Magnetotransport effects in spin-density wave state of the organic conductor (TMTSF)₂NO₃

M. BASLETIĆ, A. HAMZIĆ, N. BIŠKUP*, S. TOMIĆ*, B. KORIN-HAMZIĆ*, K. MAKI**, J.-M. FABRE*** and K. BECHGAARD****

Department of Physics, Faculty of Science, P.O. Box 162, 41000 Zagreb, Croatia

** Institute of Physics of the University, P.O. Box 304, 41000 Zagreb, Croatia*

*** Department of Physics, University of Southern California, Los Angeles, CA 90089-0484, U.S.A.*

**** Université de Montpellier II, USTL, 34095 Montpellier, France*

***** University of Copenhagen, CISMI, DK-2100 Copenhagen, Danmark*

ABSTRACT

We report a study of the transverse magnetoresistance properties in the spin-density wave (SDW) phase of the organic conductor (TMTSF)₂NO₃ at temperature down to 1.8 K and in magnetic field up to 6 tesla. The transverse magnetoresistance shows large effect and is highly anisotropic. We analyze our data in the framework of recent theoretical calculations by K.Maki. We suggest that the SDW with large imperfect nesting together with a periodic anion potential might be responsible for the magnetic field effects.

INTRODUCTION

One of the interesting features of the quasi-one-dimensional conductors of the (TMTSF)₂X family is their anomalous behaviour in a magnetic field (H) applied perpendicular to the most conducting direction [1]. In (TMTSF)₂NO₃ in the metallic phase a large and highly anisotropic magnetoresistance appears below about 30 K. For the current flow along the high conducting axis (a-axis) the magnetoresistance does not obey Köhler's rule and its magnitude cannot be accounted for by the standard theory based on the Boltzmann-equation approach [2]. Furthermore, the angular dependence of the magnetoresistance in the (b*c*) plane exhibits anomalous behaviour, which varies with temperature and field intensity.

The main intention of this paper is to present briefly a study of the influence of the imperfect nesting on the electric transport and magnetotransport in the SDW state of the (TMTSF)₂NO₃. In addition we compare our data with recent theoretical calculations by K. Maki [3].

EXPERIMENTAL RESULTS AND DISCUSSION

The measurements were performed on four different single crystals

synthesized by K.Bechgaard and J.M.Fabre[4]. Typical sample dimensions were $1.2 \times 0.23 \times 0.08 \text{ mm}^3$ with length varying between 0.6 to 1.7 mm. The current was along the a-axis, with magnetic field in the $b'-c^*$ plane. A tilt of magnetic field from c^* -axis is denoted by the angle ϑ .

First, let us present some properties of the $(\text{TMTSF})_2\text{NO}_3$ in zero magnetic field. The transition temperature T_{SDW} is 8.5 K to 9.5 K for less ($rr \approx 8$) and more ($rr \approx 100$) pure samples, respectively ($rr = \rho_{\text{RT}}/\rho_{\text{min}}$, where ρ_{RT} and ρ_{min} are the resistivities measured at room temperature and 11.5 K, respectively). This value is somewhat lower than T_{SDW} in the $(\text{TMTSF})_2\text{PF}_6$ and $(\text{TMTSF})_2\text{AsF}_6$ ($T_{\text{SDW}} \approx 12 \text{ K}$). We suggest that the SDW with large imperfect nesting might be responsible for the observed effect. From the theoretical calculations presented in ref. [5] we can estimate $\epsilon_0/\Delta_0 \approx 0.72-0.82$ for $T_{\text{SDW}} = 9.5 \text{ K}$ and 8.5 K , respectively (Δ_0 is the activation energy and ϵ_0 is the parameter characterizing the imperfect nesting). Knowing that the transition temperature T_{SDW} and the activation energy Δ_0 satisfy BCS relation: $\Delta_0 = 1.76 \times T_{\text{SDW}} \approx 21 \text{ K}$, we can estimate $\epsilon_0 = 15.2-17.4 \text{ K}$.

On the other hand we can deduce activation energy Δ from the Arrhenius plot of $\ln R$ versus $1/T$. First, we observe that Δ is not well defined. It ranges from more than about 10 K at temperatures higher than 4.2 K, to value of about 2 K at temperature of 1.8 K. This is considerably smaller than Δ_0 . It can be explained within the theory which incorporates large imperfect nesting [3]. Taking $\Delta \approx 5 \text{ K}$ from ref [6] we obtain:

$$\epsilon_0 = \sqrt{\Delta_0^2 - \Delta^2} \approx 20 \text{ K} \quad (1)$$

and $\epsilon_0/\Delta_0 \approx 0.95$, which is not in very good agreement with the value obtained above. We suggest that a potential due to the anion ordering is responsible for this discrepancy.

