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Current transport in Au/$YBa_2Cu_3O_x$ junctions in c-axis and tilted directions of $YBa_2Cu_3O_x$ thin films

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ABSTRACT: We report on the fabrication technique and investigation of current transport properties of Au/$YBa_2Cu_3O_x$ junctions. The junctions were processed in epitaxial $YBa_2Cu_3O_x$ (YBCO) thin films grown by laser ablation. (001) $LaAlO_3$ and (120) $NdGaO_3$ substrates were used to grow correspondingly (OOl)-oriented and tilted YBCO films. Current-voltage characteristics, Z-V-curves, and the dependencies of the differential resistance on the applied voltage, Rd(V), were measured and the anisotropy of the current transport in these junctions was studied.

1. INTRODUCTION

The resistance between high-temperature superconductor and normal metal, HTS/N, is an important parameter from fundumental and practical point of view. The anisotropy of c-axis and *a-b*-plane resistance (R_c and R_{a-b}) has often been observed in the tunneling characteristics of high-temperature superconductors [Divin et. al. 1995]. In the particular case of HTS/N junctions this anisotropy combined with the structural defects in the surface area of the superconductor can produce unexpected results in the work of circuits, containing such contacts. Recently, a number of attempts has been made to minimize the interface resistance in these contacts [Yuzi-Xu 1997, Daly 1997, Terai 1995, Sanders 1995, etc.]. The obtained results are often non-consistent with each other.

This paper is devoted to the experimental investigation of the current transport in Au/YBCO junctions with a current flow along (OOl)-oriented and tilted high-temperature superconducting YBCO thin films.

2. YBCO FILMS AND SAMPLE FABRICATION.

The junctions were prepared using the sequence of operations shown in Fig. 1. YBCO epitaxial films were grown by laser ablation (Fig. la) at temperatures 780-800°C and at 0.8mbar oxygen pressure. We used (001) $LaAlO_3$ substrates to grow c-axis oriented YBCO and (120) $NdGaO_3$ substrates to obtain YBCO films with c-axis tilted on 18.4' from the normal to the substrate plane (tilted YBCO films). The YBCO film was in situ covered by a thin layer of normal metal, Au, with a thickness of 20nm grown at 100°C by laser ablation

Junction areas and electrodes were defined by using photolithography and Ar ion milling (Fig. la). In order to provide an one-directional electrical contact plane of the YBCO film, the region of the junction was insulated on the side by a CeO_2 layer with a central window having an area of $10x10\mu m^2$ (Fig. lb). The geometry of electrodes allowed for 4-point measurement of the interface resistance. (Fig. lc). YBCO films were characterized by magnetic succeptibility

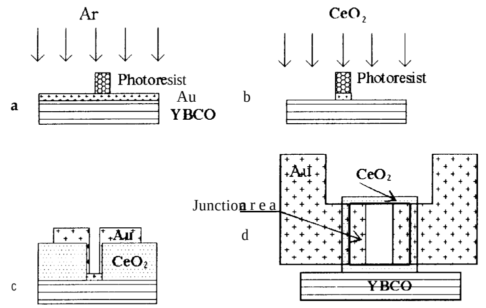

Fig. 1. A fabrication procedure of Au/YBCO junctions:
a) definition of the junction area by photolitography and ion milling;
b) deposition of insulating CeO_2 layer;
c) deposition of the contact pads;
d) top view of the junction;

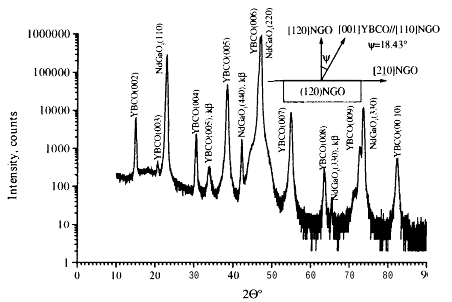

Fig. 2. X-ray diffraction pattern of Au/YBCO double layer structure on $NdGaO_3$ (120) substrate. Tilting by the angle ψ = 18.4” to the normal of the substrates provides (00n) reflections of YBCO film.

