Physica B 194–196 (1994) 2189–2190
North-Holland

PHYSICA B

Anisotropic Superconducting Gap in $Bi_2Sr_2CaCu_2O_8$: STM Spectroscopy

K. Nomura and K. Ichimura

Department of Physics, Hokkaido University, Sapporo 060, JAPAN

The tunneling conductance was measured in $Bi_2Sr_2CaCu_2O_8$ with use of the Scanning Tunneling Microscope. The electronic density of states in the superconducting phase was correctly obtained at lateral surface of single crystal. The superconducting gap was found to be finite on the whole Fermi surface, while it showed a considerable anisotropy. It was understood that the attractive interaction bringing about the superconductivity has predominant s–wave character mixed with d–wave one.

1. INTRODUCTION

Since the discovery of high T_c superconductivity in $La_{2-x}Ba_xCuO_4$, higher T_c has been found in various cuprous oxides in succession. Our major interest is for the origin of high T_c superconductivity. It is plausible from accumulated experiments that spin–singlet electron pairs are formed in the superconducting state in cuprous oxide. Accordingly, it is significant to clarify the symmetry of attractive interaction which combines electrons.

The absence of coherent peak in NMR relaxation and its non–thermally activated type temperature dependence suggest the d–wave symmetry [1]. On the other hand, the temperature dependence of magnetic penetration depth rather favors the s–wave [1]. The tunneling spectroscopy measurement is the most conclusive method for a determination of the pair symmetry. However existing tunneling results are not fully reliable. It is important to supply a reliable tunneling result. We present the trustworthy result of tunneling spectroscopy carried out on $Bi_2Sr_2CaCu_2O_8$ with use of the STM [2] and discuss the pair symmetry.

2. EXPERIMENTAL

Single crystals of $Bi_2Sr_2CaCu_2O_8$ were grown by the floating–zone method. The superconducting transition temperature was determined as 87 K from the mid–point of resistive transition. It was confirmed from the magnetic measurement that the superconductivity occurs in bulk. Lateral surface of a single crystal perpendicular to cleaved Bi–O surface was investigated at 4.2 K with the STM. Spectroscopic measurements were carried out with varying the tip position in the surface and changing tip distance at fixed point in the surface.

3. RESULTS AND DISCUSSION

In the STM spectroscopy at cleaved surface of cuprous oxide superconductors, the tunneling conductance varies its shape depending on the tip distance from the sample surface [3] and is no more precisely proportional to the electronic density of states, although it shows the characteristic gap structure. On the other hand, at the lateral surface, where the Cu–O plane appears on the surface, the tunneling conductance curve is independent of the tip distance. Figure 1 shows a typical differential conductance curve observed at lateral surface. We obtained essentially the same curve at every measured point. The sharp drop associated with the superconducting gap and the enhancement at the gap edge are clear. If we assume the normal conductance as a smooth curve shown in Fig.1, the area of enhanced regions is equal to that of removed one. This assures the conservation of state number and supports that the conductance obtained at lateral surface corresponds to the correct electronic density of

SSDI 0921-4526(93)1727-4

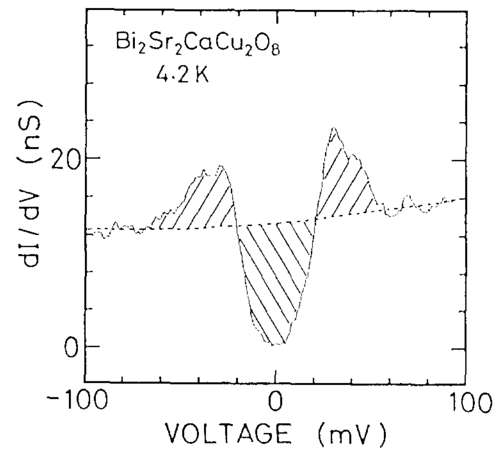

Fig. 1. Tunneling conductance at 4.2 K.

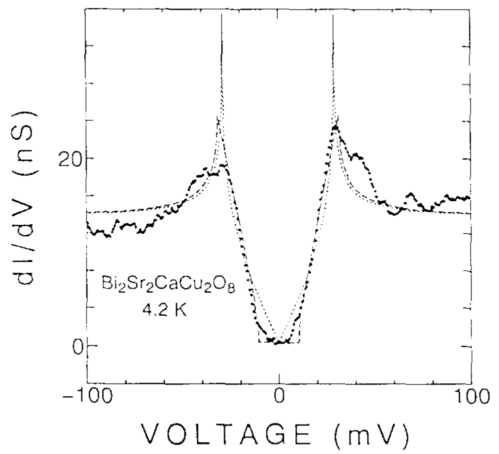

Fig. 2. Fitting to model calculations.

states in the superconducting phase.

The differential conductance is almost zero and flat near zero bias voltage. In the STM method, the tunneling conductance is given by the total sum over every wave number, because of the locality of the region through which the electron tunneling occurs. Accordingly, the observed tunneling conductance reveals that the superconducting gap is finite on the whole Fermi surface. This fact suggests a dominant contribution of s-wave. However, the total conductance curve cannot be fitted by the BCS density of states even if including the life time broadening. It is obvious that the gap has a considerable anisotropy.

In Fig. 2 we show the calculated density of states for a d-wave with line nodes of gap on the Fermi surface by the dotted line together with the observed conductance. As clear from Fig. 2, the observed curve is very different from the model with d-symmetry alone. The broken line in Fig. 2 represents the curve calculated for another anisotropic model in which the gap Δ varies from 10 meV to 30 meV along with the direction of k-space but finite everywhere [2]. The behavior near zero bias is reproduced satisfactorily. Such a gap structure is consistent with the recent angle-resolved photoemission result [4] where the gap varies in k-space. We also measured the magnetic field penetration depth λ in order to confirm the finite gap. The observed temperature dependence of λ obeyed the thermal activation behavior with Δ~14 mev [2]. The minimum gap value in the tunneling spectra agrees with that estimated from λ.

The finite gap indicates naively that the attractive interaction has a large s-wave component. On the other hand, considerable anisotropy is undoubted. It is believed that the electron correlation is relatively strong in the Cu-O layer which is main stage for the superconductivity. In such a system, it is deduced that the attractive interaction responsible for electron pair with the mixture of s-wave and d-wave plays an important role for high T_c.

REFERENCES

1. For a collection of recent papers see Proceedings of International Conference on Materials and Mechanisms of Superconductivity High Temperature Superconductors Ⅲ, Kanazawa, Japan, 1991 (Physica C185-189,1991)
2. K. Ichimura and K. Nomura, submitted to J. Phys. Soc. Japan.
3. K. Ichimura, K. Nomura, F. Minami and S. Takekawa, Solid State Commun., 82(1992) 171.
4. B. O. Well, Z. X. Shen, D. S. Dessau, W. E. Spicer, D. B. Mitzi, L. Lombardo, A. Kapitulnik and A. J. Arko, Phys. Rev., B46(1992)11830.