Phonon Structure in the Tunneling Conductance of $Bi_2Sr_2CaCu_2O_8$

Daisuke Shimada [a,1], Makoto Saitoh [b], Nobuo Tsuda [b,2]

[a] *Department of Physics, Shizuoka University, 836 Ohya, Shizuoka, 422-8529, Japan*

[b] *Department of Applied Physics, Science University of Tokyo, 1-3 Kagurazaka, Shinjuku-ku, Tokyo 162-8601, Japan*

Abstract

Reproducibility of phonon structures in the tunneling conductance was investigated by using a slightly overdoped $Bi_2Sr_2CaCu_2O_8$/Au junction. The structures are present but much weaker than those for a previous GaAs junction, and the smearing of them is discussed.

Key words: tunneling; phonon mechanism of high-T_c superconductivity; $Bi_2Sr_2CaCu_2O_8$; inhomogeneity

1. Introduction

There are many experiments which indicate a phonon contribution to high-T_c superconductivity [1-9]. Especially the spectral function α^2F deduced from tunneling conductance is large enough for explaining T_c [4]. Even a large relative gap $2\Delta/k_BT_c$ and a T_c-dependent isotope effect for underdoped materials will be explainable within the phonon mechanism [10, 11]. However, the reproducibility of tunneling experiments is not certain enough for establishing the phonon mechanism. The poor reproducibility will be due to an inhomogeneity in electronic configuration [12, 13] which broadens a tunneling spectrum. Therefore, a collection of tunneling conductance for optimal and slightly overdoped materials, for which the inhomogeneity will be weak, as many as possible is desirable to confirm the reproducibility of tunneling phonon structures.

2. Experimental and results

The details of the experiment were published elsewhere [14]. Single crystals of $Bi_2Sr_2CaCu_2O_8$ (Bi2212) were grown by using a single-reflector furnace in an atmosphere of Ar:O_2=4:1. A macroscopic T_c and the transition width were typically 89 K and 3 K, respectively, by the resistance measurement. The crystals are slightly overdoped ones. The junction is a mechanical contact of Bi2212 with a Au needle which was driven by rotating a double micrometer head. The contact area is about 0.1×0.1 mm^2. The positive voltage corresponds to an empty k-space of Bi2212. Measuring temperature was 4.2 K.

Figure 1 shows some dI/dV-V lines. #0 is for a previous GaAs junction [2]. ##1-3 were derived by merely contacting on and off the Au needle at macroscopically the same point of Bi2212. ##4 and 5 were observed in other experimental sequences. The current direction is indicated beside each line (within 3 degree from each direction). Horizontal dots at the edge peak show a distribution of the peak position. The direction is a macroscopic current direction, and an atomic-scale structure at the contact is unknown. Anyway, as seen from the figure the inhomogeneity is larger than the anisotropy in Δ. There is no large zero-bias conductance peak at a Cu-Cu direction. The line is not of a V-shape along the c-axis. All these features indicate that an s-wave is more probable than a d-wave for the present Bi2212.

The phonon structure should appear as a dip in d^2I/dV^2-V line. Then Fig. 2 shows some of the d^2I/dV^2-V lines. ##0-2 are those in Fig. 1. #3' was obtained in another experimental sequence. #4' was

[1] Corresponding author. E-mail: spdsima@ipc.shizuoka.ac.jp
[2] E-mail: tsuda@rs.kagu.sut.ac.jp

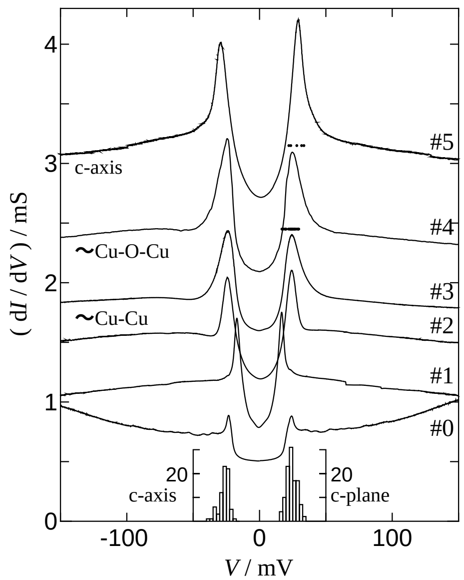

Fig. 1. As-observed dI/dV-V. The origin of ordinate is for #0, and the others were shifted upward by 0.5 mS each. Horizontal dots at the edge peak and histograms show a distribution of peak position.

