STM Tunneling Spectroscopy on High Tc Superconductors

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STM tunneling spectroscopy has been performed on the bulk single crystals of BiSrCaCuO (BSCCO) and the epitaxial thin films of YBaCuO (YBCO) at cryogenic temperatures. The STM images and tunneling spectra observed on the (001) surfaces can be classified into three cases; 1) Atomic image is visible. However, the tunneling spectrum shows semiconducting or smeared superconducting gap structures, depending on the tip-sample distance. 2) Clear atomic image can not be obtained. But, the tunneling spectrum shows flat bottom region with quite low zero bias conductance. 3) Tunneling spectra demonstrate gapless behavior, independent of the tip-sample separation. These observations support the quasi-2D electronic picture in which s-wave like 2D superconducting layers are coupled with each other through the Josephson effect.

KEY WORDS: STM; superconducting gap; symmetry of order parameter.

1. INTRODUCTION

It is of great importance to clarify the correlation between the normal and superconducting properties of high $T_c$ superconductors (HTSCs) and their two-dimensional electronic nature associated with the layered crystal structures. High anisotropies in various normal-state transport properties can be understood by modeling the HTSCs as that the conducting CuO$_2$ layer and other insulating or less conducting layers are alternately stacked and the electron conduction mainly takes place two-dimensionally in the CuO$_2$ layer. Because of the short coherence, quasi two-dimensional superconducting state is possible. That is, the superconducting order parameter may change from the different layer to another along the c-axis.

Recently, the tunneling spectroscopy using scanning tunneling microscopy (STM) has attracted much attentions as a microscopic probe which is capable of measuring the local density of states profiles near the Fermi level [1-8]. Recently, this technique, STS, has been improved to more sophisticated one in which the spectroscopic measurement locations are specified on the STM topographic image simultaneously taken with the tunneling spectra. We have proposed this technique as atomic site tunneling spectroscopy (AST) [6,9]. It has been applied to the layered dichalcogenides, and has shown the local variation of the density of states profiles depending on the atomic site relative to the charge density wave [9].

In this paper, we report on the AST observations on the cleaved surface of Bi$_2$Sr$_2$CaCu$_2$O$_8$ (BSCCO) single crystals and epitaxial thin films of YBa$_2$Cu$_3$O$_7$ (YBCO) at 4.2 K. The obtained tunneling data were classified into several cases with respect to the quality of atomic image and the inner gap conductance of superconducting gap structure. These observations were discussed in terms of the quasi two-dimensional electronic nature of HTSCs.

2. EXPERIMENTAL

Cryogenic temperature STM (CSTM) instrument was laboratory constructed. It enables us to perform AST mode operation in which STM image and tunneling spectra were simultaneously taken. The details of our CSTM system were described elsewhere [1].

Single crystals of BSCCO were grown by the floating zone method. The as-grown crystals were

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further annealed air at 500 °C. The (001) and (110) oriented thin films were prepared by the laser ablation method [7,8].

3. RESULTS AND DISCUSSION

3.1. STM Tunneling Spectroscopy on YBCO (001) and (110) Films

Tunneling spectra observed on YBCO can be classified into three groups, type I, II, and III. The type I spectra observed on the (001) oriented films are characterized by the bias voltage ($V_b$) dependence, as illustrated in Fig. 1 [7]. In Fig. 1, the set-point current is kept constant, 1 nA. Therefore, lower $V_b$ corresponds to closer tip-sample separation. For higher $V_b$, the tunneling spectrum shows semiconducting behavior, reflecting that the surface atomic layer is insulating. As $V_b$ decreases, the electron tunneling into a superconducting layers becomes dominant, and a superconducting gap structure appears. However, it is noted that no clean gap was observed in the type I spectrum.

The type II spectra showing a clean superconducting gap were found on the YBCO (001) films grown at relatively low temperatures [6,7]. Fig. 2 exhibits the typical examples of the type II spectra taken at various measurement locations. The zero bias conductance is as low as 1% of the background, which is one of the lowest value ever reported. Because the tunneling probe in STM has an atomic scale resolution, STM tunneling spectrum gives the local density of states averaged over momentum space [6]. Thus, the clean gap structure in Fig. 2 suggests a finite gap opening in the CuO$_2$ plane. Obviously, this situation is favored by $s$-wave pairing mechanisms.

The tunneling spectra taken on the YBCO (110) films, classified as the type III data, were shown in Fig. 3 [8]. The type III spectrum demonstrates a superconducting gap structure with high zero bias conductance, independent of the tip-sample separation. By comparing the type II and type III spectra, it is concluded that the CuO chain layer exposed on the (110) surface is responsible for the "gapless" feature in Fig. 3. Thus, the present STM measurements is consistent with the layered electronic model that CuO$_2$ layers are quasi-2D superconductors with $s$-wave symmetry which induce gapless superconductivity in the CuO chain by the proximity effect [10-12].

![Fig. 1. Bias voltage dependence of tunneling spectra on YBCO (001) film](image1)

![Fig. 2. Tunneling spectra on YBCO (001) film](image2)