TUNNELING SPECTRA NEAR T_c IN OVERDOPED $Bi_2Sr_2CaCu_2O_{8+\delta}$

M. Oda, Y. Tanaka, A. Hashimoto, N. Momono and M. Ido
Department of Physics, Hokkaido University, Sapporo 060-0810, Japan

Abstract In this article, we focus on the dip structure of tunneling spectra in overdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212), measured in Bi2212/vaccum/Bi2212 junctions, which are of the superconductor/insulator/superconductor (SIS) type below T_c. It is confirmed that the dip structure appears at voltages $|V| \sim (2\Delta_0 + E_{res})/e$ in the SIS type tunneling spectra, where $2\Delta_0$ is twice the d-wave superconducting (SC) gap amplitude and E_{res} the energy of an antiferromagnetic (AF) resonance mode. Furthermore, it is demonstrated that the temperature evolution of the dip structure is in good agreement with that of the AF resonance mode, which also develops below T_c. These results suggest that the tunneling dip structure will be associated with the development of AF resonance mode in accordance with the SC transition.

Keywords: high-T_c superconductor, electronic energy spectrum, tunneling spectroscopy

1. Introduction

One of the striking features for the SC state of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) is a strong suppression of spectral weights for the electronic excitations, the so-called "dip structure" in the electronic energy spectrum, in the energy regions just outside the d-wave SC gap edges ($E = \pm\Delta_0$). It has recently been demonstrated in angle-resolved photoemission spectroscopy (ARPES) and tunneling spectroscopy experiments [1, 2, 3, 4] that the energy difference Ω of the dip from the SC gap edge is almost the same with the characteristic energy E_{res} ($\sim$40 meV) of an antiferromagnetic (AF) resonance mode, which is directly observed in neutron scattering experiments [5, 6] and also seen as the excitation responsible for the sharp onset of scattering in infrared absorption spectra [7]. The AF resonance mode seems to develop markedly in accordance with the SC transition. On the basis of these results, the origin of the dip structure in the electronic energy spectrum has been argued in terms of strong couplings of electrons with the magnetic resonance mode. Interestingly, the Ω and E_{res}values exhibit a hole doping level (p) dependence similar to that of T_c;

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namely, they roughly scale with T_c [1, 4], which will be an important clue for the understanding of the SC transition mechanism.

In this article, we discuss the origin of the dip structure on the basis of tunneling spectra, which were measured in overdoped Bi2212/vaccum/Bi2212 (BVB) junctions fabricated using a scanning tunneling microscope (STM). We have confirmed that Ω is comparable to E_{res} and roughly scales with T_c, and shown that the temperature evolution of the dip structure strongly correlates with that of the AF resonance mode. These facts suggest that the dip structure of tunneling spectra in the SC state will be brought through couplings of electrons with the AF spin excitations.

2. Experiments

Single crystals of Bi2212 were grown by the TSFZ method. The SC critical temperature T_c of the as-grown crystals was $\sim$ 90 K, indicating that their hole-doping level p was nearly optimal ($p \sim 0.18$). The as-grown crystals were annealed at 700°C in a high-pressure (20 atm) oxygen gas; thus, the p value was increased to a slight overdoping one, $p \sim 0.22$, and the T_c value was reduced to 81 K. In the present tunneling experiments, BVB junctions, which are of the superconductor/insulator/superconductor (SIS) type below T_c, were fabricated in an STM system using the fabrication technique that was first achieved in a point-contact tunneling spectroscopy system by Miyakawa *et al.* [8]. The fabrication process was reported in Ref. [9].

3. Results and discussion

3.1 Tunneling characteristics of BVB junction at $T \ll T_c$

A typical example of BVB junction characteristics at $T = 10$ K ($\ll T_c$) is shown in Fig. 1; the upper and lower panels, (a) and (b), are a current-voltage (I-V) curve and the corresponding dI/dV-V curve (tunneling spectrum), respectively. In the inset in Fig. 1 (a), the I-V curve is magnified in the V range around the zero-bias voltage. One can see in the inset that the I-V curve exhibits a steep increase of current at $V \sim 0$, corresponding to the sharp zero-bias dI/dV peak in Fig. 1 (b). As mentioned above, the BVB junction is of the SIS type below T_c. This fact suggests that the steep increase of current at $V \sim 0$ will be due to the Josephson coupling. However, it should be noticed that the junction is not superconductive but resistive at $V = 0$. More interestingly, a negative resistance is observed, following the steep increase of current at $V \sim 0$, in the I-V curve. Such I-V characteristics around $V = 0$ could be explained in terms of thermal phase-fluctuation effects on the Josephson coupling in a small SIS type junction, which will be discussed elsewhere in detail.