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Physica C 282-287 (1997) 1531-1532

PHYSICA C

Single electron tunneling and superconducting energy gap in $YBa_2Cu_3O_{7-\delta}$ and $TlBa_2Ca_2Cu_3O_{9\pm\delta}$ films

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The granularity of the high-Tc cuprates, though has been considered to be obnoxious for many applications, appeared to giving rise to the exotic incremental charging effects. This paper further demonstrates that it can also serve as an alternative for extracting the superconducting gap parameters of these materials. The results of $2\Delta(0)/K_BT_c \approx 6-8$(YBCO) and ≈ 9-11(Tl-1223), though are consistent with those obtained by other methods, the $\Delta(T)'s$, however, are not BCS-like.

1. INTRODUCTION

The single electron charging effects and their implications for obtaining the energy gap of the high-Tc cuprates were first considered theoretically by Mullen et al.[1] for a system consisting of two mesoscopic junctions coupled in series and driven by a voltage source. The prominent features in the tunneling current-voltage characteristics (IVC's) of such configuration were soon replicated experimentally by McGreer et al.[2] in studying the tunneling IVC's of granular Pb films using a scanning tunneling microscope (STM). The essences were that, when both junctions are normal, the resultant IVC's of the system evidently display a series of voltage steps with equivalent width corresponding to e/C_1, where C_1 being the larger capacitance of the two junctions. As the film became superconducting, the width δV_{step} were found to depend on the voltage at the center of the steps $V_{stepcenter}$ as

$$\delta V_{step} = \begin{matrix} e/C_1 + 8\Delta, |V_{stepcenter}| < e/2C_1 + 4\Delta \\ e/C_1, |V_{stepcenter}| > e/2C_1 + 4\Delta \end{matrix} \quad (1)$$

where Δ is the superconducting gap parameter. In principle, it is thus possible to derive gap information from this type of measurements, provided that the incremental charging effects are observable. Here, we report the first temperature dependent superconduting gap of both YBCO and Tl-1223 films obtained by measurements of this kind.

2. EXPERIMENTAL

The YBCO films used in this study, with Tc's=87-90 K were prepared in-situ by pulsed laser deposition on various single crystalline ceramic substrates with deposition parameters reported previously[3]. The Tl-1223 films (Tc≈105-108K), on the other hand, were prepared by dc-sputtering followed by postannealing as described elsewhere[4]. It is noted that, although the detailed film growth mechanisms may be different in each case, the surface grain morphology for films of few tenths of micron thick, as revealed by both STM and atomic force microscopy (AFM), appeared to be very similar. Namely, they were all consisted of nanosize grains with average diameter of 100Å. That is, in the scale of tunneling measurements, they were all considered to be granular in nature.

The STM (a tubular piezoelectric scanner design manufactured by Parks Science®) and the superconducting films were situated in a cryostat with temperature controlling unit. The temperature of the whole setup was varied in the range of 4.2 K to room temperature with stability of ±0.1K in a time span of 30 minutes. The details of operating the STM for obtaining the tunneling IVCs were described previously and would not be repeated here[5]. It is noted that there has been a zero-bias anomaly observed in YBCO films when the bias voltage exceeded a certain threshold to cause the polarization-induced residual charge[5]. Such an effect is expected to be existent even when the films become superconducting. Consequently, in deriving the gap values we have taken such effect into account.

3. RESULTS AND DISCUSSION

Figure 1 shows the typical tunneling characteristics and the corresponding dI/dV-V curves for Tl-1223 films obtained at room temperature and 4.5 K by the

