO barrier thicknesses of 10 to 40 nm.

1. INTRODUCTION

$PrBa_2Cu_3O_x$ (PBCO) is an interesting object for the basic study of the interplay between high-T_c superconductivity and the localization phenomena, as well as for practical applications as a barrier or buffer layer in high-T_c multilayers. The PBCO resistivity in the a-b plane is determined by activated motion of the carriers between localized centers and often described by a variable-range hopping (VRH) mechanism [1]:

$$R_n(T) \sim R_0 \exp[(T_0/T)^{1/4}] \qquad (1)$$

However, there is a deviation from VRH-like behavior at low temperatures [2,3], which was not clearly explained. The c-axis resistivity of PBCO also has so far not been well-analyzed.

In this report we analyze the temperature and electric-field dependencies of the c-axis PBCO resistivity in YBCO/PBCO/Au planar structures. A similar behavior and the correlation of the c-axis resistivity with that of PBCO in the a-b plane is emphasized.

2. EXPERIMENTAL

A standard planar geometry has been used for YBCO/PBCO/Au structures. Due to preferable c-axis growth of YBCO and PBCO films on (100) $SrTiO_3$ substrates at high deposition temperatures, YBCO/PBCO bilayers were c-oriented with current flow along c-axis of the PBCO barrier. The thickness of the YBCO, PBCO and Au layers is 80 nm, 0-40 nm and 40 nm, respectively. PMMA e-beam photoresist was used to cover the edges of the YBCO electrodes. The junction area A varies between 8x20 μm^2 and 20x30 μm^2.

3. RESULTS AND DISCUSSION

First we analyse the temperature behavior of the PBCO resistance at small voltages. The specific contact resistance R(V=0)A of the YBCO/PBCO/Au structures rapidly increases with decreasing temperature from values of $4\cdot10^{-4}$-10^{-3} Ohm·cm^2 at 77K to values of 1-10 Ohm·cm^2 at 6-10 K. To estimate the influence of the interface resistance to the total junction resistance, YBCO/Au planar structures have been prepared in a similar way. The R·A value of the YBCO/Au contacts is 10^{-5} Ohm·cm^2 and almost temperature-independent at $T<T_c$(YBCO). Thus, the current-voltage characteristics (CVC) of the YBCO/PBCO/Au structures reflect the behavior of the c-axis resistivity of the PBCO barrier layer.

The R(T) dependencies at all PBCO thicknesses studied cannot be fitted to VRH-behavior, described by eq. (1), especially at low temperatures. Resonant motion of the carriers between defects has been calculated by Kostadinov and Alexandrov [4] as a Lifshitz correlation in the hopping conductivity:

$$\ln(R/R_0) \sim -\ln^3(T/T_0) \qquad (2)$$

where T_0 is the characteristic temperature, depending on the localization length $1/\alpha$ and the density of the localized centers. We found that this model describes the experimental data quite well. Fig.1 shows the R(T) dependencies of the PBCO resistivity for barrier thicknesses L of 10, 20 and 40 nm. $T_0\sim1$ K at L=10 nm and 20 nm and $T_0\sim$ 0.8 K at L=40 nm.

For the R(T) dependencies the data have been taken from the linear part of the current-voltage characteristics at small voltages. With an increase of the bias voltage the CVC become nonlinear. The decrease of the resistance with voltage is not due to heating ef-

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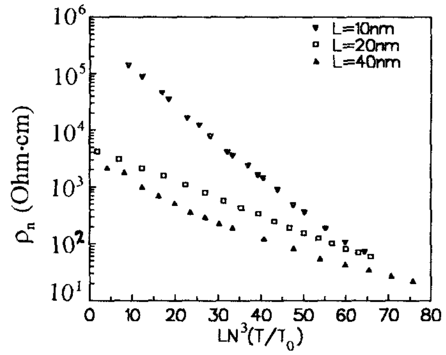

Fig.1. Temperature dependencies of *c*-axis PBCO resistivity in YBCO/PBCO/Au contacts resistances for several barrier thicknesses L.

fect. The dissipated power density $V^2/RA<10$ W/cm^2 increases the effective temperature of the structure only by 0.05-0.1K, as has been estimated from quasiparticle-injection experiments.

The R(V) dependencies of the YBCO/PBCO/Au structure with 20 nm PBCO barrier are shown in Fig.2 at different temperatures. The data are plotted as $\ln(R)\sim\ln^3(V)$. In such form the curves are quite linear in a wide voltage and temperature range.

The transition from voltage-independent to voltage-dependent R(V) dependencies in Fig.2 is consistent with the hopping model for PBCO transport. Electric field, like temperature, can activate carrier motion. If the electric-field activation energy between the hopping centers is larger than the thermal ones:

$$eE/\alpha >> kT, \qquad (3)$$

the resistance is determined by the bias voltage:

$$\ln(R/R_0) \sim -\ln^3(eV/\alpha kT_0L) = -\ln^3(V/V_0) \qquad (4)$$

In such a model the voltage values for the transition between two regimes, $eV_c=\alpha LkT$, should be a linear function of temperature and barrier thickness.

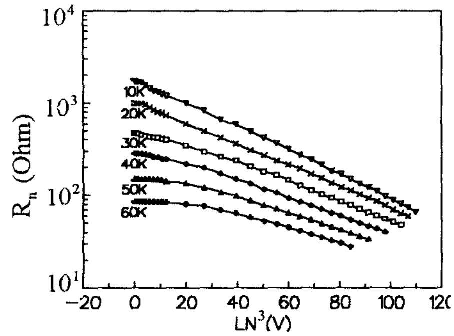

Fig.2. R(V) dependencies of YBCO/PBCO/Au stuctures with 20 nm thick PBCO barrier.

Experimental values of V_c can be determined from the extrapolated crossover point between the two linear parts of the R(V) dependencies. V_c increases linearly with T for the studied thicknesses of the PBCO barrier. From these dependencies we can estimate the localization length $1/\alpha\sim0.4$-0.7 nm for carrier motion in the *c*-axis direction of PBCO.

The proposed description of the PBCO *c*-axis resistivity by Lifshitz-correlated hopping conductivity needs clarification of the *c*-axis transport of PBCO itself. For that we can use the proposed model in ref. [5]. In the anisotropic perovskite structure the carriers are located mainly in the Cu-O planes. The interplane motion can be treated as a tunnel process. The in-plane scattering processes are much faster than the interplane tunneling. Incoherent in-plane motion blocks the coherent tunnel interplane carrier motion, yielding the same temperature dependencies for ρ_c and ρ_{ab} [5]. If the *c*-axis carrier motion is uncorrelated, field-activated motion at large bias voltages $V \gg V_c$ should be similar to the thermally-activated hopping motion at low bias voltages $V<V_c$.

4. CONCLUSIONS

The *c*-axis PBCO resistance of the YBCO/PBCO/Au planar junction depends both on temperature and bias voltage. The crossover from the linear part of CVC to the voltage-dependent resistance can be explained by the transition from temperature-activated hopping transport in PBCO barrier at low bias voltages to the voltage-dependent regime at higher bias voltages. Both temperature- and voltage dependencies of R_n have the form $\ln(R)\sim\ln^3(T,V)$, which agrees with the Lifshitz-correlated hopping conductivity model. The *c*-axis PBCO resistivity is suggested to be strongly correlated with *a-b* in-plane PBCO resistivity.

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