Observation of a large superconducting gap in Bi-based cuprates by tunneling spectroscopy

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Abstract

We report that a large superconducting gap has been observed in some tunneling spectra of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212). The observed gap magnitude is roughly twice as large as those of the recent studies of Bi2212. Magnetic susceptibility measurements reveal that the single crystals retain a single phase of Bi2212. Therefore, the experimental results suggest that the large gap arises by way of the Josephson effect, due to the junction interface of the crystal boundary, and this indicates possibilities for applications of Bi2212 single crystals.

Key words: Bi-based cuprates; Superconducting gap; Crystal boundary; Josephson effect

1. Introduction

For high-T_c cuprates, various shapes of tunneling spectra have been observed in superconducting tunneling spectroscopy, for example, a gaplike structure and a zero-bias conductance peak (ZBCP) [1–3]. These tunneling spectra were recently explained by the Andreev bound states (ABS) model for the *d*-wave pairing symmetry [4].

In this paper, we report a large superconducting gap structure observed in some $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) planar junctions. This large gap structure could not be justified within the theory of the ABS model because the gap value is much larger than those of the recent studies [1–3]. Here, it is considerable that the large gap structure appeared due to the Josephson effect or the mixed phase effect of $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ (Bi2223) in Bi2212 single crystals. Hence, it is important to determine the origin of the large gap structure.

2. Experimental procedure

Bi2212 single crystals were prepared by the traveling solvent floating-zone (TSFZ) method, and the critical temperature, T_c, was decided by the resistivity and magnetic susceptibility measurements. Bi2212 planar junctions were fabricated on a cleavage surface of an as-grown single crystal, as described below. SiO was deposited on Bi2212 as a tunnel barrier, and Ag was deposited on the SiO thin film through a metal mask with holes of 1.0 mm in diameter. Tunneling spectra were measured by using the conventional voltage modulation method.

3. Results and discussion

Figure 1 shows a typical tunneling spectrum, $\sigma(V)$, with the large gap structure in the negative bias voltage at 4.6 K. A large superconducting gap, $\Delta_L = 67.5$ meV, is estimated from the tunneling spectra, where Δ_L is defined as a value of a peak-to-peak distance. Δ_L

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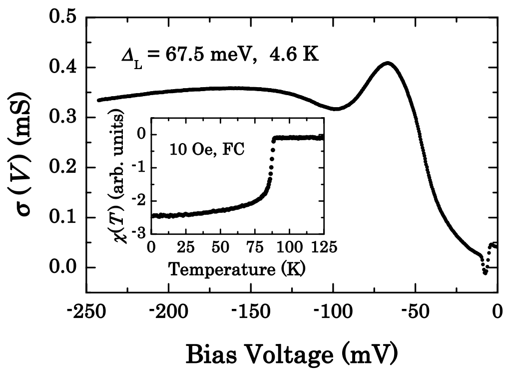

Fig. 1. The typical $\sigma(V)$ with the large superconducting gap structure. The inset shows $\chi(T)$ of Bi2212 single crystal.

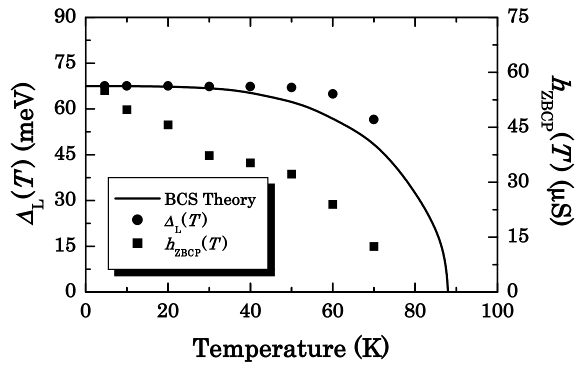

Fig. 2. The temperature dependence of $\Delta_L(T)$ and $h_{ZBCP}(T)$.

was roughly twice as large as a superconducting gap, Δ, reported in the recent studies [1–3]. There is very low leakage current around zero bias less than those of other planar junctions [1,2]. Thus, this shows that this particular planar junction has a good quality for the junction property. Further, peak, dip and hump structures exist only in the negative bias voltage [3], and there exists the small ZBCP. A similar large gap structure was also observed in the *ab*-plane junctions. The inset of Fig. 1 shows the temperature dependence of the magnetic susceptibility, $\chi(T)$, of the same Bi2212 single crystal in the field cooling (FC) as that of the planar junction. A dc magnetic field of 10 Oe was applied parallel to the *ab*-plane. This figure represents that the single crystal has a single phase of Bi2212 with T_c of 88 K without a mixed phase of Bi2223.

Figure 2 shows the temperature dependence of $\Delta_L(T)$ and the height of the ZBCP, $h_{ZBCP}(T)$. The solid line represents the temperature dependence of the superconducting gap due to the BCS theory, the solid circles $\Delta_L(T)$ and the solid squares $h_{ZBCP}(T)$. With increasing temperature, $\Delta_L(T)$ and $h_{ZBCP}(T)$ have the similar temperature dependence as those of the Josephson junction of Ref. [5], and both finally disappear at T_c of Bi2212. $\Delta_L(T)$ deviates upward from the BCS theory near T_c, so it seems that this behavior reflects the influence of the strong coupling effect of Bi2212 [6].

The experimental results suggest that each single crystal used to form planar junctions has only a single phase of Bi2212 as confirmed from the temperature dependence of $\chi(T)$, $\Delta_L(T)$ and $h_{ZBCP}(T)$. Taking it into consideration that $\Delta_L \sim 2\Delta$, we naturally conclude that the planar junction of Fig. 1 constructs the Josephson junction. Further, in this case, the appearance of the ZBCP can be elucidated by the Josephson current, not the ABS at the junction interface. Hence, we believe that this planar junction possesses a crystal boundary in the single crystal and that this crystal boundary plays a role as a tunnel barrier. The junction property is effectively influenced by the crystal boundary, rather than SiO thin film, despite our attempts to fabricate the superconductor-insulator-normal metal planar junctions. Thus, this fact indicates possibilities for applications of Bi2212 single crystals if the crystal boundary is always controlled as the good quality junction interface. Further experimental works are required to achieve this purpose.

In summary, we have observed the large superconducting gap structure in Bi2212 planar junctions and naturally conclude that this large gap structure arises by way of the Josephson effect. Thus, these experimental results indicate that there are possibilities for applications of Bi2212 single crystals.

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