In the magnetic field, changes in resistance shows large effects. For magnetic field of 6 tesla and parallel to the low conducting c^* direction the magnetoresistance $\Delta\rho/\rho(0) = (\rho(H)-\rho(0))/\rho(0)$ is approximately 8 at 4.2 K and 20 at 1.8 K (Fig 1).

According to ref. [3], the low temperature magnetoresistance is expressed in terms of the change of the activation energy in magnetic field $\Delta = \Delta(H, \vartheta)$:

$$\frac{\Delta\rho}{\rho(0)} = \frac{\Delta(H, \vartheta)}{\Delta(0, 0)} \exp \left[\left(\frac{\Delta(H, \vartheta) - \Delta(0, 0)}{T} \right) \right] - 1 \quad (2)$$

which we rewrite as:

$$\frac{\Delta\rho}{\rho(0)} = \frac{y}{\Delta(0, 0)/\Delta_0} \exp \left[\frac{\Delta_0}{T} \left(y - \frac{\Delta(0, 0)}{\Delta_0} \right) \right] - 1 \quad (3)$$

Fig 1. Magnetoresistance $\Delta\rho/\rho(0)$ at 1.8 K (a) and at 4.2 K (b) for several field (H) orientations

Fig 2. Magnetic field dependence of the quasi-particle gap ($\Delta(H, 0^\circ)/\Delta_0$) for several values of zero field gap ($\Delta(0, 0)$) at 1.8 K

where $y = \Delta(H, \vartheta) / \Delta_0$. Since the expression for y is rather complicated, we will extract y from (3) using experimental data for $\Delta\rho/\rho(0)$. Fig 2 shows calculated dependence of the y as a function of $x = v_F b H \cos \vartheta / \Delta_0$, for different values of $\Delta(0, 0)$. Here v_F , b are Fermi velocity and the lattice parameter b -axis, respectively ($v_F \cong 2 \times 10^7$ cm/s). Comparing our values of y with the ones from ref [3], we see that agreement is not very good. Yet, we can say that eq. (2) qualitatively explains magnetoresistance, especially its large value. For example, if we take $\epsilon_0 / \Delta_0 \cong 0.95$ ($\Delta(0) \cong 5$ K), ref [3] gives $y \cong 0.3$ at zero field and $y \cong 0.4$ at field of 6 tesla, while our experiment gives $y \cong 0.25$ and $y \cong 0.45$, respectively [8]. Again, we propose that the observed differences could be explained by the potential due to the anion ordering.

It should be noted that the expression for $\Delta(H, \vartheta)$ predicts zero magnetoresistance for $\vartheta = 90^\circ$, whereas we clearly observe finite effect (Fig 2.). However, recent calculations [4,7], show that if the transfer integral t_c is included, the magnetoresistance becomes finite for magnetic field parallel to the intermediate conducting b' direction. Furthermore, the predicted change for $\vartheta = 90^\circ$ is considerably smaller than the one for $\vartheta = 0^\circ$, in accordance with our experimental results.

To conclude, we have tried to understand the behaviour of magnetoresistance within a theory, developed by K.Maki [3], which incorporates large imperfect nesting of SDW. Furthermore, we have discussed the lowering of the transition temperature T_{SDW} within model developed by X.Huang and K.Maki [5]. Parameter characterizing imperfect nesting ϵ_0 extracted from the latter model is not in a very good accordance with values which gives the first model. Also, there is still unresolved problem of a poorly defined activation energy Δ in SDW state in the $(TMTSF)_2NO_3$. We suggest that a potential due to the anion ordering is responsible for encountered discrepancies.

REFERENCES

1. See for example G.Saito and S.Kagoshima (editors), "The Physics and Chemistry of Organic Superconductors" (Springer-Verlag, Berlin) 1990.
2. L.Forro et al., Phys.Rev. B, 29 (1984) 2839
3. K.Maki, Phys.Rev. B, 47 (1993) 11506
4. M.Basletic et al., Europhys.Lett., 22 (4) (1993) 279
5. X.Huang and K.Maki, Phys.Rev B, 46 (1992) 162
6. N.Biskup et al., Phys.Rev. B, 47 (1993)
7. K.Maki, private communication
8. S.Tomic et al., these Proceedings