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Synthetic Metals 156 (2005) 162–165
SYNTHETIC METALS
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Field-induced SDW phase and superconductivity of $(DMET)_2CuCl_2$ ☆

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Accepted 4 November 2005
Available online 24 January 2006

Abstract

We report low temperature electronic properties of a newly synthesized organic conductor $(DMET)_2CuCl_2$, consisting of stacks of DMET molecules constructing a quasi-one-dimensional Fermi surface. Superconductivity transition below 0.8 K is found, which is suppressed by a small magnetic field of 0.1 T. Under magnetic fields, successive step-like anomalies of magnetoresistance and plateau-like Hall resistance with sign reversals are found, indicating the occurrence of field-induced spin density wave (FISDW) transitions. The angular-dependent magnetoresistance and thermopower are measured in order to clarify the quasi-one-dimensional electronic structure.

Keywords: Organic superconductors; Magnetic phase transitions; Magnetotransport; Thermopower

1. Introduction

The quasi-one-dimensional (Q1D) organic conductors of TMTSF family attract much attention for a quarter century since they exhibit variety of intriguing electronic phenomena such as unconventional superconductivity, field-induced spin density wave (FISDW) transition, etc. [1]. Kikuchi and co-workers developed another family of charge-transfer salts using unsymmetrical donor, dimethyl(ethylenedithio)diselenadithiafulvalene (DMET), showing a variety of ground states [2]. DMET salts also have Q1D electronic structure and are interesting in view of electronic transitions [3]. We report on superconductivity, FISDW transition, angular-dependent magnetoresistance, and thermopower measurements of a newly synthesized organic conductor $(DMET)_2CuCl_2$ [4].

2. Experimental

Single crystals of $(DMET)_2CuCl_2$ were grown by slow diffusion of MeOH solution of $Cu(II)Cl_2$ (2.5 mL, 8.9 mM) into THF solution of DMET (2.5 mL, 1.9 mM). Platelet crystals were obtained after 1 week [4]. The triclinic crystal structure is shown in Fig. 1. The crystal structure is isostructural with that of $(DMET)_2Au(CN)_2$, consisting of stacks of DMET molecules along *b*-axis. Lattice parameters are $a = 7.023(3)$ Å, $b = 7.586(2)$ Å, $c = 14.868(6)$ Å, $\alpha = 80.18(1)^\circ$, $\beta = 89.31(1)^\circ$, $\gamma = 70.492(9)^\circ$, $V = 734.9(4)$ Å^3, $Z = 1$. By a tight binding approximation using extendend Hückel HOMO orbitals [5] with Hückel parameters [6], Q1D Fermi surface is calculated as shown in Fig. 2. The transfer integral along *b*-axis is 0.28 eV and transfer integrals in inter-stack directions are 0.02–0.03 eV.

The resistivity measurements were carried out by dc or low-frequency ac technique with four-terminals attached along *b*- or c^*-axis in the temperature range from 0.3 to 300 K. The magnetic field was applied by superconducting solenoids. Hall resistance was obtained from voltages in a' direction under *b*-axis current measured in two opposite magnetic field directions

☆ Based on presentation at the International Conference on Synthetic Metals, Wollongong, Australia, June 28-July 2, 2004 (ICSM 2004).
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0379-6779/$ – see front matter
doi:10.1016/j.synthmet.2005.12.001

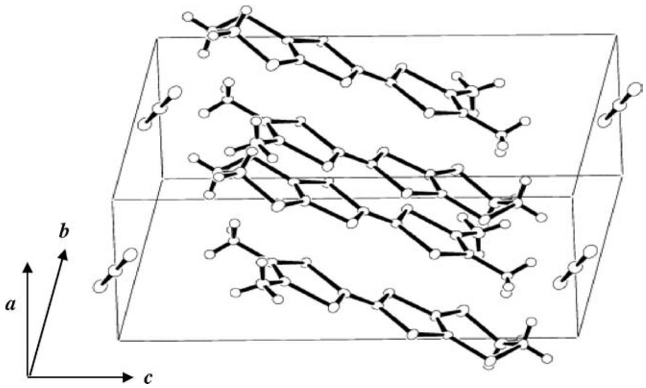

Fig. 1. Crystal structure of $(DMET)_2CuCl_2$. The *a*–*b* plane forms the conducting plane, and *c*-axis is the least conducting direction.

