Cryogenic STM/STS observations of Pb-doped $Bi_2Sr_2CuO_y$ single crystals

Hideki Mashima [a,1], Go Kinoda [a], Hiroshi Ikuta [b], Tetsuya Hasegawa [a]

[a] *Frontier Collaborative Research Center, Tokyo Institute of Technology, Midori-ku, Yokohama 226-8503, Japan*

[b] *Center for Integrated Research in Science and Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan*

Abstract

Cleaved ab-surfaces of Pb-doped $Bi_2Sr_2CuO_y$ (Bi2201) single crystals were probed by scanning tunning tunneling microscopy/spectroscopy (STM/STS) at cryogenic temperatures below T_c. The obtained STS spectra clearly indicate a d-wave like gap structure superimposed on inverse V-shaped background, similar to the previous STS observations on pure Bi2201. Furthermore, we found that the gap value Δ was spatially non-uniform in a nanometer scale and ranged from 20 to 30 meV.

Key words: Bi2201; STM/STS; superconductiving gap;

1. Introduction

Scanning tunneling spectroscopy (STS) has been extensively used for the elucidation of the pseudo-gap state in a high temperature superconductor, $Bi_2Sr_2CaCu_2O_y$ (Bi2212) in various doping levels [1,2]. As a result, it has been clarified that the superconducting gap changes into the pseudo-gap almost continuously at T_c, and that the pseudo-gap state survives up to room temperature in the underdoped or optimally doped compounds. Recently, similar STS measurements have been perfomed on $Bi_2Sr_2CuO_y$ (Bi2201), containing a single CuO_2 layer in a unit, and confirmed the pseudo-gap above T_c [6]. However, its doping dependence has not been examined yet.

In this paper, we present the results of STM/STS measurements on Pb-doped Bi2201 in the overdoped regime. The obtained STS spectra at 4.3 K revealed a granular behavior of superconductivity that superconducting and pseudo-gap-like regions are mixed up in a nanometer scale, similar to those reported on Bi2212 [3,4].

[1] E-mail:deki@rlem.titech.ac.jp

2. Experiment

Pb-Bi2201 single crystals were grown by a FZ method. The single crystals exhibit a superconducting diamagnetic transition at $T_c = 10$ K. By means of inductively coupled plasma spectrometry (ICP), their chemical composition was determined as $Bi_{1.83}Pb_{0.37}Sr_{1.91}CuO_y$. The base pressure of the STM chamber was maintained at less than 2×10^{-11} Torr during the measurements. The single crystals were cleaved at 77 K to avoid oxygen loss from the surfaces. STM tips used in this study were mechanically sharpened Pt/Ir wires.

3. Results and discussion

Fig. 1 is an STM image taken on the cleaved ab plane of a Pb-Bi2201 single crystal at 4.3 K. The figure clealy indicates a two-dimensional atomic arrangement separated by 0.35 nm, which is comparable with the a- or b-axis length of Pb-Bi2201 unit cell [5]. In the present Pb-Bi2201 samples, we did not observe any sign of phase separation into Pb-rich and Pb-poor re-

Preprint submitted to LT23 Proceedings *14 June 2002*

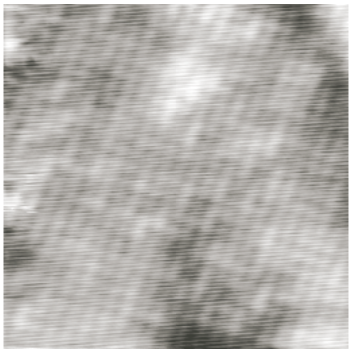

Fig. 1. Constant current STM image on the cleaved ab surface of Pb-Bi2201 single crystal at 4.3 K. The scanning area is 7.5 $\times$ 7.5 nm^2. The sample bias voltage and set-point current are V_s = 100 mV and I_t = 0.4 nA, respectively.

