PROPERTIES OF THE INTERFACES IN THE $YBa_2Cu_3O_x$/Au AND $Tl_2Ba_2CaCu_2O_y$/Au HETEROSTRUCTURES*

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The $YBa_2Cu_3O_x$(YBCO)/Au and $Tl_2Ba_2CaCu_2O_y$(TBCCO)/Au sandwich-type heterostructures were studied with the aim to enhance the interface quality of high temperature superconductor (HTS) in contact with a normal metal which is frequently used in cryoelectronic devices. To characterize the superconducting properties of thin films and interfaces of superconductor/normal metal (SN) heterostructures, the resistance vs. temperature ($R - T$) dependences, current-voltage characteristics ($I - V$) and $dI/dV - V$ characteristics were measured. The YBCO/Au heterostructures exhibit tunnel properties due to the existence of the so-called native barrier created from oxygen depleted YBCO surface layer. Our results show that the properties of YBCO based planar tunnel junctions are strongly influenced by the state of superconductivity at the SN interface. On the other hand, in TBCCO/Au heterostructures a direct metallic contact is realized in the most cases. Our investigations show that the degradation of TBCCO/Au interface is negligible and no native oxide barrier on the surface of TBCCO film was observed. These results confirm that the surface of TBCCO film in close contact with Au is much more stable in comparison with YBCO films and therefore the TBCCO films are more suitable for the preparation of HTS planar structures and tunnel junctions.

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1 Introduction

Although high temperature superconductors (HTS) were discovered 14 years ago and a lot of effort has been done to prepare high-quality sandwich-type tunnel junction based on the HTS, their applications in cryoelectronics have not yet been successfully accomplished. The problem consists in specific properties of HTS, and especially in a considerable chemical activity of oxygen

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with another material [1] which results in the degradation of an HTS surface layer at the superconductor/normal metal (SN) interface. Despite the difficulties, such junctions can be applied in many ways covering the dc (SQUIDs) and very high frequency bands applications (mixers, detectors) [2]. In addition, as HTS possess d-wave charge pairing, they should be used as superconducting qubits for quantum computers. In a series of our publications [1] we have shown that $YBa_2Cu_3O_x$ (YBCO), mostly used HTS, loses oxygen in the contact area with solids or gases. Thus a native barrier with semiconducting properties is created due to an oxygen deficiency in the HTS surface (2-3 nm). The thin layer below the native barrier is not degraded so strongly and its properties continuously change from metallic to superconducting ones. Such type of interface is not well defined and it is not suitable to prepare a Josephson tunnel junction. Therefore, there has been a great effort to solve the interface problem using other HTS materials. It was shown that the surface of $Bi_2Sr_2CaCu_2O_z$ (BSCCO) material is much more stable than that of YBCO because BSCCO tunnel junctions with the metal counter electrode show Andreev reflections [3, 4]. In the present work we study $Tl_2Ba_2CaCu_2O_y$(TBCCO)/Au heterostructures with the aim to achieve oxygen stability at the TBCCO surface and to compare the results obtained with YBCO/Au heterostructures.

2 Experimental

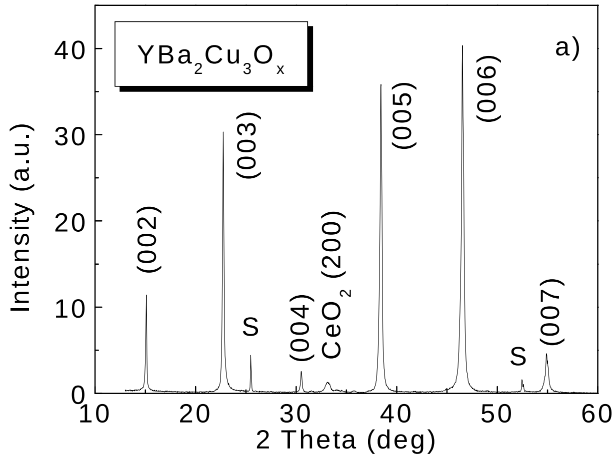
YBCO thin films were deposited by high-pressure dc magnetron sputtering in oxygen atmosphere (pressure 260 Pa) on single crystal $SrTiO_3$, MgO and r-cut sapphire (buffered by CeO_2) substrates at temperature about 700 °C. The thin films of a thickness of about 100 nm exhibited single-phase, epitaxial c-axis-oriented growth. In Fig. 1a the peaks denoted by (00l) relate to the $YBa_2Cu_3O_x$ phase, and the peaks denoted by S belong to the sapphire substrate. The YBCO/Au structures were prepared using standard optical lithography and the etching of the films followed by the evaporation of Au strips through a metal mask across the YBCO pattern.

