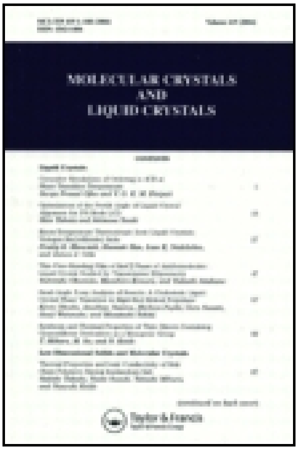

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Superconducting Tunneling in $(TMTSF)_2ClO_4$ /a-Si/Pb Junctions

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SUPERCONDUCTING TUNNELING IN $(TMTSF)_2ClO_4$/a-Si/Pb JUNCTIONS

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Abstract We have fabricated $(TMTSF)_2ClO_4$/a-Si/Pb junctions using CVD a-Si film as low-potential tunnel barriers. From measurements well below T_c, 3D superconducting transition temperature of $(TMTSF)_2ClO_4$, the superconducting energy gap comparable to the BCS theory was detected. At higher temperatures no significant change other than the superconducting transition of Pb was observed. In the quenched crystals much larger gap structure $2\Delta \simeq 3$ meV was observed, resulting from the SDW state.

INTRODUCTION

The property of $(TMTSF)_2ClO_4$ below $T_c = 1.2$ K at ambient pressure is on the whole understood as a highly anisotropic BCS superconductor. The superconducting energy gap is not yet measured in a spectroscopic way, but the electronic specific heat jump $\Delta C_e = 1.67\gamma T_c$ is consistent with the BCS theory.[1] When $(TMTSF)_2ClO_4$ is rapidly cooled through $T_Q \simeq 30$ K, the anions do not order at $T_a = 24$ K and it becomes an SDW insulator below $T_S = 6$ K and the superconducting transition is suppressed. The transport property above T_Q is well understood as a quasi-1D metallic conductor. Between T_Q and T_c anomalies exist with controversial interpretations:[2] enhanced electric conductivity; large transverse magnetoresistance; and depressed thermal conductivity against the Wiedemann-Franz law. Orsay group has ascribed these anomalies to the 1D superconducting fluctuation, making use of the spectroscopic data showing the "pseudo-gap", the depression of the density of states, e.g. far infrared reflection data[3] and the

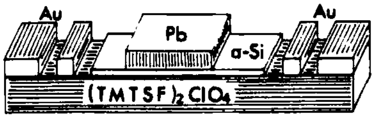

FIGURE 1 Structure of $(TMTSF)_2ClO_4$/a-Si/Pb junctions.

tunneling measurements on $(TMTSF)_2ClO_4$/n-GaSb Schottky diodes,[4] $(TMTSF)_2ClO_4$/oxide/Au[5] and $(TMTSF)_2ClO_4/Al_2O_3$/Au[6] junctions. Of course the gap structure should not always be assigned to the superconductivity, since there are various phases adjacent to the metallic state. Tunneling density of states around the Fermi level is one of the most important keys to solve the conflicting problems. The purpose of this work is to detect the 3D superconducting gap below T_c, the SDW gap in the quenched state and the "pseudo-gap" between T_c and T_Q. Tunneling current I(V) is given by the relation

$$I(V) = P(V)\int dE\, N_1(E-eV)N_2(E)[f(E-eV)-f(E)],$$

where P(V) is the bias dependent tunneling probability, $N_1(E)$ and $N_2(E)$ the state densities in the electrodes and f(E) the Fermi distribution function. If N_1 is precisely known, especially if it is a divergent superconducting density of states, the tunneling experiment provides the fine probing to the unknown density of states N_2.