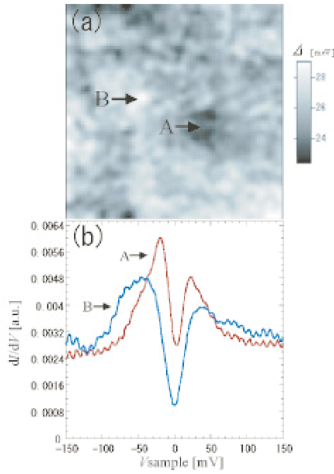

Fig. 2. (a) Δ distribution on the cleaved ab surface of Pb-Bi2201 at 4.3 K. The scanning area is 7.5 $\times$ 7.5 nm^2. (b) Tunneling spectra at the locations A and B in Fig.2(a).

gions, as seen in heavily Pb doped Bi2212. From Fig. 1, it is notable that in the present Pb-Bi2201 the modulation along the b-axis completely disappears. This is in sharp contrast to Pb-Bi2212, in which the modulation survives, at least, up to $x\sim$ 0.4, although the modulation period is expanded along with x.

Fig. 2(a) is a spatial map of the gap value Δ, defined as the energy separation between conductance peaks. As can be seen, Δ is non-uniform and is substantially distributed, ranging from 20 to 30 meV, over the scanned area of 9 $\times$ 9 nm^2.

Δ varies on a scale of 1-2 nm, which is in accordance with the in-plane coherence length. These features are essentially same as those observed in Bi2212 in the underdoped and optimally doped regimes. Thefrefore, it can be concluded that the inhomgeneity in Δ is an inherent nature of Bi-based cuprates in common, irrespective of carrier number. However, relative standard deviation of Δ, $\delta\Delta/\Delta$, as a measure of the magnitude of inhomogeneity, is fairly smaller than those of pure Bi2212 and Pb-doped Bi2212 [3,4]. This suggests that the random potential introduced by Pb atoms is not a major cause of the gap inhomegeneity observed here.

The site-specified tunneling spectra observed on the locations A and B in Fig.2 (a) are shown in Fig. 2(b), as previously reported in pure Bi2201 [6]. Both spectra exhibit an inverse-V shaped background, which may be due to the van Hove singularity. Notably, the zero bias conductance of curve B is much lower than that of A, while the coherence peak at B is substantially depressed. The similar tendencies have also been found in underdoped and optimally doped Bi2212 [3,4]. Opening of a relatively wide gap accompanied with the suppression of conductance peaks has been frequently argued as a typical character of pseudo-gap state, so that the present STS results suggest nano-scale phase separation into superconducting and pseudo-gap domains.

4. Summary

We have performed low temperature STM/STS measurements on Pb-doped Bi2201 at 4.3 K. The gap value Δ evaluated from the STS spectra was found to be spatialy non-uniform, as seen in Bi2212, although the extent of gap inhomegeneity is relatively smaller. The coherent peaks tend to be suppressed, and, at the same time, zero bias conductance is lowered, as Δ is increased. These finding lead to a conclusion that granular superconductivity is a general feature of Bi-based cuprates, regardless of number of CuO planes and carrier concentration.

References

[1] Ch. Renner, B. Revaz, J. Y. Genond, K. Kadowaki, ϕ. Fischer, Phys. Rev. Lett. **80** (1998) 149.

[2] A. Matsuda, S. Sugita, T. Watanabe, Phys. Rev. B. **60** (1999) 1377.

[3] S. H. Pan, J. P. O'Neal, R, L, Badzey, C. Chamon, H. Ding, J. R. Engelbrecht, Z. Wang, H. Eisaki, S. Uchida, A. K. Gupta, K. -W. Ng, K. M. Lang, J.C. Davis, Nature **413** (2001) 282.

[4] K. M. Lang, V. Madhaven, J. E. Hoffman, E. W. Hudson, H. Eisaki, S. Uchida, J. C. Davis, Nature **415** (2002) 412.

[5] I. Chong, T. Terashima, Y. Bando, M. Takano, Y. Matsuda, T. Nagaoka, K. Kumagai, Physica C **282-287** (1997) 57.

[6] M. Kugler, ϕ. Fischer, Ch. Renner, S. Ono, Y. Ando, Phys. Rev. Lett. **86** (2001) 4911.