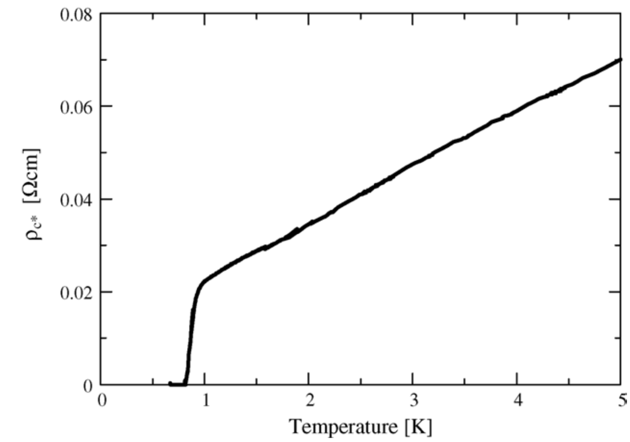

Fig. 3. Superconducting transition of $(DMET)_2CuCl_2$.

perpendicular to the conducting plane. In order to avoid microcracks during cooling often reported for TMTSF salts, crystals are embedded in Apiezon N grease. The grease is known to induce weak pressure of ~ 0.3 kbar to the crystal [7]. The thermopower was measured with a MMR Seebeck Mesurement system with typical temperature gradient of 1 K.

3. Results and discussion

3.1. Superconductivity

The resistivity shows metallic behavior from room temperature down to 0.8 K, at which superconducting transition to zero resistance is observed as shown in Fig. 3. The resistivity recovers its normal value with a small magnetic field of 0.1 T applied perpendicular to the *a*–*b* plane.

3.2. FISDW transitions

As shown in Fig. 4, a series of step-like magnetoresistance anomalies above 4 T is observed below 4 K. The position of anomalies can be scaled with inverse of magnetic fields. At the same time, Hall resistance shows plateau-like behavior with sign reversals as shown in the inset. All these features represent the FISDW transition similar to that observed in TMTSF salts [1]. The field range of transitions is similar to TMTSF salts but are smaller than that for $(DMET)_2I_3$ [8].

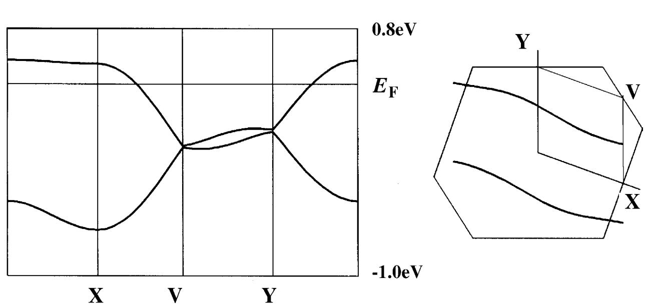

Fig. 2. The band dispersion and Fermi surfaces of $(DMET)_2CuCl_2$. d-orbitals of S and Se atoms are not included in the calculation.

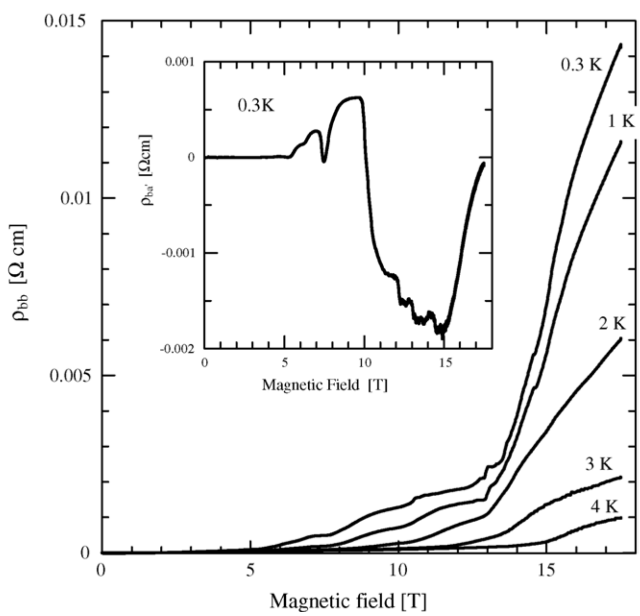

Fig. 4. In-plane magnetoresistance below 4 K. Large magnetoresistace with step-like anomalies typical for FISDW phases appear above 4 T. *Inset*: Hall resistance at 0.3 K.

3.3. Lebed resonances

In Fig. 5, we show c^*-axis resistivity at 1.5 K under magnetic field of 9 T rotated within the a'–c plane, scaled with the tangent of angle q of the magnetic field with respect to the c^*-axis. In this magnetic field configuration, Lebed resonance appears at which electron motion on the Q1D Fermi surface is commensurate with the periodicity of the Brillouin zone [9]. The commensurability condition is written as:

$$\tan\theta = \frac{p}{q} \times \frac{a'}{c} - \cot\beta^* \qquad (1)$$

where p and q are integers. We observe corresponding Lebed resonance magic angles at $p/q = 0, \pm 1, \pm 2$ as resistance dips. The spacing between each dip is $\tan q = 0.45$, which agree well with the value of a'/c^*.