Tunneling-spectroscopic evidence for unconventional pairing interaction in $Bi_2Sr_2CaCu_2O_{8+\delta}$

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Abstract

The quasiparticle density of states (DOS) is measured as a function of magnetic fields up to 9 T by the short-pulse interlayer tunneling spectroscopy for slightly overdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$. It is found that the quasiparticle DOS near the Fermi level E_F remains almost unchanged when the magnetic field parallel to the c-axis is applied up to 9 T. This is totally at variance with the conventional behavior in which the quasiparticle DOS at E_F increases with the increasing magnetic field. The present result implies that the quasiparticles involved in pairing come from higher energies apart from E_F, providing evidence for unconventional pairing mechanism.

Key words: high-T_c superconductors, $Bi_2Sr_2CaCu_2O_{8+\delta}$; superconducting gap; quasiparticle density of states; interlayer tunneling spectroscopy;

1. Introduction and conclusion

It is no exaggeration to say that the understanding of the high-T_c superconductivity in cuprates relies on the elucidation of its unconventional gap structure consisting of the superconducting gap and the pseudogap [1]. However, the close proximity of these two gaps both in the temperature and energy scales makes it significantly difficult to elucidate detailed characteristics of each gap and the relationship between them. One way to know such relationship is to depress superconductivity by applying magnetic fields, by which the superconducting gap is suppressed and the pseudogap becomes observable in an extended temperature range. Moreover, applied magnetic fields result in transfer of the quasiparticle density of states (DOS), from which we gain insight into the pairing interaction.

In order to know such relationship and energy scales of interaction through the quasiparticle DOS transfer, we have measured the gap structure for slightly overdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$ by interlayer tunneling spectroscopy (ITS) [2] in the presence of magnetic fields, B, parallel to the c-axis up to 9 T. It is found that the quasiparticle DOS at the Fermi level E_F remains almost unchanged under magnetic fields up to $B = 9$ T. This is a striking result in that the DOS transfer that is essential in conventional superconductivity is missing. The result implies that totally unconventional pairing interaction is involved in high-T_c superconductivity, or a magnetic field induces an ordered state that competes with superconductivity.

2. Interlayer tunneling measurements

The gap structure of a slightly overdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$ was measured by short-pulse ITS. The current-voltage characteristics were measured with an arbitrary waveform generator and a four-channel digital oscilloscope. The pulse voltage responses were acquired at $600 - 700$ ns at the top of sinusoidal and rectangular composite pulses of a 1.7 μs width and a

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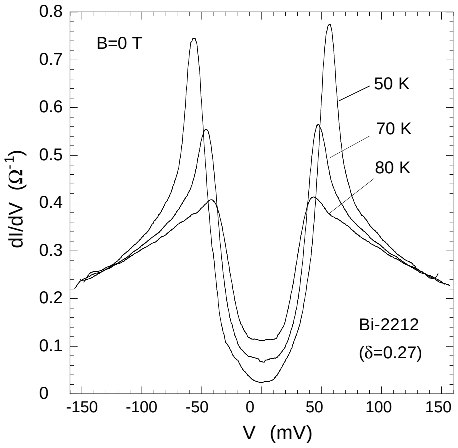

Fig. 1. $dI/dV - V$ characteristics for slightly overdoped Bi_2-$Sr_2CaCu_2O_{8+\delta}$ at 50, 70, and 80 K and $B = 0$ T.

0.08% duty ratio using a differential input technique [3]. Specimens were $10\,\mu m \times 10\,\mu m$ square and 15 nm thick mesas fabricated by fine-processing a cleaved surface of a $Bi_2Sr_2CaCu_2O_{8+\delta}$ TSFZ single crystal. Fabrication and specimens were detailed elsewhere [2].

3. Spectroscopy results and discussion

Figure 1 shows short-pulse ITS $dI/dV - V$ curves in the absence of a magnetic field at three different temperatures. In the V range up to 160 mV, the curve exhibits a single sharp conductance $\sigma(V)$ peak, which corresponds to the superconducting gap of approximately $2\Delta_S = 60$ mV. This $\sigma(V)$ peak decreases with increasing T both in magnitude and separation as described earlier [2], presenting typical tunneling characteristics for slightly overdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$. The decreasing behavior of $\sigma(V)$ for $V > 100$ mV is possibly ascribed to self-heating due to current injection.

Figure 2 shows the $dI/dV - V$ curves in the presence of a magnetic field of 9 T under otherwise the same condition as in Fig. 1. It is seen that the $\sigma(V)$ peak decreases in height and broadens under $B = 9$ T, accompanied by an increase in $2\Delta_S$ [4], which behavior is at variance with results reported earlier [5]. However, more striking is that the quasiparticle DOS near E_F is unchanged by the application of magnetic fields up to 9 T, as shown in Fig. 3. This absence of DOS transfer is totally at variance with the conventional behavior, in which the DOS at the $\sigma(V)$ peak is transferred to within of the gap when the superconductivity is suppressed by magnetic fields. There are two scenarios that may account for this unconventional behavior. The first scenario invokes unconventional pairing interaction in which electrons at much lower or higher than E_F energies are involved in pairing. The second scenario invokes competition between superconductivity and another ordered state of different kind. In this state, the unknown ordered state is energetically lower than the superconducting state under magnetic fields.

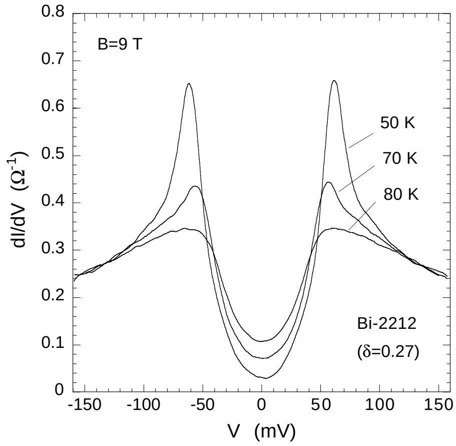

Fig. 2. $dI/dV - V$ characteristics for the same specimen in Fig. 1 in the presence of a magnetic field of $B = 9$ T under otherwise the same conditions as in Fig. 1.

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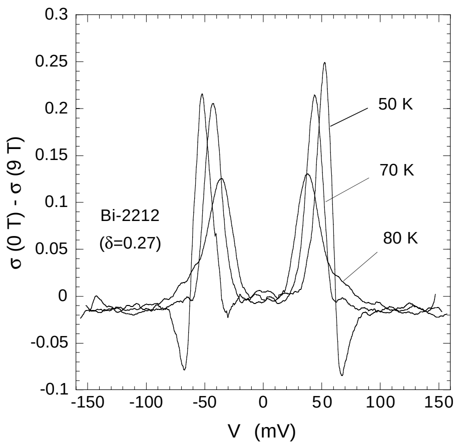

Fig. 3. Subtracted tunneling conductance $\sigma(0\,T) - \sigma(9\,T)$, indicating the change in the quasiparticle DOS by the application of a magnetic field of $B = 9$ T.

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