EXPERIMENTAL

We adopted Pb as the superconducting counter electrode in our junctions depicted in Fig. 1. Since $(TMTSF)_2ClO_4$ is a very strong acid and oxidizes the whole counter electrode in hours, it is difficult to use its native oxide as a durable barrier. We adopted chemically inactive a-Si:H as a low potential tunneling barrier ≃ 0.1 eV. A thin film of a-Si:H of ≃ 20 nm thickness was deposited on the side surfaces of needle like crystals by glow discharge of SiH_4 gas before Pb was evaporated. Since the side surfaces of the crystals are not perfectly flat, the tunnel current can flow along various crystallographic axes. Thin Au leads were attached on the Pb counter electrode and Au ohmic contacts by silver paint with carefully prepared

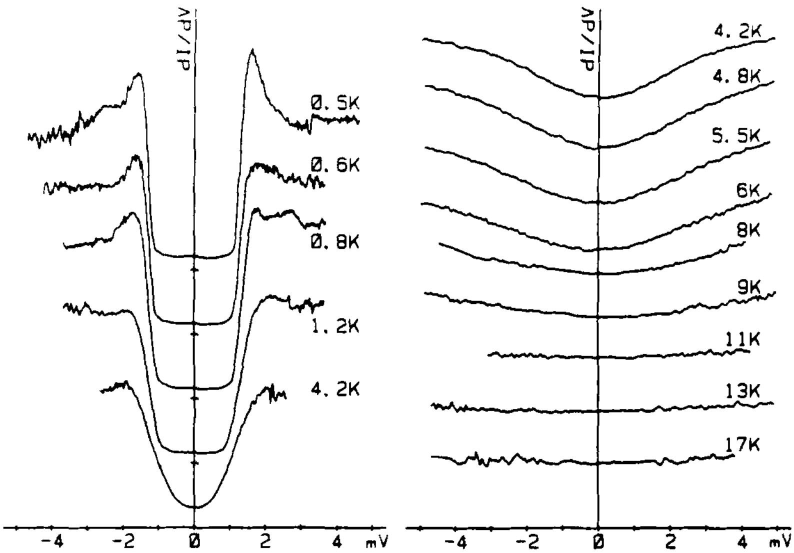

FIGURE 2 Differential conductance of the relaxed state.

nonpolar organic thinner. The 4-wire resistance of the crystal was always monitored to check in which state the sample is staying.

RESULTS AND DISCUSSIONS

Experimental results of the relaxed state are shown in Fig. 2. 1) Below T_c an SIS' junction is realized in the differential conductance dI/dV. Subtracting the known value Δ_{Pb}= 1.38 meV from the data of gap sum at 0.5 K, we obtained the BCS relationship $2\Delta(0) = 3.4k_BT_c$. The gap difference signal is smeared out because the energy gap of $(TMTSF)_2ClO_4$ has 10 % distribution which is estimated from that of T_c. 2) Between T_c and 7.2 K, the transition temperature of Pb, the SIN signal is observed. The gap structure of Pb is reduced on approaching 7.2 K. 3) Above 7.2 K only a broad dip in the differential conductance was observed, which is temperature dependent and visible up to 13 K. It is also visible at lower temperature as a background. Recently Fournel et al. detected similar dip of conduc-

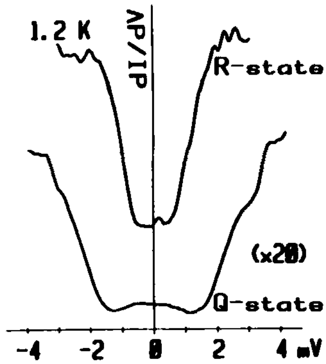

FIGURE 3 Differential conductance of the relaxed (R) state and the quenched (Q) state.

tance in the $(TMTSF)_2ClO_4$/oxide/Pb junctions between 1.2 K and 4.2 K, which they ascribed to the "pseudo-gap".[7] However, the nonlinear feature is common to the high impedence junctions or those with complicated barriers. At this moment we cannot specify the origin of the structure. For this purpose measurements under magnetic field is now in progress. 4) In the quenched samples we observed the characteristics much broader than $2\Delta_{Pb}$ and temperature dependent, as shown in Fig. 3. The width of this gap, presumably due to the SDW phase, is $\sim$ 3 meV and comparable to those reported as the quasi-1D "pseudo-gap". Then they would be ascribed to the quenched state.

In summary, we observed the 3D superconducting gap in the relaxed state and an SDW gap $2\Delta_{SDW} \sim 3$ meV in the quenched state, but obtained no evident indication of the 1D fluctuation above T_c.

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