

# Non-ohmic electrical transport in the Peierls-Mott state of deuterated copper-DCNQI systems

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## Abstract

Electric-field-dependent measurements are reported in the low-temperature state of the organic conductors  $\text{Cu}[2,5(\text{CD}_3)_2\text{-DCNQI}]_2$  and  $\text{Cu}[(2,5(\text{CH}_3)_2\text{-DCNQI})_{0.70}(2,5(\text{CD}_3)_2\text{-DCNQI})_{0.30}]_2$  with  $N=3$  commensurate CDW. We correlate observed features of the electric conduction below and above threshold field with the temperature evolution of the  $N=3$  CDW order as detected by the low-frequency dielectric measurements.

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

We have used DC electrical transport measurements in order to investigate  $N=3$  CDW in the Peierls-Mott insulating state of two systems: (a) the fully deuterated system  $\text{Cu}[2,5(\text{CD}_3)_2\text{-DCNQI}]_2$  (abbreviated as  $d_8$ ) and (b) the partially deuterated system, that is, the alloy  $\text{Cu}[(2,5(\text{CH}_3)_2\text{-DCNQI})_{0.70}(2,5(\text{CD}_3)_2\text{-DCNQI})_{0.30}]_2$  (abbreviated as  $h_8/d_6$  70%:30%). We have already reported the low-frequency dielectric response of these materials. Our results gave a clear evidence of a collective mode contribution to the dielectric properties in the insulating state [1].

Nonlinear conductivity measurements were made at increasing temperatures until  $T_{\text{C1warm}}$  was reached, after the sample was cooled from 100 K through the M-I transition at  $T_{\text{C1cool}}$  down to 35 K (see Fig. 1).  $T_{\text{C1warm}} \approx 80$  K and 55.6 K and  $T_{\text{C1cool}} \approx 77$  K and 47 K for the  $d_8$  and the  $h_8/d_6$  70%:30% system, respectively. The respective hysteretic regions, in which cooling and warming  $R$  vs.  $T$  traces differ, are situated between 70 K -  $T_{\text{C1warm}}$  and 40 K -  $T_{\text{C1warm}}$ , respectively. In Fig. 2, we show the ohmic conductivity and non-ohmic conductivity at twice the threshold field, for the  $d_8$  system. The preferred choice for the fit (full lines) was Mott's variable range hopping (VRH) formula, which applies when the dominant conduction mechanism becomes the conduction by the carriers localized on impurities. This behavior and the  $T$ -independent behavior of the mean relax-

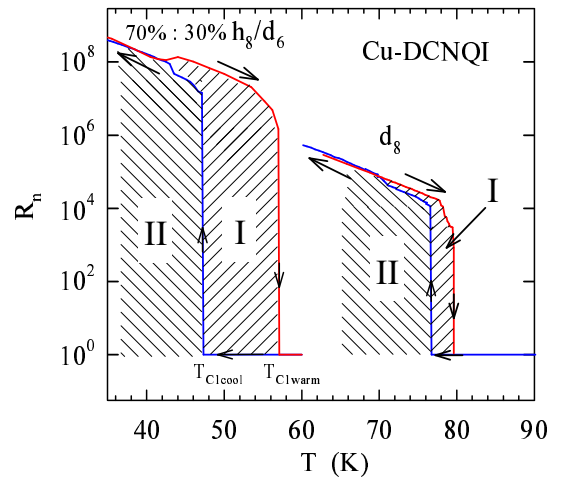


Fig. 1. Normalized resistance vs. temperature for both systems.

ation time [1], are in accordance with an extremely low free electron density in the insulating state. The collective and single particle conductivities are closely related since they both obey the same temperature dependence. In Fig. 3, we show the field-dependent conductivity normalized to its Ohmic value at a few selected temperatures, for the  $d_8$  system. Note that the nonlinear effect is quite small but the threshold field  $E_T$  is clearly defined. For the  $d_8$  system  $E_T$  decreases below  $T_{\text{C1warm}}$ , reaching a minimum value of about 400 mV/cm around 65K, and then increases again towards low temperatures. The nonlinear effect is constant in the broad  $T$ -range between

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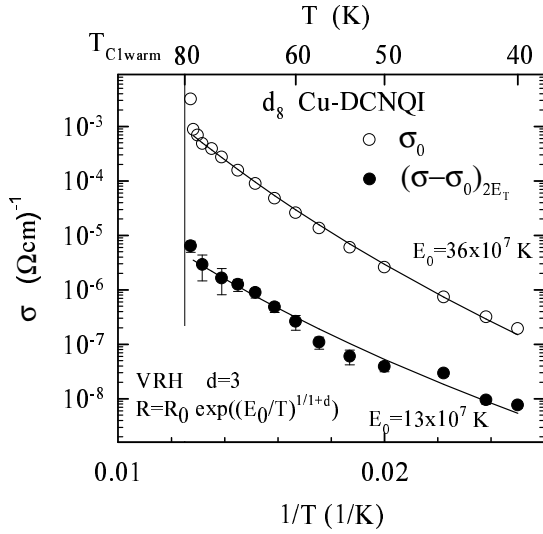


Fig. 2. Ohmic conductivity (open points) and non-ohmic conductivity at twice the threshold field (full points).