0921-4534/97/$17.00
PII S0921-4534(97)00870-8

procedures described before[5]. Similar results were observed for YBCO films and their connections with incremental charging effects were described and discussed elsewhere[5] and will not be repeated here. Here, we will concentrate on how the superconducting gap modifies the Coulomb staircase structure and use it to obtain the temperature dependence of superconducting gap Δ (T). As is evident from Fig. 1, the width of the zero-bias step δV_0 increased from 12 mV at room temperature to 54 mV at 4.5 K with the STM\ PtIr tip biased with a same voltage of 0.1 V. Moreover, the width of the other steps ($\delta V_n \approx 12$mV) remains essentially unchanged, indicating that the junction capacitance is insensitive to temperature and has been retained constantly when the bias voltage was fixed. Since the values of δV_n has been found to vary linearly with the magnitudes of the bias voltage, the results further imply that the limiting junction for single electron to tunnel must be the one formed by tip-vacuum-grain. With the assurance that the widening of zero-bias step was indeed due to the opening of the superconducting gap, we proceed to extract the Δ (T) by using Eq.(1).

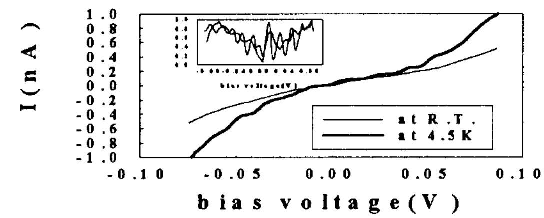

Fig.1:The IVC and dI/dV for Tl-1223 films at R.T. and 4.5K.

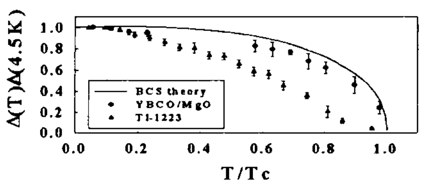

Fig.2:The Δ(T) for YBCO and Tl-1223 films. The solid curve is calculated from the BCS theory.

Figure 2 shows the results of Δ(T) obtained for represent samples of YBCO and Tl-1223 films, respectively. Each data point shown in the figure is representing an average value of data obtained from four different bias voltages while at each bias voltage there were 16 IVC's taken over an area of 10×10nm^2. The degree of the scattering in the data reflects that the films were reasonably uniform and is consistent with their high critical current densities, Jc(77K)> 10^6 A/cm^2. The gap values obtained at 4.2 K give $2\Delta(0)/K_B T_c \approx 6-8$ and $\approx$9-11 for YBCO and Tl-1223 films, respectively. These values are, in fact, quite consistent with those obtained by other methods[6]. However, as can be seen from the figure, the normalized Δ(T)/Δ(0) as a function of reduced temperature deviates from that predicted by the BCS theory significantly. Unfortunately, due to the lack of consensus on the mechanisms of HTSC and the unavailability of full Δ(T) from the theoretical side, we were unable to offer definite physical interpretations for what the behavior may imply at present. Nonetheless, the present data do offer, at least, two advantages over other tunneling measurements. First of all, it is not necessary to strive against the almost forbidden task of making planar SIS junctions for HTSC's for obtaining superconducting gaps. Secondly, the degradation of top surface layers, though might have been responsible for the zero-bias anomaly observed[5], appeared to be irrelevant for this type of experiments.

4. SUMMARY

We have demonstrated that, although the granularity may have been considered to be deleterious to many applications of HTSC films, it can provide a convenient alternative for obtaining superconducting gap parameter of these materials. This is particularly useful considering that making reproducible tunneling junctions has been from almost a forbidden task over decade. Our preliminary results gave values of $2\Delta(0)/K_B T_c \approx 6-8$ and 9-11 for YBCO and Tl-1223 films, respectively, in fair agreement with that obtained by other methods. However, the Δ(T) appears to deviate from the classical BCS-like dependencies.

REFERENCES

1. K. Mullen, et al., Phys. Rev. B38, (1988)5150.
2. McGreer, et al., Phys. Rev. B39, (1989)12260.
3. K.H. Wu et al., Physica C 195, (1992)241.
4. J.Y. Juang et al., Appl. Phys. Lett. 66, (1995)885.
5. Kao et al., submitted to Jpn. J. Appl. Phys. and in this conference.
6. A. Maeda, et al., Materials Science Forum Vol.137-139 (1993) pp.1-58.