Temperature and field dependence of the gap structure in $Bi_2Sr_2CaCu_2O_{8+\delta}$ studied by short-pulse interlayer tunneling spectroscopy

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Abstract

We measure tunneling characteristics of $Bi_2Sr_2CaCu_2O_{8+\delta}$ intrinsic junctions by a sub-microsecond pulse technique to investigate temperature T and the magnetic field H dependence of the bulk-intrinsic gap structure without excess Joule heating. The conductance curve shows a peak at the superconducting gap voltage (V_p) at low temperatures, and the peak becomes broader when we increase either T or H that is a pair breaking parameter. However, V_p has a non-monotonic T-dependence with a dip near T_c, while V_p increases monotonically with H. This difference indicates that $V_p(T)$ cannot be explained in terms of a single gap model, and implies that the superconducting gap is distinct from the pseudogap, which is represented by $V_p(T)$ above T_c.

Key words: interlayer tunneling spectroscopy ;pseudogap ;superconducting gap

1. Introduction

Among the mysteries of high temperature superconductivity, the depression of quasiparticle density of states in low energy region above T_c, which is often called the pseudogap, is one of the most important subjects [1]. However, we have no consensus about the origin of the pseudogap so far [2]. Especially, there has been a long standing debate about whether the pseudogap and the superconducting one are the same gap or not. To obtain detailed information on the gap structure, spectroscopic studies of the pseudogap and the superconducting gap as functions of temperature and the magnetic field are important.

Among various spectroscopy measurements, interlayer tunneling spectroscopy (ITS) is very powerful since it detects bulk properties and is free from complicated surface-related problems. ITS measurements in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO) have revealed peculiar temperature T [3,4] and the magnetic field H [5] dependence of the gap structure. However, most of them were done by using dc current, which can cause serious Joule heating problem in the high voltage regime of interest near the gap voltage V_p.

Here, we report our ITS measurements of the gap structure in magnetic fields up to 9 T by using a short-pulse current technique [3]. The results without excess heating effect show that the effects of temperature and the magnetic field are quite different near T_c. This suggests that the key features of the observed gap structure are difficult to explain sufficiently in terms of a single gap model ,which employs the energy- and temperature-dependent quasiparticle relaxation mechanism [6].

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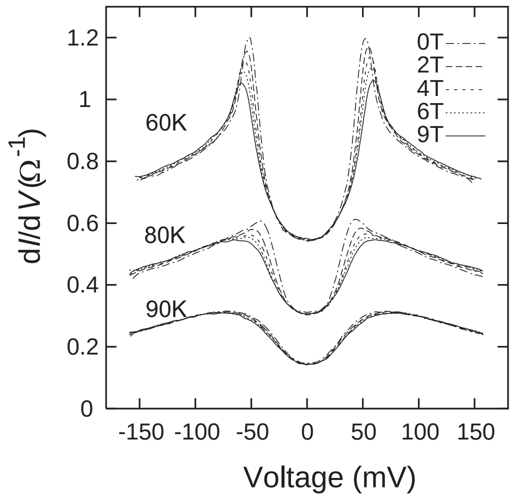

Fig. 1. dI/dV-V characteristics in various magnetic fields (0 T $< \mu_0 H <$ 9 T). The characteristics at 60 K and 80 K are shifted up by 0.05 and 0.02 (Ω^{-1}), respectively.

2. Experimental

Small mesas were fabricated out of a cleaved surface of a BSCCO single crystal by the standard photolithography and Ar ion-milling technique [3]. They have a lateral size of 10 μm and a thickness of 15 nm or less, which consists of 10 or less intrinsic Josephson junctions in series. The number of junctions was determined by the number of resistive branches in the oscilloscope current-voltage ($I - V$) characteristics. The crystals were annealed at 430°C in oxygen flow for 1 h. From the transition of the stack resistance, T_c for these mesas was found to range between 84 and 88 K, indicating that these samples are in slightly overdoped region.

Tunneling characteristics in magnetic fields along the c axis were measured at 0.6 μs after the leading edge of current pulses having a width of 1 μs and a duty of 0.08% in a temperature range from 10 K to 200 K.

3. Results and discussion

Figure 1 shows $dI/dV - V$ characteristics of the slightly overdoped sample ($T_c = 87$ K) in various magnetic fields. Below T_c, we observed the conductance peaks corresponding to the superconducting gap. These peaks become broader with increasing H. The broadening behavior also occurs when the temperature is raised from 60 K to 80 K as seen in Fig. 1. However, the effects of the magnetic field and temperature are completely different in nature. V_p increases with increasing H and decreases with increasing T. This behavior is more clearly demonstrated in Fig. 2, which summarizes the T-dependence of $V_p(T)$ at various H.

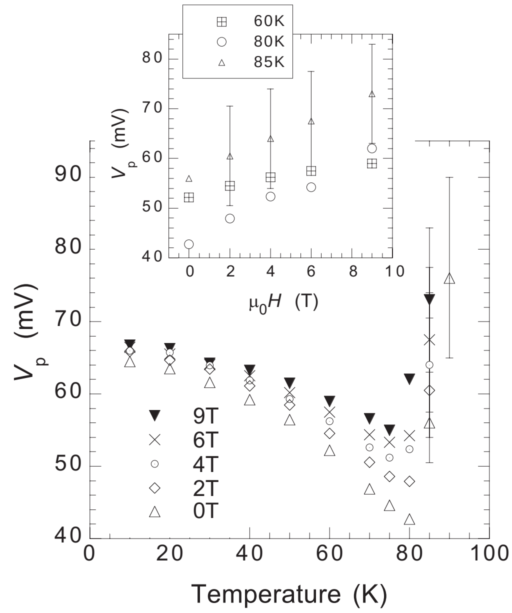

Fig. 2. Temperature dependence of the gap voltage V_p for the same sample in Fig. 1. Inset: The field dependence of V_p.

Above T_c, the pseudogap structure still depends on H weakly but definitely, which is in contrast to the dc measurement [5].

As shown in Fig. 1 and the inset of Fig. 2, $V_p(H)$ increases with H, which is accompanied by the broadening of the conductance peak. This behavior could be explained in terms of a single gap model. On the other hand, $V_p(T)$ decreases with increasing T and shows a dip structure near T_c. This complicated behavior is inconsistent with single gap models, which predict a broadening of the gap structure and a monotonical increase in V_p with increasing T.

The observed results of the decreasing $V_p(T)$ up to T_c and the increasing $V_p(H)$ may lead to a conclusion that the superconducting gap itself is decreasing with T and disappears at T_c, while the pseudogap still remains. This implies the existence of two distinct gaps in BSCCO.

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