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Metal Instability of $(DMe\text{-}DCNQI)_2Cu$ Induced by Uniaxial Stress and Enhancement of Electron Mass

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The metal instability of $(DMe\text{-}DCNQI)_2Cu$ was induced by applying uniaxial stress or coating the crystal with Apiezon L grease. The quadratic temperature dependence of the resistivity gave an indication of the large enhancement of the effective mass of the conduction electrons.

It has been pointed out that the DCNQI-Cu system is a new type of molecular metal with pπ-d mixing band (DCNQI= dicyanoquinonediimine).[1] There are two types of the DCNQI-Cu systems[1,2] : (1) compound with stable metallic state at ambient pressure ($(DMe\text{-}DCNQI)_2Cu$, $(DMeO\text{-}DCNQI)_2Cu$,...), (2) compound exhibiting a sharp metal-insulator(MI) transition ($(MeBr\text{-}DCNQI)_2Cu$, $(DBr\text{-}DCNQI)_2Cu$...).

It is well known that the metallic state of $(DMe\text{-}DCNQI)_2Cu$ becomes unstable at the critical pressure(P_c) as small as 100 bar.[3] We tried to reproduce the metal instability without use of the He gas pressure technique.[3] In this paper, we report simple methods to induce the metal instability and the T^2-dependence of the low-temperature resistivity indicating the mass enhancement of the conduction electrons.

A needle crystal of $(DMe\text{-}DCNQI)_2Cu$ with four gold wires (15 μmϕ) bonded by Au paint was fixed on a small Teflon block by an adhesive agent and a small weight (W= 0-25 g) was put carefully on the top of the needle (Fig. 1). The typical dimensions of the crystals used are 2x0.02x0.02 mm^3. The resistivity was measured by a four-probe method down to 4.2 K. The uniaxial pressure was estimated roughly as W/S, where S is the cross sectional area of the crystal. As seen from Fig. 1 (sample #8), the

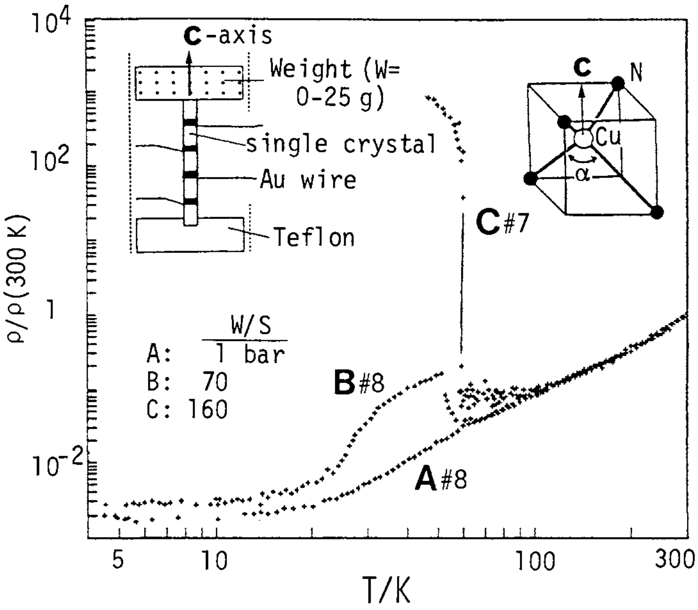

Fig. 1.
Temperature dependence of resistivity of $(DMe\text{-}DCNQI)_2Cu$ under uniaxial stress and schematic drawing of the setting of the measurement.

resistivity showed an anomaly around the uniaxial pressure of 70 bar. At 160 bar, a sharp MI transition was observed ($T_{MI} \simeq$ 60 K). At first, the uniaxial pressure along [001] was supposed to be more effective to induce the metal instability than the hydrostatic pressure, because the increase of the bond angle N-Cu-N (α) (Fig. 1) was considered to be a key factor for the metal instability.[1,4] But the results were in good agreement with those obtained by the He gas pressure technique. In order to investigate further the effect of non-hydrostatic pressure, another experiments was made.

As reported recently, an organic superconductor, κ-$(ET)_2Cu[N(CN)_2]Cl$ (T =12.8 K at 0.3 kbar)[5] becomes an "ambient-pressure superconductor" by coating the crystal with grease.[6] In the case of the experiment on the κ-type ET superconductor, the "effective pressure" produced by freezing of grease was estimated roughly to be about 0.2 kbar,[6] which is large enough to make $(DMe\text{-}DCNQI)_2Cu$ an insulator. The needle crystal was coated by Apiezon L grease as illustrated in Fig. 2. The freezed grease was considered to compress the crystal mainly along the direction perpendicular to [001]. The resistivity showed a small anomaly around 50 K, indicating that the crystal felt the effective pressure approximately equal to P_C.