The TBCCO thin films were prepared in two steps. At first, a Ba-Ca-Cu precursor film was prepared on a CeO_2 buffered sapphire substrate using a sequential evaporation technique of components. It was subsequently patterned approximately into a 1 mm-wide strip. In the second step, the thalliation procedure was performed at 850 °C for 30 min to obtain a superconducting TBCCO strip in flowing oxygen with a crude Tl-Ba-Ca-Cu-O pellet [5, 6]. The upper Au electrode was evaporated across the TBCCO strip through a metal mask. The resulting junction dimensions were 0.5×0.5 mm^2. The TBCCO samples exhibited c-axis oriented $Tl_2Ba_2CaCu_2O_y$ single-phase films (peaks denoted by (00l) in Fig. 1b).

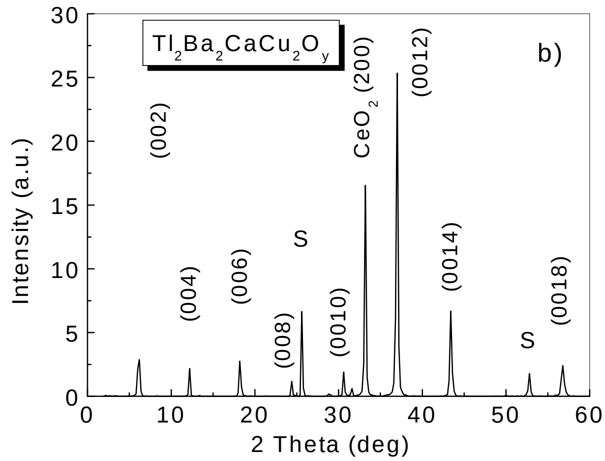
To characterize superconducting properties of the thin films and the SN interfaces, a standard 4-probe technique was used to measure the following characteristics: Thin film resistance vs. temperature ($R - T$), junction resistance vs. temperature ($R_j - T$), and current vs. voltage ($I - V$) dependency. Additionally, the differential conductance vs. voltage ($dI/dV - V$) was measured using a low-frequency phase-sensitive detection technique.

3 Results and discussion

The $R - T$ dependences of both YBCO and TBCCO thin films are shown in Fig. 2. The zero-resistance critical temperatures T_{C0} for both materials are 88 K and 106 K, respectively, which



(a)



(b)

Fig. 1. X-ray diagrams of a c-axis-oriented $YBa_2Cu_3O_x$ thin film (a) and a $Tl_2Ba_2CaCu_2O_y$ thin film (b), both prepared on r-cut sapphire (S) buffered with a CeO_2 thin film.

corresponds to superconducting phases determined from the X-ray diffraction patterns (Fig. 1). These temperatures and phases characterize bulk properties of the thin films and not their surface (depth of a few nm) properties. After the deposition of the metal on the HTS, the surface properties of the HTS were modified. For the preparation of planar tunnel junctions, the quality of the SN interface is crucial because it determines the quality of the tunnel junction.

To estimate the surface properties of the thin film, the $R_j - T$ and $dI/dV - V$ characteristics were measured. In Fig. 3, the $R_j - T$ dependences of YBCO/Au and TBCCO/Au junctions are shown. The YBCO/Au junction exhibited a tunnel character, i.e. junction resistance R_j increases below T_{C0} of YBCO due to the opening of an energy gap at the interface of the superconducting film. Because we applied no artificial tunnel barrier onto the HTS film surface,

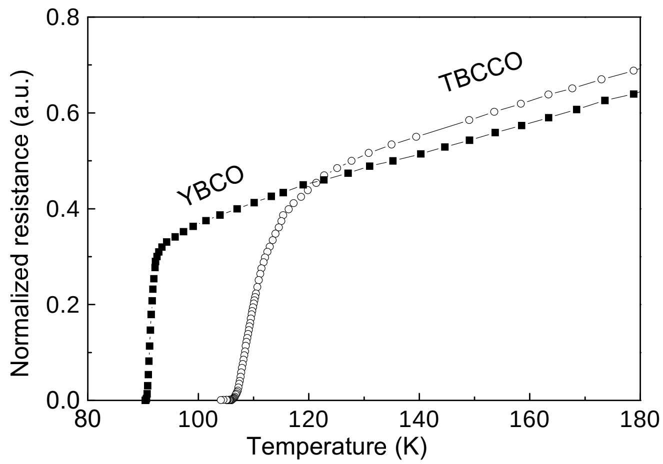


Fig. 2. Resistive transition into the superconducting state of both YBCO and TBCCO thin films characterizing bulk properties of the films.

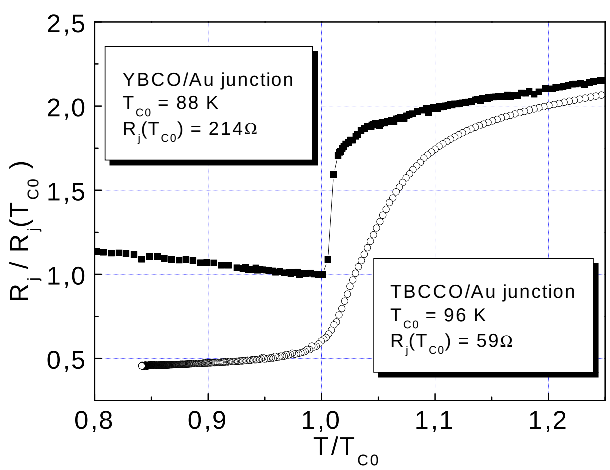


Fig. 3. Normalized temperature dependences (T/T_{C0}) of the junction resistance [$R_j/R_j(T_{C0})$] for the YBCO/Au and TBCCO/Au heterostructures in a temperature region close to T_{C0}. The curve that belongs to the TBCCO/Au junction is shifted down a little to simplify the comparison.

