LT-STM observation of $YBa_2(Cu_{1-x}Zn_x)_3O_{7-\delta}$ single crystals

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Abstract

Low-temperature scanning tunneling microscopy on the BaO layer of cold-cleaved $YBa_2(Cu_{1-x}Zn_x)_3O_{7-\delta}$ single crystals reveals the one-dimensional charge modulations at lower bias voltage. These charge modulations have various lengths and are distributed randomly in space. The spatially inhomogeneous electronic state is regarded to be induced by Zn impurities in the CuO_2 plane just under the BaO layer, because there are no charge modulations on Zn-free samples. The one-dimensional character possibly reflects the interaction between the CuO_2 and the CuO-chain layers.

Key words: STM; $YBa_2Cu_3O_{7-\delta}$; Zn impurity

1. Introduction

Impurity effects provide us with valuable information when considering the mechanism of high-temperature superconductivity. Low-temperature scanning tunneling microscopy and spectroscopy (LT-STM/STS) is a powerful technique to investigate them because it is capable of finding the quasiparticle scattering resonances at the impurity sites directly. Recently, Pan *et al*. have shown that the four-fold symmetric quasiparticle cloud at Zn atoms doped in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) [1]. Their results indicated that the superconducting gap symmetry is *d*-wave and Zn is interpreted as the unitary limit scatterer in this material. On the other hand, only a few LT-STM/STS measurements of the impurity effects for the other high-T_c materials have been successful because of their highly reactive surfaces and complicated electronic structures [2]. In this paper, we present LT-STM observation of Zn-substituted $YBa_2Cu_3O_{7-\delta}$ (YBCO) and show the one-dimensional (1D) charge density modulations induced by a few Zn impurities.

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2. Experimental

$YBa_2(Cu_{1-x}Zn_x)_3O_{7-\delta}$ single crystals with $x \simeq 0.003$ were grown by a self-flux method using yttria crucibles. The actual Zn concentration is measured with inductively-coupled plasma spectrometry (ICP), and the homogeneity of Zn is confirmed with electron-probe microanalysis (EPMA). Superconducting transition temperature T_c determined by magnetization measurements was 88 K with a transition width of ~1.5 K. Samples were introduced into the ultrahigh vacuum (UHV) chamber and then mechanically cleaved at low temperature below 20 K in order to obtain clean surfaces without oxygen desorption. STM measurements were carried out in constant height mode at 4.2 K using a Pt-Ir tip mounted perpendicular to the *ab* plane of cleaved sample [3].

3. Results and discussion

Figure 1 shows a STM current image of the cleaved surface of Zn-doped YBCO. We can see a square lattice pattern with the lattice constant of about 3.9 Å and a few disordered islands on the right side (and

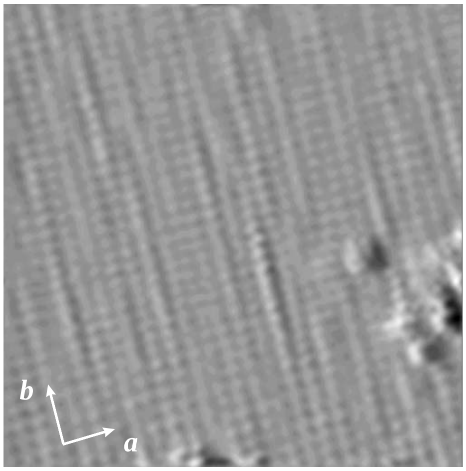

Fig. 1. Constant-height image (11 nm on a side) of the BaO layer in Zn-doped YBCO ($V_{\rm tip}$ = 10 mV, I = 0.45 nA). The b-axis is assigned along the direction of 1D charge modulations.

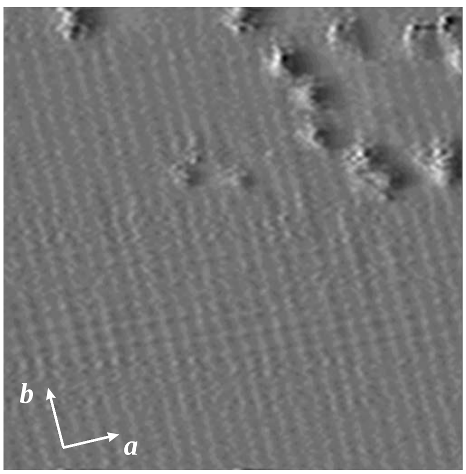

Fig. 2. Constant-height image (11 nm on a side) of the BaO layer in Zn-doped YBCO ($V_{\rm tip}$ = 50 mV, I = 0.45 nA).

on the bottom edge) of the image shown in Fig. 1. These are the characteristics of STM images on the BaO layer, which is one of the surface terminations of mechanically cleaved YBCO [4]. The images obtained on the CuO-chain layer in Zn-doped YBCO were similar to the charge density corrugation images in Zn-free YBCO [5].

Moreover, above figure shows very interesting features; several electronic modulations are superimposed on the atomic lattice. On Zn-free YBCO, we have not observed such modulations. When the tip bias voltage increases up to about 40 mV, the charge modulations disappear as shown in Fig. 2. Therefore, the charge modulations reflect the change of electronic states near the Fermi level caused by Zn doping. Since the Zn impurities are expected to selectively replace the Cu sites in the CuO_2 plane [6], we believe the 1D charge modulations are attributed to the electronic structure of the CuO_2 plane just under the BaO layer.

These charge modulations have various lengths and are distributed randomly in space. Note that Zn concentration of $x \simeq 0.003$ corresponds to about four Zn atoms per a 11 nm × 11 nm area of Fig. 1 in average. The number of the charge modulations is much more than that of Zn atoms doped in the sample, which indicates that the charge modulations are not originated from the quasiparticle bound states formed around each Zn impurity but the whole electronic structure in the CuO_2 plane is altered by a few Zn impurities.

On underdoped Bi2212, the microscopic-spatial variations of the superconducting-gap magnitude have been reported via LT-STM/STS [7,8]. We consider that the most possible explanation for our LT-STM results is that the innate electronic inhomogeneity in the CuO_2 plane like in Bi2212 is induced by a few Zn impurities. The 1D character of the charge modulations possibly reflects the interaction between the CuO_2 and the CuO-chain layers, which is the characteristic of the electronic inhomogeneity in YBCO.

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References

[1] S. H. Pan, E. W. Hudson, K. M. Lang, H. Eisaki, S. Uchida, and J. C. Davis, Nature (London) **403**, 746 (2000).

[2] N.-C. Yeh, C.-T. Chen, G. Hammerl, J. Mannhart, A. Schmehl, C. W. Schneider, R. R. Schulz, S. Tajima, K. Yoshida, D. Garrigus, and M. Strasik, Phys. Rev. Lett. **87**, 087003 (2001).

[3] M. Maki, T. Nishizaki, K. Shibata, T. Sasaki, and N. Kobayashi, Physica C **357-360**, 291 (2001).

[4] M. Maki, T. Nishizaki, K. Shibata, and N. Kobayashi, J. Phys. Soc. Jpn. **70**, 1877 (2001).

[5] M. Maki, T. Nishizaki, K. Shibata, and N. Kobayashi, Phys. Rev. B **65**, 140511 (2002).

[6] H. Alloul, P. Mendels, H. Casalta, J. F. Marucco, and J. Arabski, Phys. Rev. Lett. **67**, 3140 (1991).

[7] C. Howald, P. Fournier, and A. Kapitulnik, Phys. Rev. B **64**, 100504 (2001).

[8] 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, E. W. Hudson, K. M. Lang, and J. C. Davis, Nature (London) **413**, 282 (2001).