

## Non-ohmic electrical transport in the charge-density wave state of $(2,5(\text{OCH}_3)_2\text{DCNQI})_2\text{Li}$

M. Pinterić<sup>a,b</sup>, N. Biškup<sup>a</sup>, S. Tomić<sup>a</sup>, J. U. von Schütz<sup>c</sup>

<sup>a</sup>Institute of Physics, POBox 304, HR-10000 Zagreb, Croatia

<sup>b</sup>Faculty of Civil Engineering, University of Maribor, SI-2000 Maribor, Slovenia

<sup>c</sup>3. Physikalisches Institut, Universität Stuttgart, D-70550 Stuttgart, Germany

### Abstract

Electric-field-dependent conductivity measurements are reported in the low-temperature charge density wave state of the organic conductor  $(2,5(\text{OCH}_3)_2\text{DCNQI})_2\text{Li}$ . We associate non-linear conductivity to the sliding of  $2k_F$  CDW pinned by commensurability to the background lattice. The sliding mechanism ceases to be valid below 25K concomitantly with the onset of the variable range hopping in single particle conduction.

*Keywords:* Transport measurements, Metal-insulator phase transitions, Organic conductors

### 1. Introduction

Both infrared measurements [1] and X-ray diffuse scattering [2] on  $(2,5(\text{OCH}_3)_2\text{DCNQI})_2\text{Li}$  revealed the existence of two charge density waves (CDWs) with different orders  $N=2$  and  $N=4$ .

We have already reported dielectric response in this material [3]. There we have identified, for the first time, a Debye-like relaxation of the CDW phase mode with Arrhenius-like decay determined by the resistive dissipation. We have proposed that the  $2k_F$  ( $N=4$ ) CDW pinned by commensurability to the lattice be the origin of the relaxation observed. A coupling of the  $2k_F$  ( $N=4$ ) CDW to coexisting  $4k_F$  ( $N=2$ ) CDW was suggested as the mechanism which yields to the dominant pinning. Here we present additional DC measurements for further clarification of the ground state of this material.

### 2. Theory

Having the commensurate CDW, we expect a good correspondence to the model of a classical particle. Starting from a single particle equation of motion we can relate parameters characterizing the response of pinned CDW with parameters describing the non-linear conduction associated with the sliding CDW condensate. The product of oscillator strength  $\Delta\epsilon$  and threshold field  $E_T$  should be a constant

$$\Delta\epsilon \cdot E_T = \frac{Ne}{\pi ab\epsilon_0} \quad (1)$$

where  $N$  is the number of DCNQI molecules in the unit cell and  $a, b$  are lattice constants. Additionally, we can obtain the expression which relates the field  $E$  dependent conductivity  $\sigma_{\text{CDW}}$  with the relaxation time  $\tau_0$ :

$$\sigma_{\text{CDW}} = \frac{Ne}{\pi ab\tau_0} \left( \frac{1}{E_T} - \frac{1}{E} \right) \quad (2)$$

### 3. Experimental and results

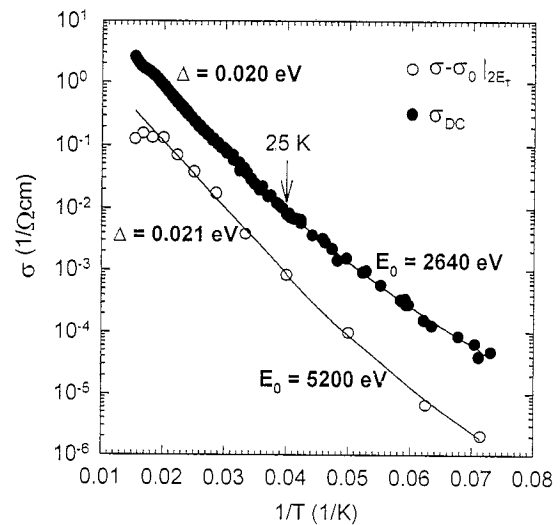


Fig. 1. Ohmic conductivity (full points) and non-ohmic conductivity at twice the threshold field (open points).

The conductivity temperature dependence was already shown and discussed in [3]. Here we concentrate on the temperature region below  $T_{\text{C2}} \sim 50\text{K}$  (Fig. 1.). Between 50K and 25K the conductivity follows a typical semiconductor (Arrhenius) behaviour as reported before. Note that below 25K conductivity decrease starts to saturate. Then the leading conduction mechanism might be associated to carriers localized on randomly distributed impurities and described by Mott's variable-range hopping formula

$$\sigma = \sigma_0 e^{-\left(\frac{E_0}{k_B T}\right)^{1/d}} \quad (3)$$

where  $d$  is the dimensionality of hopping,  $E_0 = 16\alpha^3/n_i(E_F)$ ,  $n_i(E_F)$  the energy-volume density of carriers on Fermi surface, while  $\alpha$

describes the space length of the wave function of localized states. As we see in Fig. 1, Eq. (1) perfectly describes the temperature dependence of the conductivity in this temperature domain with  $d=3$ .

