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STM Spectroscopy on Partially Deuterated κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br

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Abstract

We report the electron tunneling spectroscopy on κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br using a low temperature STM. Protonated d[0,0] and partially deuterated d[2,2] salts were studied. In both salts, the functional shape of the tunneling differential conductance curve in the superconducting state is explained by the *d*-wave pairing symmetry. We obtain the gap parameter Δ as 2.1-3.9 and 3.0-4.8 meV for d[0,0] and d[2,2] salt, respectively. The value of $2\Delta/kT_c$ in d[2,2] salt is slightly larger than that in d[0,0] salt. The pseudogap is observed below about 50 K in both salts.

Keywords: atomic force microscopy, scanning tunneling microscopy, superconducting phase transitions, organic superconductors

1. Introduction

The quasi-two dimensional electronic band with strongly correlated electrons plays an important role in BEDT-TTF salts. It is recognized that the superconducting phase adjoins the antiferromagnetic phase [1]. A lot of attentions have been given to which mechanism brings about the superconductivity in the neighbor of the Mott insulating phase. For κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br, Kawamoto *et al.* [2] revealed that the effective correlation can be controlled finely near the Mott boundary by partial deuteration of BEDT-TTF molecules.

In investigating the superconducting state, the electron tunneling is useful since the electronic density of states can be obtained directly with high energy resolution. The tunneling spectroscopy using STM especially has an advantage because of non-contacting tip configuration. We revealed the $d_{x^2-y^2}$-paring symmetry in κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ by STM spectroscopy on lateral surfaces [3]. Our present interest is how the paring symmetry and the gap parameter depend on the effective correlation. In this article, we present tunneling spectra obtained by STM on protonated d[0,0] and partially deuterated d[2,2] κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br. We discuss the superconducting gap parameter and the pseudogap state as a function of the effective correlation strength.

2. Experimental

The superconducting transition temperature was determined as T_c=11.5 K and 12.0 K for d[0,0] and d[2,2] salts, respectively. As grown surface of the *a-c* plane was investigated by a low temperature STM. The tunneling differential conductance was directly obtained by the lock-in detection.

3. Results and Discussion

Both for d[0,0] and d[2,2] salts, the superconducting gap structure was clearly observed in tunneling spectra below T_c. In our STS measurements, we confirmed the reproducibility of the tip-sample distance dependence of

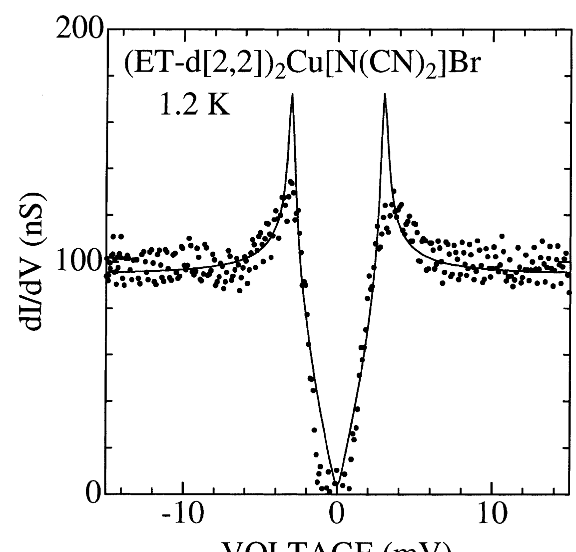

Fig. 1. Typical tunneling differential conductance at 1.2 K in d[2,2] salt. The solid line represents the *d*-wave calculation with Δ=3 meV.

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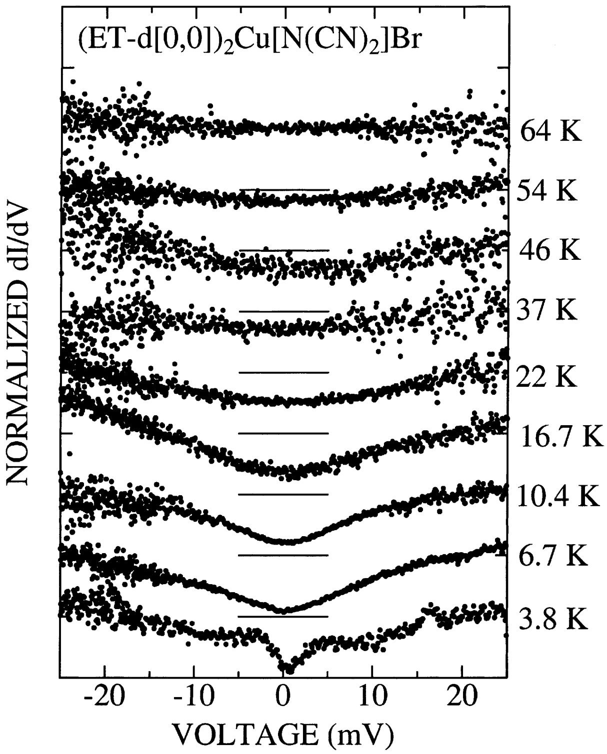

Fig. 2. Tunneling spectra in d[0,0] salt at various temperature. The zero conductance line of each curve, which is represented by the horizontal bar, is shifted by one division for clarity.

