STM/STS studies on $YBa_2Cu_3O_{7-\delta}$ thin films treated with an atomic oxygen beam

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Abstract

The surface electronic states of $YBa_2Cu_3O_{7-\delta}$ (YBCO) films are studied by scanning tunneling microscopy/spectroscopy (STM/STS) at 10K. In order to improve the sample surface quality, we have developed a vacuum transfer system combined with an atomic oxygen beam. The conductance spectra of the YBCO films showed the gap structure in most area of the surface, which indicates the successful surface treatment in the present system. The spatial variation of electronic states observed near a step structure suggests the presence of interference effect of the d-wave pair potential induced by surface roughness.

Key words: YBCO; STS; atomic oxygen beam

1. Introduction

The surface bound states due to $d_{x^2-y^2}$-wave pair potential have been studied by a large number of experimental and theoretical works of tunneling spectroscopy in high-T_c superconductors [1–3]. According to the theoretical studies, zero-bias conductance peak (ZBCP) in tunneling spectra is expected on (110)-oriented surfaces of $d_{x^2-y^2}$-wave reflecting the internal phase-shift of the pair potential, but not on (100)- and (001)-oriented flat surfaces [2]. On the other hand, if the defects and steps exist on a surface, the surface bound states is expected to be locally induced around these structures even at (100)- and (001)-oriented surfaces [4]. In order to testify the theoretical prediction of Ref. [4], low-temperature ultrahigh vacuum scanning tunneling microscopy (STM) and scanning tunneling spectroscopy (STS) measurements have been performed on YBCO(001) films. The origin of the spatial variation of the electronic state is discussed.

2. Results and discussions

The (001)-oriented YBCO films were fabricated by sputtering method on $SrTiO_3$ or MgO substrates. Since the critical temperatures of the samples were ~90K, the samples were regarded as optimum doping. The film surfaces were treated with an atomic oxygen beam generated by thermodynamic non-equilibrium plasma [5]. The improvements of film qualities gained by the treatment were confirmed using reflection high energy electron diffraction, ultraviolet and X-ray photoemission spectroscopy and STM. Details about the treatment process and the characterization are described in Ref. 5. After the treatment, the sample was transported from a sample preparation chamber to an STM chamber without exposing to the air by using

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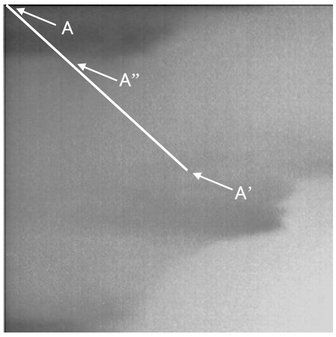

Fig. 1. Constant-current-mode topographic image ($29\times29\,\mathrm{nm}^2$; tip bias voltage −400 mV; tunneling current 0.63 nA) on a YBCO(001) film treated with an atomic oxygen beam at 10 K.

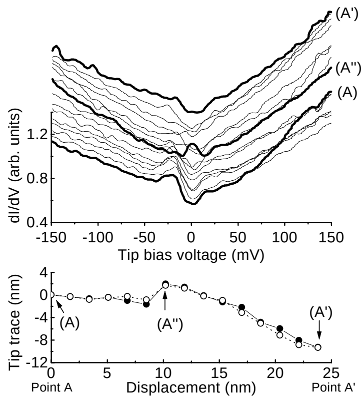

Fig. 2. Scanning tunneling spectra on a YBCO(001) film treated with an atomic oxygen beam by successive 15 point measurements along a line (A−A') in fig. 1. The lower figure shows the tip traces before (•) and after (∘) the spectroscopy.

transfer vessel equipped with a getter pump (10^{-8} Torr range). The sample was mounted on a home built low-temperature ultrahigh vacuum (10^{-9} Torr range) STM. All STM/STS measurements described below were performed with Pt-Ir tips at 10 K. Local work function (LWF) values were obtained simultaneously with topographic measurements using an ac modulation method.

Figure 1 shows an STM image obtained on a treated film. The image shows the surface structure of three terraces separated by two steps (3−4 nm heights). In topographic images obtained on other samples, we found steps of various heights (1−6 nm heights) and terraces of wider area. At terraces of relatively high quality surfaces, tunneling spectra of V-shaped gap structures and LWF of about 0.5eV were found to be uniformly distributed. This fact suggests the successful surface treatment and transport in the present system. Figure 2 shows the spatial dependence of conductance spectra obtained at 15 points with 1.65-nm intervals along a line shown Fig. 1. In the lower part of the figure, tip traces that reflect the surface morphology along the scanning line before and after the STS measurement are also shown. The series of spectra exhibit gap structures on the flat terrace (A), ZBCP at the step edge (A"), and asymmetric gap structures at the upper terrace (A'). In other STS measurements, ZBCP's or peaks whose centers were not positioned exactly at zero-bias inside gap structure were observed within distances of about two coherence lengths (2−3 nm) from step edges.

There are mainly two possible explanations for the present data. First, the features that various types of conductance spectra are spatially distributed in a few coherence lengths from the step edges are consistent with the theoretical calculations which takes account the surface roughness [4]. Second, the spatial inhomogeneity is intrinsic nature to high-T_c superconductors as shown in the other experiment [6]. In such case, the inhomogeneity of electronic states is closely related to the variation of the doping rate due to chemical inhomogeneity. We believe that the ZBCP observed at the step edge have the former origin, that is, the interference effect caused by the surface structures reflecting the internal phase-shift of $d_{x^2-y^2}$-wave pair potential. On the other hand, the asymmetric gap structures observed at the upper terrace suggest the breakdown of electron-hole symmetry of the electronic states, therefore it is closely related to the latter origin, *i.e*, the local variation of the doping rates. At present we cannot identify details because observation of the atomic image of YBCO was unsuccessful in the present system. Further improvement of the STM/STS system is required to study the correlation between spectra and morphology.

In conclusion, we observed spatial dependence of tunneling spectra around step structures that may suggest the existence of an interference effect due to $d_{x^2-y^2}$-wave pair potential.

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