measurements of the critical temperature (T_c) and the width (ΔT_c) of the superconducting transition. Values of T_c’s$>$ 89K and ΔT_c’s$<$ 0.5K for c-axis YBCO films and T_c’s$>$ 85K and ΔT_c’s$<$ 2K for tilted YBCO films were obtained. X-ray θ-2θ scan was performed at the angle $\psi = 18.4°$ and showed that c-axis of YBCO film on (120) $NdGaO_3$ substrates follows the tilting angle of (120) from (110) $NdGaO_3$ substrate ($\psi = 18.4°$), see Fig.2

3. EXPERIMENTAL RESULTS AND DISCUSSIONS.

The dependencies of resistance *R* versus temperature T, R(T), for Au/YBCO junctions and test planar YBCO microbridges (4µm wide) were measured at temperatures 4.2-300K at 1-5µA bias currents as well as their I-V curves. Parameters of c-axis and tilted Au/YBCO junctions presented in the table 1.

Table 1. Parameters of Au/YBCO junctions.

Sample	ψ,°	T_c, K	$R_N(T=T_c, V=0,)$, Ω	R_d(T=4.2K, V=0), Ω	R_d(T=4.2K, V=0)/R_N	R_NS, 10^{-6}, $\Omega \cdot cm^2$
P32J2	0	89.3	33.2	103.0	3.1	33.2
P32J3	0	89.5	19.5	52.0	2.7	19.5
P32J4	0	89.9	22.9	55.3	2.4	22.9
P34J3	0	89.2	56.1	102.0	2.1	56.1
H2J2	18.4	18.7	1.6	0.7	0.4	1.6
H2J3	18.4	48.2	1.6	1.0	0.6	1.6
H2J4	18.4	40.1	1.8	1.3	0.7	1.8
H5J2	18.4	42.3	0.4	0.2	0.5	0.4
H5J3	18.4	60.3	0.3	0.2	0.7	0.3
H5J4	18.4	61.1	0.5	0.3	0.6	0.5

R(T) dependencies for both types of investigated Au/YBCO junctions are shown in Fig. 3: (a) a solid line for ψ=0, the direction of the current flow coincides with the (OOl)-direction in YBCO film (a *c*-axis junction), and (b) a dashed line for ψ=18.4°, the direction of the current flow deviates on ψ=18.4° in relation to the (OOl)-axis of YBCO film (a tilted junction).

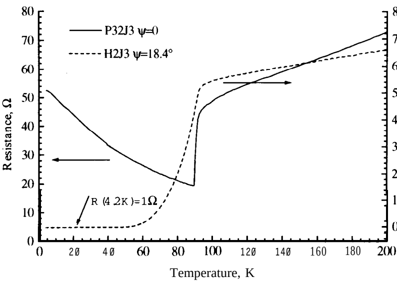

Fig. 3. R(T) dependencies in the cases of tilted, $\psi=18.4°$ (dashed line), and c-axis, $\psi=0$ (solid line), orientations of YBCO film to the direction of the current flow.

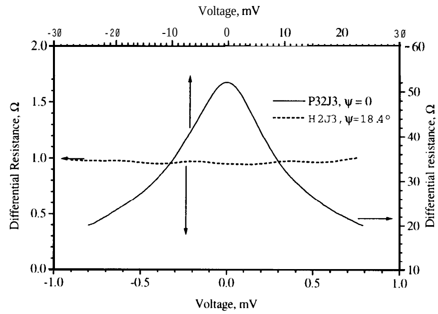

Fig. 4. A comparison of the Rd(V) dependencies in the case of tilted, ψ = 18.4" (dashed line) and c-axis, $\psi=0$ (solid line), Au/YBCO junctions.