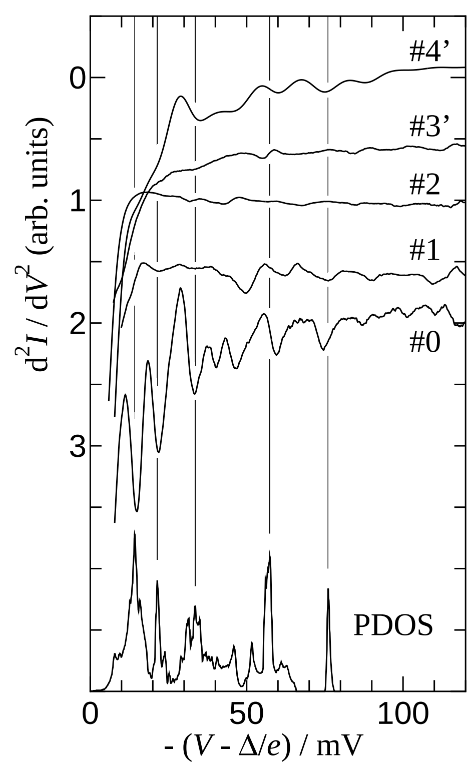

Fig. 2. The observed $\mathrm{d}^2I/\mathrm{d}V^2$ of negative bias voltage is compared with the PDOS. The origin of ordinate is for #4', and the others were shifted downward by 0.5 each.

obtained by smearing #0 by assuming a Gaussian distribution in Δ with a standard deviation of 3 meV. At the bottom the calculated phonon density of states PDOS is shown [4]. For #1, some of the phonon dips are faintly seen but for #2 whose edge peak is much broader than that of #1 the dips are absent. For #3' whose edge peak is narrower than that of #2, two dips seem to exist at lower frequencies.

3. Discussions and conclusion

The phonon structures for the Au junctions are too weak for confirming the reproducibility of #0 structures, and it will be due to the inhomogeneity. For instance, the #4' line in Fig. 2 demonstrates how easily the structures are smeared out by the inhomogeneity. For observing a tunneling phenomenon, the Au needle must contact on an insulating or semiconducting surface of Bi2212 while the GaAs on a metallic surface. This will be a reason why the Au results are much weaker than the GaAs one. Thus the absence of clear phonon structures for the natural barrier junction cannot deny the phonon nature of the GaAs result.

In summary, we observed phonon structures for the natural barrier Bi2212/Au junctions. However, they are too weak for confirming the reproducibility of the clear phonon structures for the GaAs junction. Smearing of the structures was discussed.

References

[1] S. I. Vedeneev et al., Physica C **235-240** (1994) 1851.

[2] D. Shimada et al., Phys. Rev. B **51** (1995) 16495.

[3] R. S. Gonnelli et al., Physica C **275** (1997) 162.

[4] D. Shimada et al., Physica C **298** (1998)195.

[5] Ya. G. Ponomarev et al., Solid State Commun. **111** (1999) 513.

[6] V. M. Svistunov et al., Physica C **314** (1999) 205.

[7] A. Lanzara et al., Nature **412** (2001) 510.

[8] J. P. Franck et al., Phys. Rev. Lett. **71** (1993) 283.

[9] C. Thomsen et al., Solid State Commun. **75** (1990) 219.

[10] T. Oki et al., Physica C **353** (2001) 213.

[11] D. Shimada et al., Physica C **371** (2002) 52.

[12] S. H. Pan et al., Nature **413** (2001) 282.

[13] J. C. Phillips, Philos. Mag. B **81** (2001) 35.

[14] N. Tsuda et al., to be published in: I. Bozovic, D. Pavuna (Eds.) Proc. SPIE Symposium, Materials and Nanotechnology, Vol. 4811 (2002).