Inhomogeneous electronic structures in heavily Pb-doped $Bi_2Sr_2CaCu_2O_y$ single crystals probed by low temperature STM/STS

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Abstract

We have performed cryogenic scanning tunneling microscopy/spectroscopy (STM/STS) of heavily Pb-doped $Bi_2Sr_2CaCu_2O_y$ single crystals to investigate local electronic structures in the overdoped regime. The obtained STM/STS results at 4.3 K clearly showed local inhomogeneity of gap structure Δ (Δ=20-60 meV) in a scale of several nm, giving evidence for the coexistence of sperconducting and pseudogap-like regions even in the overdoped regime.

Key words: electronic inhomogeneity; Pb-doped Bi2212; STM/STS

1. Introduction

Recent STM/STS studies, mainly conducted on optimally [1] and underdoped $Bi_2Sr_2CaCu_2O_y$ (Bi2212) [2–5] single crystals, have elucidated that magnitude of superconducting energy gap Δ is not spatially uniform in a nanometer scale. In underdoped Bi2212 [5], in particular, granular superconductivity was found, in which superconducting domains with a size of $\sim$ 3 nm are separated by the regions indicating pseudogap-like spectra.

In order to investigate local electronic structures in the overdoped regime, we have performed cryogenic STM/STS on single crystals of heavily Pb-doped $Bi_{2-x}Pb_xSr_2CaCu_2O_y$ (Pb-Bi2212) with $x = 0.6$. The obtained spatial map of Δ at 4.3 K clearly demonstrates strong inhomogeneity in gap structures that superconducting and pseudogap-like domains coexist, similar to those seen in optimally [1] and underdoped [2–5] Bi2212.

2. Experimental

Pb-Bi2212 single crystals with $x = 0.6$ were grown by the floating-zone method, and were post-annealed in pure oxygen atmosphere of $P(O_2)$=2.1 atm at 400°C for 3 days. T_c was determined to be 68 K.

STM/STS measurements were carried out using an UHV-low temperature STM instrument equipped with a low temperature cleavage stage. The base pressure of the STM chamber was maintained at less than 2.0×10^{-10} Torr during the measurements. All samples examined here were cleaved *in situ* at 77 K to avoid the oxygen loss from sample surfaces. Mechanically sharpened Pr-Ir alloy were used as the STM tips.

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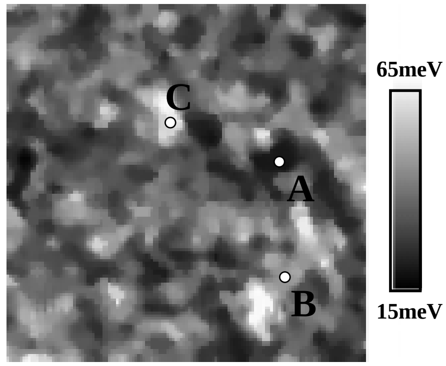

Fig. 1. Δ map obtained on a Pb-Bi2212 single crystal at 4.3 K. The image size is 48×48 nm^2, and the tunneling conditions are V_s=100 mV, I_t=0.5 nA.

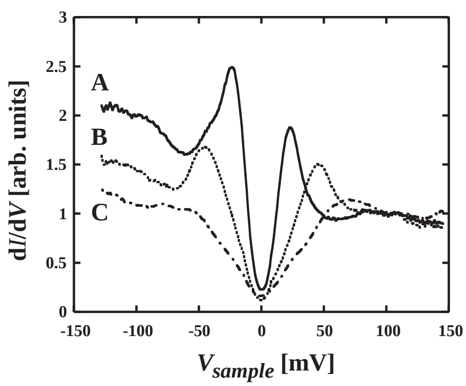

Fig. 2. Tunneling spectra averaged around locations A, B and C in Fig. 1. These spectra are normalized at 100 mV.

3. Results and discussion

Figure 1 is a spatial map of peak-to-peak gap Δ of a Pb-Bi2212 single crystal, derived from STS measurement at 4.3 K. As can be seen, Δ shows spatial variation in a nanometer scale, ranging from 20 to 60 meV. Notably, smaller and larger gap regions, imaged with brighter and darker contrasts in Fig. 1, are smoothly connected by intermediate ones. The lateral sizes of the domains are roughly estimated to be 2 to 6 nm.

Typical tunneling spectra, averaged around the locations marked by A, B and C in Fig. 1, are compared in Fig. 2. In the tunneling spectrum A, taken in the smallest gap domain, reveals superconducting gap features with asymmetric background and well-developed coherence peaks. Furthermore, the Δ value estimated from the spectrum A, $\sim$ 23 meV, is close to that reported for pure Bi2212 in the overdoped regime [6]. Therefore, we tentatively identify that the gap structure in the spectrum A represents a superconducting gap. As seen from the spectra B and C, the conductance peaks are gradually suppressed as Δ is increased. Particularly, the spectrum C exhibits pseudogap-like behavior, characterized by a large gap and dull gap edges, similar to the previous observations on optimally [1] and underdoped [2–5] Bi2212.

The present STM/STS results clearly indicate that overdoped Bi2212 contains substantial inhomogeneity in Δ, which seems to be a common phenomenon, widely seen in Bi2212, irrespective of carrier number.

4. Summary

STM/STS observations of Pb-Bi2212 single crystals were performed at 4.3 K. We successfully imaged spatial distributions of Δ of a nanometer order, ranging from 20 to 60 meV. We also observed that the conductance peak height is suppressed as Δ is elevated. These lead to a conclusion that superconducting and psuedogap-like domains coexist even in the heavily overdoped Bi2212, which is thought to be relatively free from chemical instability.

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