Physica C 185-189 (1991) 941-942
North-Holland

SCANNING TUNNELING SPECTROSCOPY ON $Bi_2Sr_2CaCu_2O_{8-\delta}$

Koichi ICHIMURA*, Kazushige NOMURA*, Fujio MINAMI** and Shunji TAKEKAWA***

* Department of Physics, Hokkaido University, Sapporo 060, Japan
** Research Institute of Applied Electricity, Sapporo 060, Japan
*** National Institute for Research in Inorganic Materials, Tsukuba, Ibaraki 305, Japan

Tunneling measurement was carried out on single crystals of superconductiong oxide $Bi_2Sr_2CaCu_2O_{8-\delta}$ with use of the STM. Tunneling conductance varies with the distance between the tip and the sample surface at the outside region of superconducting gap, while the midgap conductance is independent of the tip distance. The superconducting gap parameter was obtained as Δ=26±4 meV, and correspondingly $2\Delta/kT_c$=7±1. Temperature dependence of gap parameter is consistent with the BCS.

In various high T_c superconducting oxides, larger values of energy gap Δ than the BCS prediction have been reported by several tunneling studies. These values have shown a wide scatter. For instance, values of $2\Delta/k_BT_c$ from 6 to 11 have been assigned to $Bi_2Sr_2CaCu_2O_{8-\delta}$ [1-3]. Here, we report the tunneling spectroscopy measurement performed on $Bi_2Sr_2CaCu_2O_{8-\delta}$ by use of a low temperature STM (Scanning Tunneling Microscope).

Single crystals of $Bi_2Sr_2CaCu_2O_{8-\delta}$ were used in this study. The superconducting transition temperature was determined as T_c=87 K from the midpoint of the resistive transition. Tunneling (dI/dV)-V characteristics were measured in the temperature range from 4.2 K to room temperature at different positions of the cleaved sample surface by scanning the tip.

Figure 1 shows differential conductance curves obtained by varying the distance between the tip and the sample surface. We controlled the tip distance by keeping the tunneling current I constant for a constant bias voltage of 150 mV, which is much larger than the superconducting energy gap, before the voltage sweep. As the current increases, the tip distance becomes narrowed. Each curve is normalized at 30 mV. We can see the sharp drop of the differential conductance corresponding to the superconducting gap. We also find that the conductance is strongly enhanced at the outside region of the gap with decreasing the tip distance. Similar behavior was reported by Kitazawa *et al.* [4]. They claimed that the fit of the conductance curve to Dynes' equation as,

$$N_S(E)=\mathrm{Re}(E-i\Gamma)/[(E-i\Gamma)^2-\Delta^2]^{1/2}N_N(E), \quad (1)$$

is not suitable. The origin of such a distance-dependent tunneling conductance has not been explained yet. The tunneling through Bi-O layer may be partly responsible.

In our present result, however, the inner gap conductance is almost independent of the tip

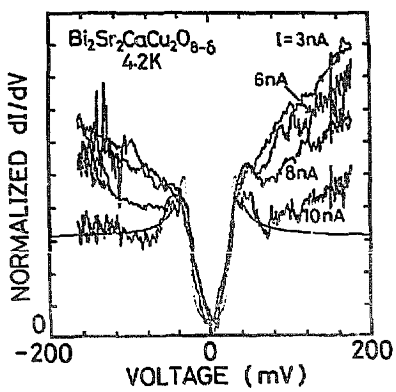

Fig. 1. dI/dV vs V characteristics at various tip distances. The tunneling current I denotes the tip distance as described in the text. The dotted curve represents the fit of the curve at I=10 nA to eq. (1).

distance as seen in Fig. 1 and is considered to show an intrinsic property of the superconductivity of this material. We can, therefore, determine the gap parameter as Δ=29 meV from the separation between points, where the conductance is 70% of its maximum in value, irrespective of the tip distance. This value of Δ corresponds to that obtained by a fit of the (dI/dV)-V curve at I=10 nA to eq. (1). Although this determination of Δ is not based on any specified theory, it gives probably the reasonable value for the superconducting gap parameter.

As we reported previously [5], the (dI/dV)-V curve shows the spatial variation. The gap parameter Δ varies over a length about 10 nm. This comes from both the short coherence length and the inhomogeneity of the sample, and is one of the causes for scattered values reported. As a result, the gap parameter was determined as Δ=26±4 meV, and correspondingly $2\Delta/kT_c$=7±1. This indicates that the superconductivity in $Bi_2Sr_2CaCu_2O_{8-\delta}$ is that of strong-coupling.

As shown in Fig. 2, (dI/dV)-V curve varies with the temperature. As the temperature raises, the structure of the energy gap becomes smeared and disappears at about T_c.

The temperature dependence of the gap

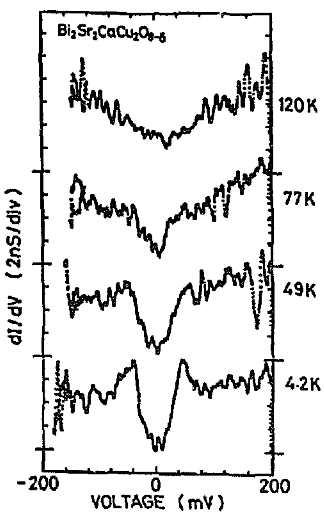

Fig. 2. dI/dV vs V characteristics at various temperatures.

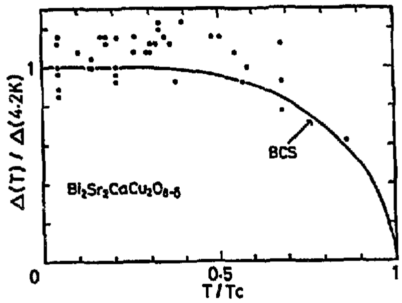

Fig. 3. Normalized gap parameter $\Delta(T)/\Delta(4.2\ K)$ vs reduced temperature T/T_c, where $\Delta(4.2\ K)$=26 meV. The solid curve represents the BCS prediction.

parameter Δ is shown in Fig. 3. Because of thermal expansions of STM unit materials, we could hardly keep the tip at the fixed position of the sample surface as the temperature changes. Accordingly, the spatial variation of Δ described above is also included in Fig. 3. At low temperature the gap parameter is almost constant and decreases as the temperature raises. The temperature dependence of Δ is qualitatively consistent with the BCS theory.

In summary, tunneling conductance was investigated on single crystals of $Bi_2Sr_2CaCu_2O_{8-\delta}$ with the STM. Although the conductance curve varies with the tip distance from the sample surface at the outside region of the superconducting gap, the midgap conductance is independent of the tip distance. The obtained gap parameter indicates the strong-coupling superconductivity. The temperature dependence of the gap parameter is explained with the BCS.

References

[1] T. Ekino and J. Akimitsu, *Phys. Rev.* **B40**, 6902 (1989)
[2] H. Ikuta, A. Maeda, K. Uchinokura and S. Tanaka, *Jpn. J. Appl. Phys.* 27, L1038 (1988)
[3] N. Miyakawa, D. Shimada, T. Kido and N. Tsuda, *J. Phys. Soc. Jpn.* 59, 2473 (1990)
[4] K. Kitazawa, T. Hasegawa and M. Nantoh, *Research Report on Mechanism of Superconductivity I*, 287 (1991)
[5] K. Ichimura, K. Nomura, F. Minami and S. Takekawa, *J. Phys.: Condens. Matter* **2**, 9961 (1990)