Coexistence of Superconducting Gap and Pseudogap in Underdoped Bi2212

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Abstract

We have carefully studied the temperature dependence of tunneling spectra in underdoped and slightly overdoped Bi2212 single crystals. The underdoped spectra clearly show a pseudogap above T_c, while this gap features get very weak in slightly overdoped crystals. Without the pseudogap depression, the states in slightly overdoped spectra are always conserved. However, underdoped spectra do not conserve states even at temperatures when the material is in its superconducting state. We found that the conservation of states can be recovered by normalizing the superconducting spectra with the normal state pseudogap spectra. This clearly indicates the coexistence of pseudogap and superconducting gap. As we will show in the analysis section, this coexistence can also explain the hump and dip features commonly observed in tunneling spectra.

Key words: pseudogap; BSCCO; high T_c; density of states; tunneling

1. Introduction

One interesting feature in high T_c superconductivity is the existence of a pseudogap structure at temperatures above the critical temperature [1]. However, there is no common consensus on the origin of pseudogap. One explanation is the pre-formation of pairs above T_c [2]. These pairs give rise to an energy gap, but lack the coherence for superconductivity. There is also possibility of loss of states near E_f. This can be resulted from many possible reasons, like lattice distortion or magnetic instability as suggested by various authors [3-6].

2. Coexistence of Gaps

In this paper, we want to point out the coexistence of pseudogap and superconducting gap in tunneling spectra. We have carefully studied the low temperature tunneling spectra and compare with those above T_c. For slightly overdoped $Bi_2Sr_2CaCu_2O_y$ (Bi2212), there is no pseudogap above T_c and the states are conserved in the superconducting state. The areas below and above the normal curve are equal, as in all other conventional superconductors well described by the BCS theory. However, we have observed that underdoped Bi2212 does not follow this rule.

In figure 1, we show two SIS tunneling conductance curves for underdoped Bi2212 (T_c=65K), one taken at 85K (above T_c) and the other taken at 15K. The 85K one clearly displays the pseudogap. For the 15K curve, if we use the high bias portion as the baseline of the normal curve, the area above the normal curve is significantly smaller than the area below. The conservation of states can only be recovered by normalizing the 15K curve with the whole 85K curve, and the result is shown in the lower portion of figure 1. This implies the high temperature curve, including the pseudogap feature, form the real normal density of states (DOS). There is an apparent loss of states in the supercon-

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ducting DOS because of the depression caused by the pseudogap. The pseudogap coexists with the superconducting gap in the low temperature tunneling spectra.

3. Analysis

Following this line of thought, we can develop a quantitative procedure to properly normalize tunneling conductance curves in high T_c superconductors. The normal state DOS has a linear asymmetric background and a wide pseudogap depression near E_f, which can be modeled as an inverted Gaussian with an offset as follow:

$$N_n(E) \propto \left(1+\frac{E}{\alpha}\right)\left[1-\beta\exp\left(-\frac{E^2}{\gamma^2}\right)\right]. \qquad (1)$$

where α, β, and γ are constants. The linear background (commonly observed in SIN tunneling) will give rise to the parabolic background in SIS tunneling. This can be used to replace the constant normal DOS in the BCS theory to form the superconducting DOS of high T_c superconductors:

$$N_s(E) = N_n(E)\mathrm{Re}\left\{\frac{(E-i\Gamma)}{\sqrt{(E-i\Gamma)^2-\Delta^2}}\right\}. \qquad (2)$$

These densities of states can then be used to calculate the tunneling current and conductance for both SIN and SIS junctions. Figure 2 show two generated curves for both superconducting (upper) and normal (lower) cases, together with the original data. The parameters used to generate these curves are given in the figures. Note that the fitting is not a best fit for the whole curve, as we focus more at the peak area. As a result, the parameters used in the two figures are slightly different because of the missing superconducting peak in the normal state. The fitting is reasonable well provided that we have not considered the gap anisotropy and fine tuned the Gaussian model for the pseudogap state. From the upper figure we can see that this model successfully generates the hump and dip features commonly observed in tunneling spectroscopy, as a signature of the pseudogap.

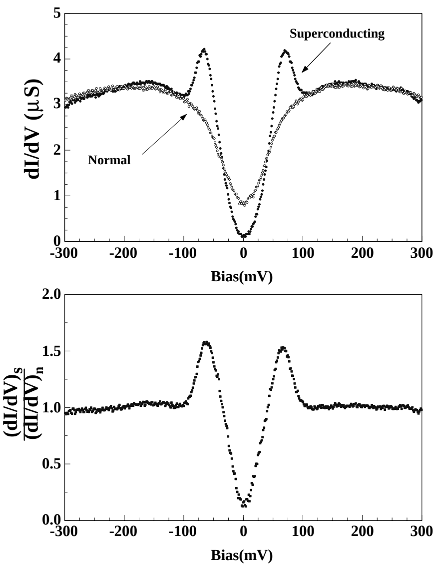

Fig. 1. Upper: SIS tunneling conductance spectra for underdoped Bi2212 at 15K (superconducting) and 85.1K (normal). Lower: The 15K spectrum divided by the 85.1K spectrum.

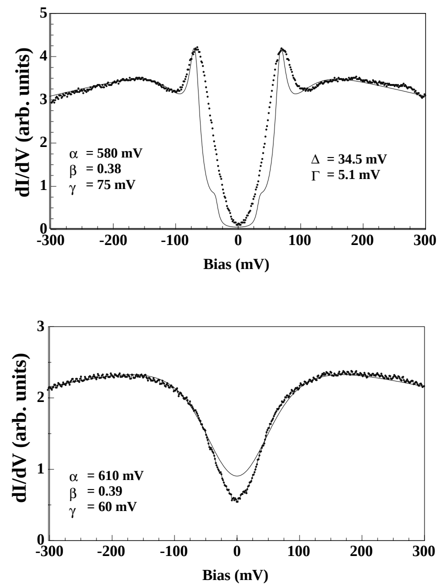

Fig. 2. Numerical calculated spectra using the model described in the text. Also displayed are the original data from figure 1. Upper: 15K for superconducting state. Lower: 85.1K for normal states. Parameters used are given in the figures.

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