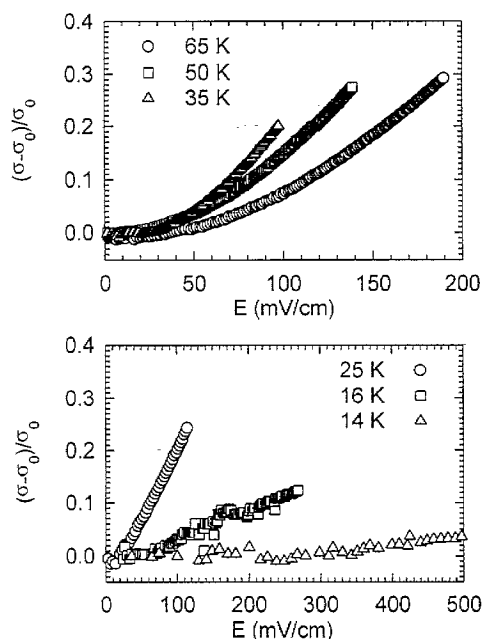


Fig. 2. Non-ohmic conductivity vs. field at a few selected temperatures.

Fig. 2. shows the field-dependent conductivity normalized to its ohmic value at a few selected temperatures. Note that the onset of the nonlinear conductivity becomes much sharper at  $T \leq 25K$ . Further note that a weak, but observable non-linear contribution exists even above 50K, in the region of CDW fluctuations. We start to observe these effects at  $T < 75K$  when  $2k_F$  fluctuations start to grow up [2]. The non-linear contribution

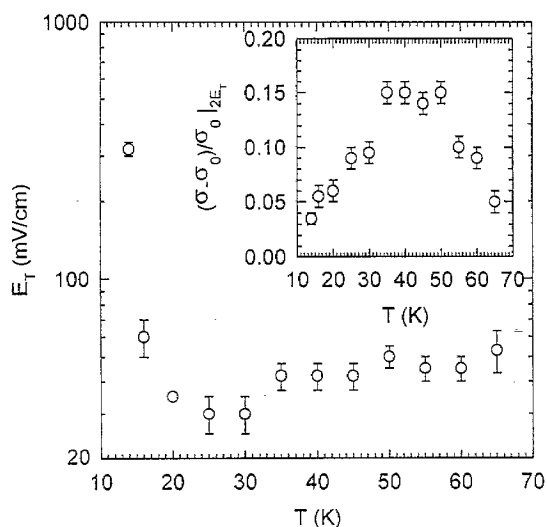


Fig. 3. Threshold field and non-ohmic conductivity at twice the threshold field, normalized to its ohmic value (Inset).

reaches maximum and starts to weaken below 25K, concomitantly with a strong increase of the threshold field, as shown in Fig. 3.

We recall that above 25K  $\Delta \epsilon$  has a fairly constant value [3], so the product  $\Delta \epsilon E_T$  has a narrow spectrum of values  $(5.4 \pm 1.1) 10^7$  V/m and therefore obeys qualitatively Eq. (1). However, the theoretical value of the product is two orders of magnitude bigger than the observed one. Below 25K, this product is not constant any more.

The collective and single particle conductivities are closely related. As shown in Fig. 1., they both obey the same temperature dependence in the temperature range from 50K down to 14K: above 25K following Arrhenius and below 25K variable range hopping temperature dependence.

The change of the behavior at  $T \leq 25K$  might be related with the fact that the free-carrier screening becomes negligible. One could expect that the latter happens once the electrical density becomes smaller than the one electron per Lee-Rice domain  $L_{CDW}$ . We estimated  $L_{CDW}$  from [4] and get 25K for the crossover temperature.

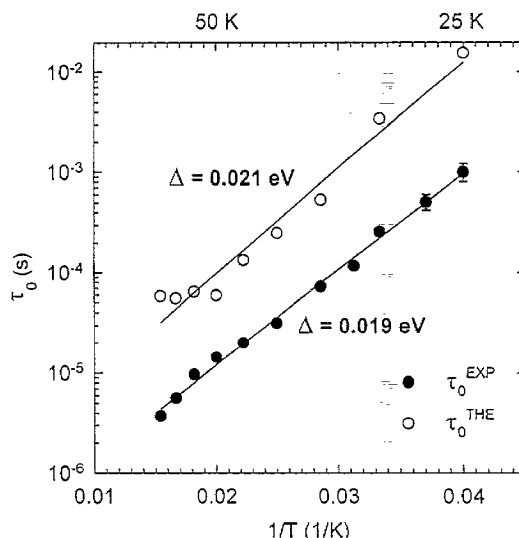


Fig. 4. Experimentally obtained (full dots) and theoretically calculated from non-ohmic contribution data (empty dots) values for relaxation times.

Finally, we can test Eq. (2) comparing experimentally obtained  $\tau_0^{EXP}$  [3] and  $\tau_0^{THE}$  calculated from the nonlinear conductivity. As shown in Fig. 5., their activation fits perfectly. The factor of 10 in amplitudes might be due to the fact that the model doesn't take into account the existence of free charge carriers.

\*\*\*

This work was partially supported by the Croatia-Germany bilateral collaboration project, ref. KRO-020-95.

References

[1] M. Meneghetti, G. Lunardi, R. Bozio, C. Pecile, Synth. Metals, 42 (1991) 1775.  
 [2] R. Moret, private communication.  
 [3] S. Tomić, N. Biškup, M. Pinterić, J. U. von Schütz, H. Schmitt and R. Moret, Europhys. Lett., 38 (1997) 219.  
 [4] A. Bjeliš and K. Maki, Phys. Rev. B, 44 (1991) 6799.