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Study of rapid oscillations in $(TMTSF)_2FSO_3$ under pressure and under very high magnetic fields

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Abstract

$(TMTSF)_2FSO_3$ is very special in that its electric transport properties are described by electrons from two-dimensional Fermi surfaces (FS) whereas those in most other Bechgaard salts are intrinsically explained with electrons from weakly warped quasi-one-dimensional FS. Conventional Shubnikov-de Haas oscillations, described with the Lifshitz-Kosevich formula, has been observed. In this study, we measured magnetoresistance along the least conducting direction (c^*) under pressures of up to 11 kbars and magnetic fields of up to 55 T, generated in a pulsed magnet, and found that the oscillations preserved two-dimensional nature to the highest measured field. There is no field-induced electronic transition. Pressure dependence and magnetic field dependence of parameters of oscillations are presented and discussed.

Keywords: Organic superconductors, Transport measurements, conductivity, Hall effect, magnetotransport

1. Introduction

A variety of physical phenomena observed in the Bechgaard salts $(TMTSF)_2X$ (TMTSF = tetramethyltetra-selenafulvalene, X = monovalent anions) when temperature, pressure, magnetic field, or anions were varied, could essentially be explained in the context of quasi-one-dimensional electron physics [1] with the simple Fermi surfaces consisting of a pair of simple weakly warped sheets at $k_x{\sim}\pm k_F$.

However, angle dependent magnetoresistance (AMR) measurements of $(TMTSF)_2FSO_3$ with a magnetic field in the *bc*-plane under pressure around 6.2 kbar showed Yamaji-type resonance [2], which is well documented for the quasi-two-dimensional weakly corrugated cylindrical Fermi surfaces such as those of numerous $(\beta EDT\text{-}TTF)_2X$ (BEDT-TTF = bisethylenedithiotetrathiofulvalene) compounds [3-6], of inorganic two-dimensional compounds such as Sr_2RuO_4 [7], and of the stage 2 $SbCl_5$-intercalated graphite [8]. Considering that it is the Lebed resonances [9,10] which have been observed in at least three Bechgaard salts with X = ClO_4 [11,12], PF_6 [13], and ReO_4 [14], this observation is very much unusual.

X = FSO_3 anions are unique in that they carry permanent electric dipole moments arising from the difference in electronegativity between fluorine and oxygen atoms [15,16]. Our recent reinvestigation showed that $(TMTSF)_2FSO_3$ has a very complex and reproducible phase diagram [17], which is presumably related with the additional degree of freedom given by the electric dipole moments. The AMR resonance and rapid oscillations (RO) are observed at pressures of between 5.2 and 11.8 kbar [18]. The characteristics of RO are well described with the well-known Lifshitz-Kosevich (LK) formula which leads to the conclusion that they arise from the two-dimensional FS formed somehow through one (or some) of phase transitions shown in the *P-T* phase diagram [17]. Another intriguing observation is the pressure dependence of the oscillation amplitude and effective mass drawn from the temperature dependence of the oscillation amplitude, showing a marked discontinuity around 8.8 kbar [18].

In this paper, we report on the magnetoresistance study of $(TMTSF)_2FSO_3$ along the least conducting c^* direction under pressure of up to 11 kbar and in a magnetic field as large as 55 T. Dependence of electron effective mass both on pressure and on magnetic field was derived

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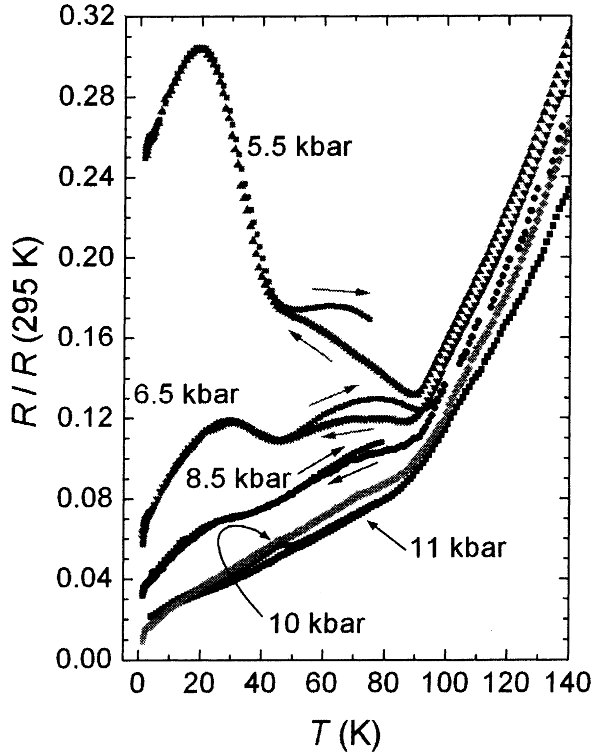