The resistivity anomaly around 50 K presumably associated with the appearance of the magnetic ions (Cu^{2+}) and the reentrance of the metallic state at low temperature remind us the resistivity behavior of "heavy Fermion system".[7-9] So that, the low-temperature resistivities (ρ) were analyzed according to the relation commonly observed in heavy (or semi-heavy) Fermion compounds : $\rho = AT^2 + \rho_0$ and $A/\gamma^2 = 1.0 \times 10^{-5}$ $\mu\Omega$cm(mol K/mJ)^2,

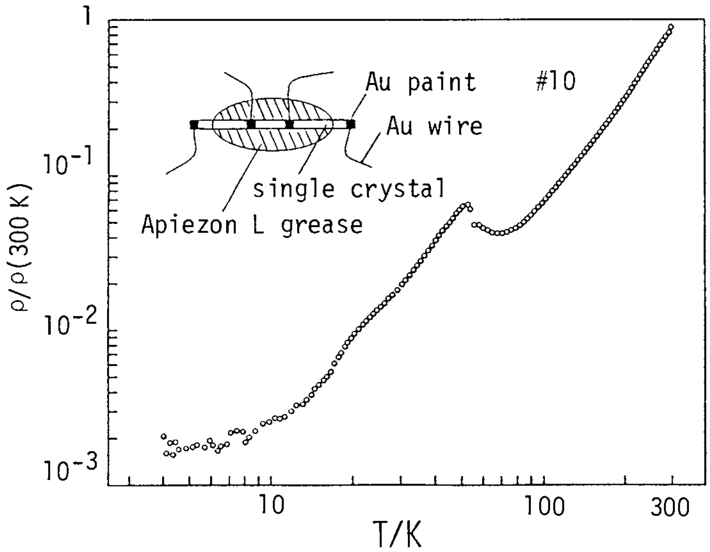

Fig.2.
Resistivity of a grease-coated crystal of $(DMe\text{-}DCNQI)_2Cu$.

where γ is the linear term in the temperature dependence of low-temperature specific heat.[10] From the A-value obtained by the least-squares fitting of the T^2-dependence of ρ shown by the straight lines in Fig. 3, γ was estimated as, 120 mJ mol^{-1} K^{-2} (uniaxial pressure (W/S) of about 70 bar), 110 mJ mol^{-1} K^{-2} (Apiezon L grease).

Considering that γ of $(DMeO\text{-}DCNQI)_2Cu$ is 9 mJ mol^{-1} K^{-2} (1 bar),[11] the obtained γ is anomalously large. Note that γ of heavy (or semi-heavy) Fermion system is 50-1000 mJ mol^{-1} K^{-2}.[10] Enhanced γ was also suggested by the similar analyses on the resistivities of $(DMe\text{-}DCNQI)_2Cu$ (γ= 40

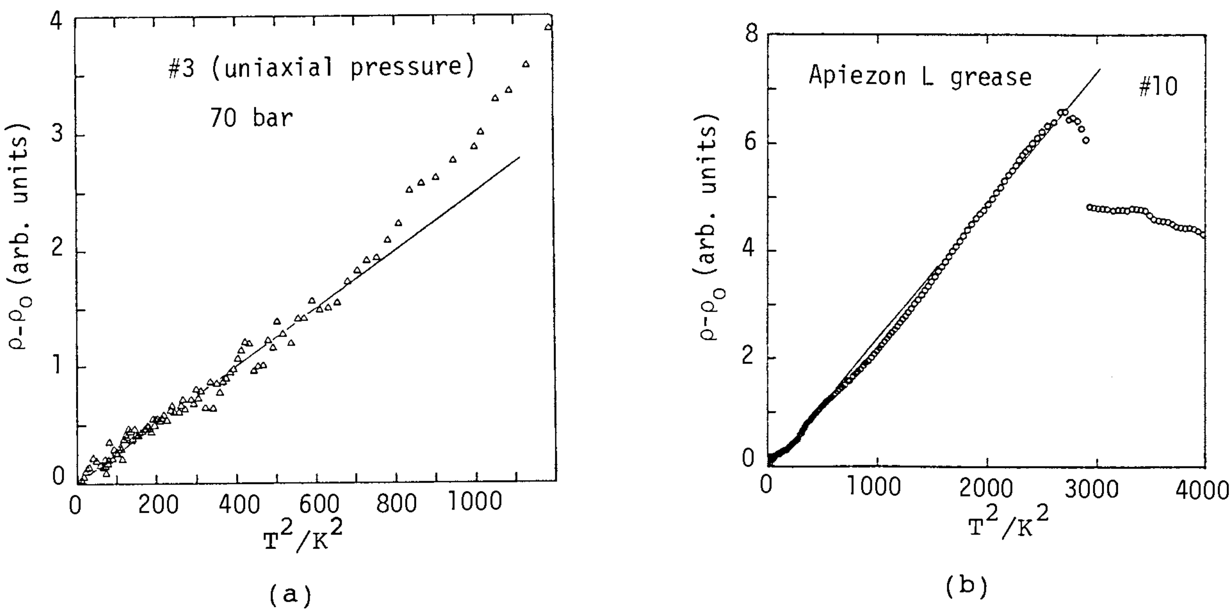

Fig. 3. The T^2-dependence of the resistivity of $(DMe\text{-}DCNQI)_2Cu$.
(a) Crystal under uniaxial stress (b) Grease-coated crystal

mJ mol^{-1} K^{-2}(1 bar)) and (DMeO-DCNQI)$_2$Cu (45 mJ mol^{-1} K^{-2}(6 kbar), 200-400 mJ mol^{-1} K^{-2}(6.5 kbar)).[12] The γ-value of (DMe-DCNQI)$_2$Cu (= 40 mJ mol^{-1} K^{-2}) agrees well with that obtained from the specific heat measurements.[13,14] Extraordinarily large γ suggests that the electron becomes very heavy in the low-temperature metallic state around the critical condition where metal instability begins to appear.[9] Good agreement between γ-values determined from the resistivity data and those from specific heats in the alloyed system, [(DMe)$_{1-x}$(MeBr)$_x$-DCNQI]$_2$Cu will be reported elsewhere.[12]

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