At T > T_c, the *R(T)* dependencies for both cases are of a metallic type, i.e., the resistance decreases with decreasing temperature, the latter is typical for YBCO film carrying current in the basal plane of YBCO. As a rule, the values of T_c for bridges and investigated tilted junctions were lower than ones of YBCO films measured immediately after deposition of the double-layer Au/YBCO structure. The degradation of superconducting properties of the films was apparently associated with a decrease in the amount of oxygen during ion etching. This effect is strong in the case of tilted YBCO films because of the high rate of the oxygen depletion in a-b basal planes of YBCO film.

It can be seen from the Fig. 3 that the resistance R of tilted junctions decreases monotonously with T at T < Tc. For c-axis junctions we have $R \sim 1/T^2$. This different behavior indicates a different type of conductivity of the YBCO/Au interface in tilted and c-axis junctions. In the tilted junctions thecurrent transport is partially in a-b-planes which results in an ohmic type contact with metallic conductivity,. In the case of c-axis junctions an oxygen depleted semiconducting surface layer is realized. We have not observed a zero-bias conductance peak probably because of the lower junction resistances compared with [Sanders 1995]. Similar R(T) behaviour and the values of characteristic interface resistance (R_NS) were obtained in [Ekin 1988, Daly 1997] in the case of c-axis Au/YBCO interface.

Fig. 4 presents the typical dependencies of differential resistance of Au/YBCO junctions on applied voltage. R_N of the tilted junction is a constant value of 0.3-1 .6Ω in the current range below approximately 1mA, which provides a value of $R_NS \sim 10^{-7}$- 10^{-6} $\Omega \cdot cm^2$. Taking into account the square of a-b-plane area, involving in the current transport, we have $R_NS(a\text{-}b) \sim 10^{-7}$ $\Omega \cdot cm^2$. There are four orders of magnitude difference of this value with the theoretically estimated one [Kupriyanov 1995, Kupriyanov 1991, Deutscher 199 1]. This difference is possibly caused by the oxygen depletion along a-6 planes during the ion milling of Au/YBCO tilted junction. According to our estimations the in-plane superconducting critical current density for proceeded tilted YBCO films is $J_c \sim 10^3 A/cm^2$ at T =4.2K, i.e. a least four orders of magnitude lower than in the case of *c*-axis YBCO films.

For c-axis structures R_d(V) dependence has a maximum at zero bias current (and voltage) with the value of $\sim 10^{-5}$ $\Omega \cdot cm^2$, see a solid line on Fig. 4. As it was already mentioned, an oxygen depletion effect is a possible reason for the tunnel R(T) dependence and for the high value of R_NS. Fig. 5 presents R_d(V) dependencies for c-axis junction, obtained after the annealing of this junction in oxygen atmosphere at 600°C. The R_d(V) dependencies were measured at T=4.2K immediately after each annealing step. The value of R_NS decreases rapidly with the increase of the annealing time and after 5 hours of annealing is equal to $\sim 10^{-6}$ $\Omega \cdot cm^2$. The subsequent annealing for 15 hours did not affect the R_NS value. This means that the oxygen contents in the surface layer of YBCO is close to the maximum value.

4. CONCLUSIONS.

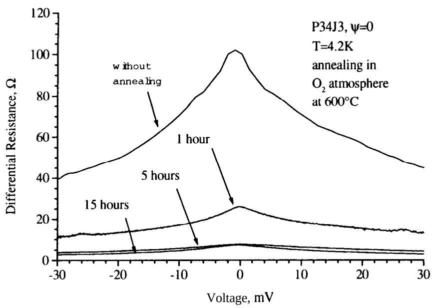

Fig. 5. $R_d(V)$ dependencies of c-axis Au/YBCO junction from the annealing time in oxygen atmosphere at 600°C.

We have investigated the current transport properties of c-axis and tilted Au/YBCO junctions. A strong anisotropy of the R(T) dependencies and I-V-curves was observed, caused by the different type of conductivity in a-b-plane and in c-axis direction of YBCO. An oxygen depletion effect and its influence on the contact resistance value weas investigated. The depression of Tc and Jc in tilted YBCO film during the fabrication of Au/YBCO junction makes it questionable the applications of these films in superconducting devices.

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