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Tunneling spectroscopy on κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br using STM☆

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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. In the superconducting state, tunneling spectra show the energy gap structure clearly. The tunneling differential conductance shows linear dependence on energy inside the gap edge. The conductance curve is well fitted by the d-wave calculation with a little broadening. The d-wave gap parameter is obtained as $\Delta_0 = 2.5-3.5$ meV, correspondingly, $2\Delta_0/kT_c = 5.0-7.1$. The pairing symmetry is consistent with that in κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ as well as the gap parameter. The broad dip structure around the Fermi level is found in tunneling spectra above T_c. The pseudogap structure is observed below 50 K.

Keywords: STM; Organic superconductors; Paring symmetry

1. Introduction

The pairing symmetry in organic superconductors has attracted a lot of interests in clarifying the mechanism of the superconductivity brought about by highly correlated electrons. The power law temperature dependence, which suggests the d-wave pairing, was reported in the magnetic field penetration depth [1], the NMR relaxation rate [2] and the electronic specific heat [3]. On the other hand, the s-wave pairing was often suggested [4,5]. In our previous report [6] on (BEDT-TTF)$_2$Cu(NCS)$_2$, the d-wave pairing was indicated by the in-plane anisotropy of the tunneling spectra. Moreover, the pseudogap was found above T_c in (BEDT-TTF)$_2$Cu(NCS)$_2$ [7]. We investigate the features, which are directly concerned with the mechanism of the superconductivity, such as the gap parameter, pairing symmetry and the pseudogap as a function of the effective correlation or the chemical pressure in BEDT-TTF salts. The electron tunneling spectroscopy by STM is useful to study the superconducting state because of its non-contacting tip configuration and high energy resolution. In this paper, we report the STM spectroscopy on (BEDT-TTF)$_2$Cu[N(CN)$_2$]Br, of which the effective correlation is larger than that of (BEDT-TTF)$_2$Cu(NCS)$_2$.

2. Experiment

Single crystals of (BEDT-TTF)$_2$Cu[N(CN)$_2$]Br, which are hexagonal shape, were synthesized electrochemically. The superconducting transition temperature was determined as $T_c = 11.5$ K. As grown surface of the *a–c* plane was investigated by a low temperature STM with a mechanically sharpened Pt–Ir tip. The tunneling differential conductance was directly measured by the lock-in detection, in which 1 kHz of AC modulation with amplitude of 0.05 mV was superposed in bias voltage.

3. Results and discussion

Tunneling spectra below T_c shows clear energy gap structure associated with the superconducting state. Fig. 1 shows the tunneling differential conductance at 2.4 K. The gap edge is observed as the conductance peak at the bias voltage $V = 3.5$ mV. The conductance at zero bias voltage is reduced to about 30% of the normal conductance. The conductance curve around zero bias is not flat. The finite conductance inside the gap suggests the gap anisotropy. We examine the d-wave symmetry, which brings about the

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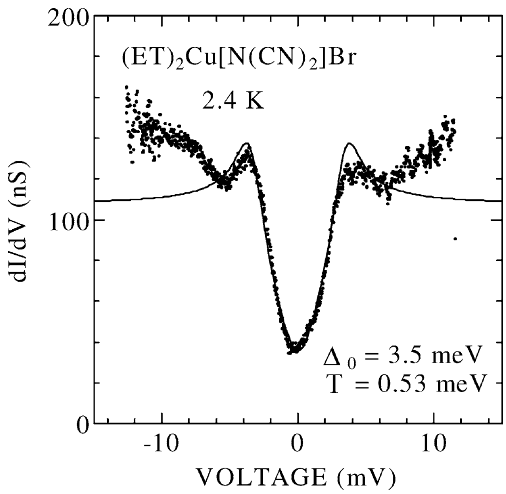

Fig. 1. Tunneling differential conductance at 2.4 K. The solid line represents the d-wave calculation with $\Delta_0 = 3.5$ meV and $\Gamma = 0.53$ meV.

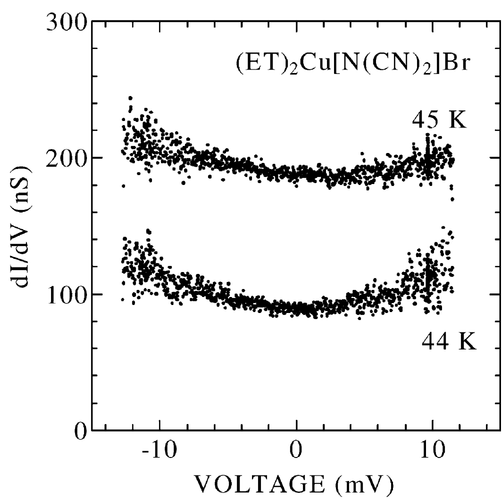

Fig. 2. Tunneling spectra at 44 and 45 K.

anisotropy of the gap. The solid line in Fig. 1 represents the calculation for the d-wave gap symmetry with the gap parameter $\Delta_0 = 3.5$ meV and the lifetime broadening parameter $\Gamma = 0.53$ meV. As shown in the figure, the linear dependence on the energy near zero bias is well explained by the d-wave. A little lifetime broadening of the quasi-particle explains the finite conductance at zero bias. The d-wave pairing symmetry with line nodes is suggested for (BEDT-TTF)$_2$Cu[N(CN)$_2$]Br similarly to (BEDT-TTF)$_2$Cu(NCS)$_2$, in which the d-wave pairing is indicated by STS at lateral surfaces [6]. Among several samples of (BEDT-TTF)$_2$-Cu[N(CN)$_2$]Br, we obtained the gap value of $\Delta_0 = 2.5-3.5$ meV, which corresponds to $2\Delta_0/kT_c = 5.0-7.1$. These values are roughly consistent with that for (BEDT-TTF)$_2$Cu(NCS)$_2$, in which we obtained $\Delta_0 = 2.5-4.9$ meV $2\Delta_0/kT_c = 5.6-11$ for $T_c = 10.4$ K [7].

The superconducting gap structure becomes smeared with increasing temperature. The broad dip around zero bias still exists above T_c as shown in Fig. 2. The pseudogap is observed below about 50 K in (BEDT-TTF)$_2$Cu[N(CN)$_2$]Br similar to (BEDT-TTF)$_2$Cu(NCS)$_2$, in which the broad pseudogap is observed below 45 K [7]. In contrast to high-T_c oxides [8], we cannot find any edge structure in spectra in which the conductance increases monotonously with bias voltage. There is an anomaly around 50 K in the magnetic property both for (BEDT-TTF)$_2$Cu[N(CN)$_2$]Br and (BEDT-TTF)$_2$Cu(NCS)$_2$. The static spin susceptibility decreases rapidly below 50 K. NMR $(T_1T)^{-1}$ shows a peak at 50 K and decrease rapidly with decreasing temperature [9]. We think anomalies in magnetic measurements, which suggest the decrease in the electronic density of states at the Fermi level below 50 K, have a concern with the pseudogap in tunneling spectra. We are investigating the correlation between the pseudogap and superconducting state in BEDT-TTF salts by measuring precise temperature dependence of tunneling spectra.

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