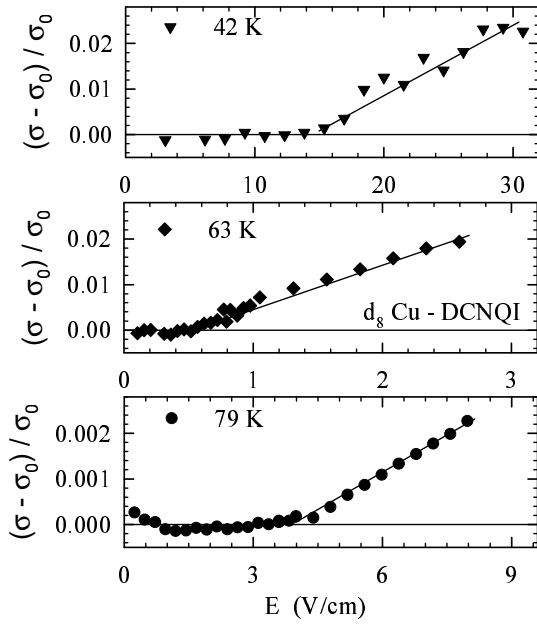


Fig. 3. Non-ohmic conductivity *vs.* field at three temperatures.

55 K and 75 K and starts to increase at lower temperature (Fig. 4(a)). For the  $h_8/d_6$  70%:30% system there is also a pronounced increase of  $E_T$  at low temperatures. However, the magnitude of this feature appears to be sample dependent (see Fig. 4(b)). For this system we did not observe divergence of  $E_T$  at temperatures close to  $T_{C1warm}$ . Again, as in  $d_8$  system, the magnitude of non-linear effect decreases towards  $T_{C1warm}$ . Finally, using the observed values of  $E_T$  we estimated the CDW characteristic length to be 0.1-1  $\mu\text{m}$ , for both systems.

It should be noted that a concomitant rise of both  $E_T$  and the nonlinear effect at low temperatures is a feature not usually encountered in CDW and SDW. However, we have already reported a qualitatively

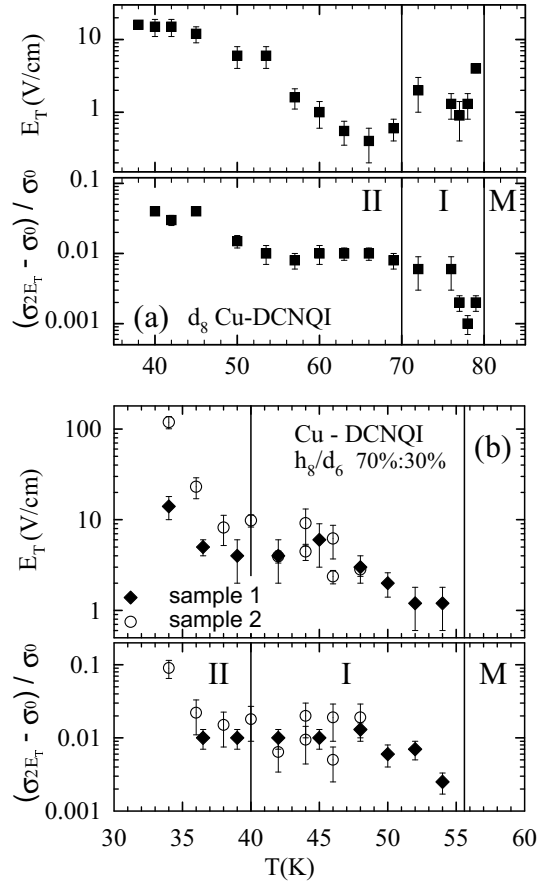


Fig. 4. Threshold field and non-ohmic conductivity at twice the threshold field, normalized to its ohmic value, for (a)  $d_8$  system and (b)  $h_8/d_6$  70%:30% system, two different single crystals.

same behavior in commensurate SDW of  $\kappa$ -(BEDT-TTF) $_2$ Cu[N(CN) $_2$ ]Cl [2]. A common aspect of these two systems is a domain structure of DW ground state [3]. On the other hand, for a DW in an incommensurate structure a rise of  $E_T$  followed by a disappearance of the nonlinear effect, once the free-electron screening becomes ineffective, would be expected. Indeed, we have observed such a behavior in  $N=4$  CDW of DCNQI-Li system [4].

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