the tunnel character of the junction is caused by the existence of a native barrier created from a degraded surface layer of the HTS. We confirmed this assumption by performing the $dI/dV - V$ measurements illustrated in Fig. 4. In these dependences, many features typical for NIS (normal metal-insulator-superconductor) junctions can be recognized. The main characteristic is an increase of differential conductance with increased voltage above $V_g = \Delta/e$ (V_g - voltage cor-

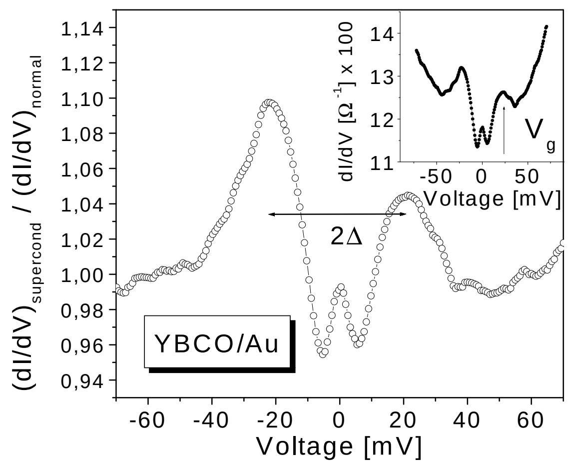


Fig. 4. Normalized differential conductance of the YBCO/Au junction. The inset shows an increase of the differential conductance at higher voltage typical for an NIS junction.

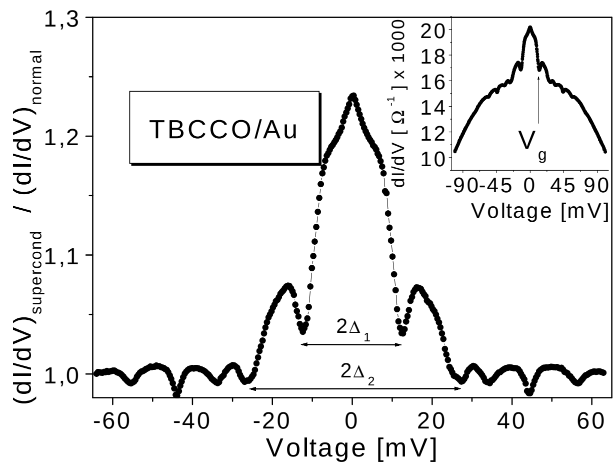


Fig. 5. Normalized differential conductance of the TBCCO/Au junction. The inset shows a decrease of the junction differential conductance with increasing voltage.

responding to an energy gap Δ, e - charge of electron) given by the measurement of the tunnel probability for quasiparticles with higher energy. In addition, the local increase of differential conductance at the gap voltage V_g induced by changes in the density of states of the superconductor and by a decrease of differential conductivity for voltage below V_g, are also features typical for NIS junctions.

On the other hand, the TBCCO/Au junctions exhibit a decrease of the junction resistance with temperature indicating a direct metallic NS contact. Such an assumption is confirmed by the $dI/dV - V$ characteristics shown in Fig. 5. The differential conductance decreases with increasing voltage but a rapid increase of the differential conductance below V_g is a typical feature in the presence of Andreev reflections at the NS interface [3]. We interpret the multiple dips in differential conductance as the result of a possible presence of various phases in the Tl-based HTS film at the interface region. The behavior of $dI/dV - V$ curve below the gap Δ_1 voltage is typical for Andreev reflections for a d-wave superconductor [7]. Thus no native barrier in the NS interface is created. On the basis of these results we can claim that the surface of TBCCO thin films is much more stable than that of YBCO and therefore its surface is more convenient for the preparation of direct metallic SN contact and potentially for the preparation of sandwich-type tunnel contact heterostructures (devices) . On the other hand, TBCCO surface morphology is much worse compared with YBCO surface morphology. Therefore, it is necessary to improve sufficiently the technology for the preparation of high quality TBCCO thin films.

4 Summary

We investigated the interface properties of $YBa_2Cu_3O_x$/Au and $Tl_2Ba_2CaCu_2O_y$/Au heterostructure junctions. While in the case of YBCO/Au junctions the degradation of superconducting properties at the interface and the creation of a "native" barrier were observed, the TBCCO/Au junctions exhibited much more stable surface properties with the presence of superconductivity in close proximity to a normal metal. From this point of view, the TBCCO family of HTS materials may be more suitable for the preparation of cryoelectronic sandwich-type devices. On the other hand, it is necessary to improve the composition as well as surface morphology of TBCCO films.

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