Fig. 1. Temperature dependence of the c^*-axis resistance under various pressures. Data from two samples of almost identical sizes are presented: 8.5 and 11 kbar curves are from one sample, and 5.5, 6.5 and 10 kbar curves are from the other. The pressure values given here are the estimated pressures at the liquid helium temperature.

and compared with previous results. No departure from the conventional two-dimensional behavior was found. Neither field-induced phase nor magnetic breakdown/interference was observed. It can be considered that the quasi-one-dimensional part of the Fermi surface is completely removed, leaving behind only small cylindrical pockets. However, a simple anion ordering with a wavevector (0,1/2,1/2) does not reconcile with this picture.

2. Experimental

The samples were grown using conventional electro-crystallization techniques. Four 20 μm annealed gold wires were attached to each sample with carbon paste to measure the interlayer resistance (R_{zz}). A 55 T pulsed magnet of Laboratoire National des Champs Magnètiques Pulsés, Toulouse was used for experiments. Pulse duration was 300 ms of which the longer, decreasing portion of the magnetic field was usually taken for analysis. The sample was inserted in the tiny sample chamber of the ceramic anvil cell. Silicon oil was used as pressure medium. The detail of pressure generation is described in Ref. [19]. Sample resistance was measured with a SR830 lock-in amplifier, of which the analog output was read with a personal computer through a National Instruments data acquisition board. Temperature as low as 1.4 K was obtained in pumped liquid helium. Temperature was monitored with a silicon diode sensor and a stable temperature was obtained by maintaining the helium vapor pressure constant with a manostat. Temperature increase during the pulse field application could be estimated from the sample resistance, which was not larger than a tenth of degree at base temperature. It was negligible at 4.2 K. Throughout the article, pressure values estimated at low temperature are used within an uncertainty of ±0.2 kbar.

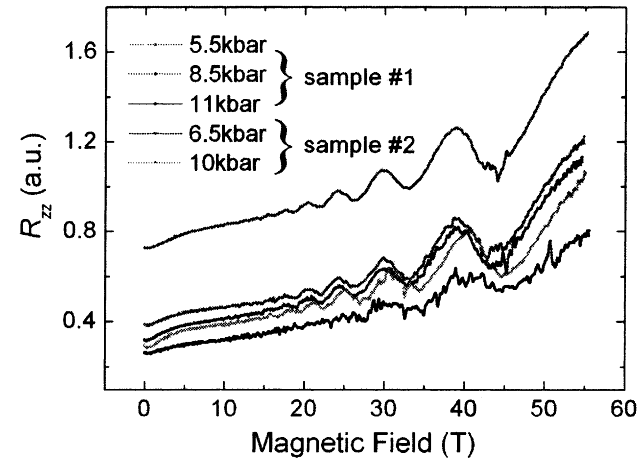

Fig. 2. Magnetic field dependence of the resistance at 1.4 K for five different pressure values. The curves are in the increasing order of pressure from above.

3. Results and Discussion

Figure 1 shows resistance monitored during initial cooling and final warming up process for each pressure. They correspond very well with those described in Ref. [17] and clearly reveal the various pressure-dependent anion ordering transitions. Both temperature dependence and anomalies at low temperature are in agreement with the pressure values deduced from calibration at room temperature. Fig. 2 shows magnetoresistance as measured. Well developed oscillations are superposed with slowly increasing magnetoresistance. Pressure dependence is not clear for the moment, but the oscillation attenuates much at 11 kbar.

Figure 3 shows the pressure dependence of the fundamental frequency and the phase factor γ when the positions of oscillations (H) are traced with $H = H_0 / (n + \gamma)$, where H_0 is the fundamental frequency, γ is the phase factor, and n is a positive integer. It is a good estimation that H_0 can be linearly fitted to $H_0 = 123 + 1.1P$, where H_0 is in T and P in kbar. The linear behavior is in contrast with the result reported in [18] where H_0 is constant up to 8.8 kbar and sharply increases above it. The reason for the discrepancy is not yet clear, but might be due to different pressure environments. Because the relevant closed orbit is a small fraction of the initial Fermi surface, it must be sensitive to the presence of small amount of shear stress. The phase factor γ is almost independent of pressure. As the pressure limit available to this study was limited to 11 kbar, it was not possible to confirm the discrete behavior above 11.9 kbar reported in [18].