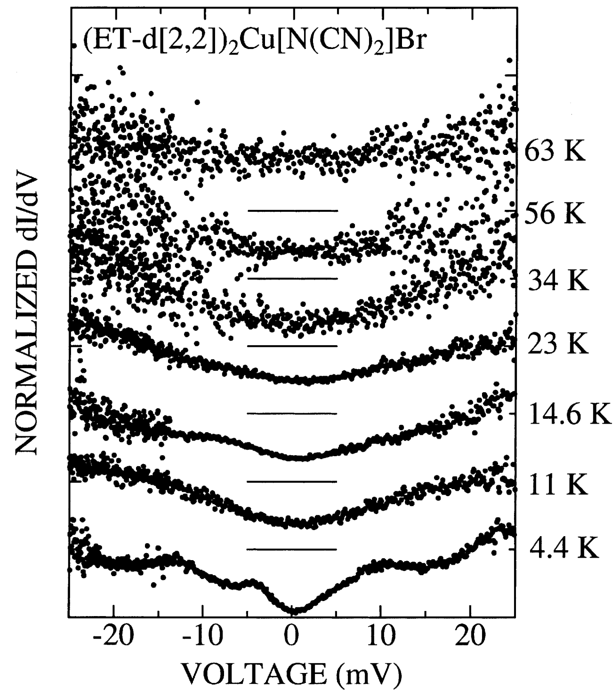

Fig. 3. Tunneling spectra in d[2,2] salt at various temperature.

tunneling spectra, which assures the vacuum tunneling [3]. A typical conductance curve at 1.2 K in d[2,2] salt is shown in Fig. 1. As the same as d[0,0] salt [4], the conductance around zero bias shows a linear dependence on the energy. The conductance curve is explained by the *d*-wave pairing with line nodes of the gap. The solid line in Fig. 1 represents the fitting by the calculation for the simple *d*-wave paring symmetry with the gap parameter Δ=3.0 meV. Although the gap parameter varies depending on sample, the functional form of the conductance curve inside the gap edge is essentially identical.

We obtained Δ=2.1-3.9 meV and 3.0-4.8 meV for d[0,0] and d[2,2] salt, respectively. The variation in values is due to the sample dependence. Correspondingly, we obtained values of $2\Delta/k_BT_c$ as 4.3-7.9 and 5.8-9.3 for d[0,0] and d[2,2] salt, respectively. These values are almost consistent with the prediction of 4.35, which is according to the mean field theory for *d*-wave superconductors [5]. It should be noted that the value of $2\Delta/k_BT_c$ for d[2,2] salt is larger than that for d[0,0] salt as the effective correlation becomes strong.

Figure 2 shows tunneling spectra in d[0,0] salt at various temperature. Although spectra show a little scatter due to a system noise, the superconducting gap structure is found to become smeared with increasing temperature. Even above T_c, the broad dip structure around zero bias was found similarly to κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ [6]. In contrast to the pseudogap in high-T_c oxides [7], no peak structure is found in tunneling spectra, in which the conductance increases monotonously with the bias voltage. Essentially the same behavior was observed in the temperature dependence for d[2,2] salt as shown in Fig. 3.

The pseudogap disappears about at 50 K both in d[0,0] and d[2,2] κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br. The temperature is almost consistent with that in κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ of about 45 K [6]. We conclude that the decrease in the electronic density of states around the Fermi level above T_c is common feature in BEDT-TTF superconductors. Anomalies were found around 50 K in magnetic properties in κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ and κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br. The static spin susceptibility decreases rapidly below 50 K. The temperature dependence of NMR $(T_1T)^{-1}$ shows a peak at 50 K and decreases rapidly with decreasing temperature [8]. We think that anomalies in magnetic properties have a concern with the pseudogap in tunneling spectra. In the future, we must determine accurately the temperature, at which the pseudogap appears, by measuring the precise temperature dependence in order to clarify the relation between the pseudogap and the effective correlation strength.

References

[1] K. Kanoda, Hyperfine Interact. 104 (1997) 235
[2] A. Kawamoto, H. Taniguchi, K. Kanoda, J. Am. Chem. Soc. 120 (1998) 10984.
[3] T. Arai, K. Ichimura, K. Nomura, S. Takasaki, J. Yamada, S. Nakatsuji, H. Anzai, Phys. Rev. B 63 (2001) 104518.
[4] K. Ichimura, K. Suzuki, K. Nomura, A. Kawamoto, to be published in Synth. Metals.
[5] F. J. Ohkawa, J. Phys. Soc. Jpn. 56 (1987) 2267.
[6] T. Arai, K. Ichimura, K. Nomura, S. Takasaki, J. Yamada, S. Nakatsuji, H. Anzai, Solid State Commun. 116 (2000) 679.
[7] Ch. Renner, B. Revaz, J. Y. Genoud, K. Kadowaki, O. Fischer, Phys. Rev. Lett. 80 (1998) 149.
[8] A. Kawamoto, K. Miyagawa, Y. Nakazawa, K. Kanoda, Phys. Rev. Lett. 74 (1995) 3455.