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RESISTIVITY AND THRESHOLD ELECTRIC FIELD MEASUREMENTS UNDER PRESSURE FOR THE INORGANIC CHAIN CONDUCTOR $(NbSe_4)_{10/3}I$

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We report resistivity and threshold electric field measurements under pressure on the linear chain compound $(NbSe_4)_{10/3}I$ which is a charge density wave system showing nonlinear conductivity. From resistivity measurements (in low electric field) we determined the phase transition temperature T_c and the value of the energy gap Δ .The threshold field was determined from measurements of differential resistance dV/dI.The results are compared with pressure work on the related compound $(TaSe_4)_2I$ and are discussed in the light of some recently published theoretical models.

$(NbSe_4)_{10/3}I$ is a quasi one-dimensional (1d) metal which shows a structural phase transition of the Peierls type at T_c=280 K, associated with the formation of a charge density wave (CDW)[1] As in other 1d compounds, the CDW is pinned by impurities or defects, but can be depinned by a small electric field above a threshold value (E_T)[2].The "sliding" CDW gives then an extra contribution to the electrical conductivity and the response of the system to the applied voltage becomes non-linear.

In this paper we report resistivity and threshold field measurements for $(NbSe_4)_{10/3}I$ under pressures up to 16 kbar.

The single crystals of $(NbSe_4)_{10/3}I$ were synthesized at the Institute of Physique Appliquee , Lausanne, by prof. F. Levy. Current and voltage probes were made on samples of typical dimensions 2.5x0.15x0.05 mm^3 by evaporating gold. All the measurements were carried in a commercially available pressure cell ("Unipress, Poland, LC 20 liquid cell ; on loan from the Central Research Institute for Physics, Budapest) which can be used for pressures up to 20 kbar.The pressure transmitting medium was isopentane and the pressure was monitored inside the cell with an InSb resistance sensor.

In Fig. 1 are shown some resistivity data in the region of the phase transition for two samples under different pressures. The phase transition temperature T_c was determined from the peak in the logaritmic derivative. Below T_c the resistivity is activated ($\rho = \rho_0 \exp \Delta/k_B T$) and the values of energy gap Δ were deduced from the slopes of $\log\rho$ -1/T curves in the low temperature region (140K-200K).

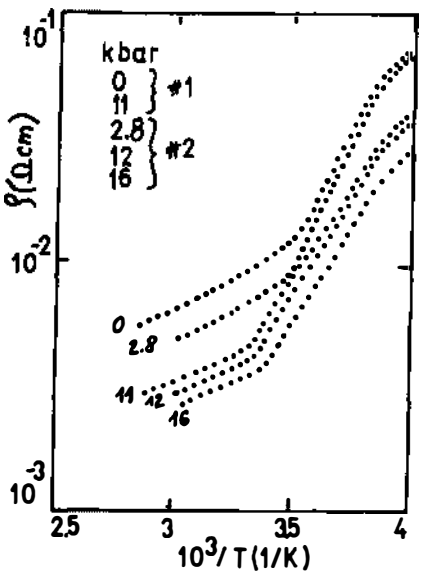

FIG. 1.

Fig. 2 shows the pressure dependence of T_c and Δ determined as described above.

Fig. 3 shows a typical dV/dI characteristic from which the threshold electric field was determined as the value of applied voltage (divided by the distance between the contacts) for which the dV/dI characteristic begins to show non-liner behaviour.

The temperature dependence of the threshold field for three samples under different pressures is shown in Fig. 4. We do not understand why E_T for sample 1

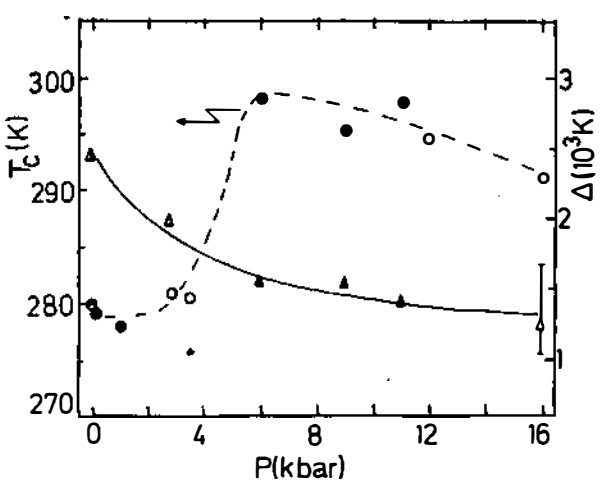

FIG. 2.

saturates below 180K and this set of data was excluded from the analysis given below.

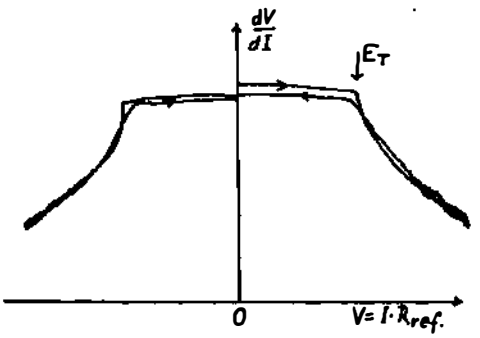

FIG. 3.

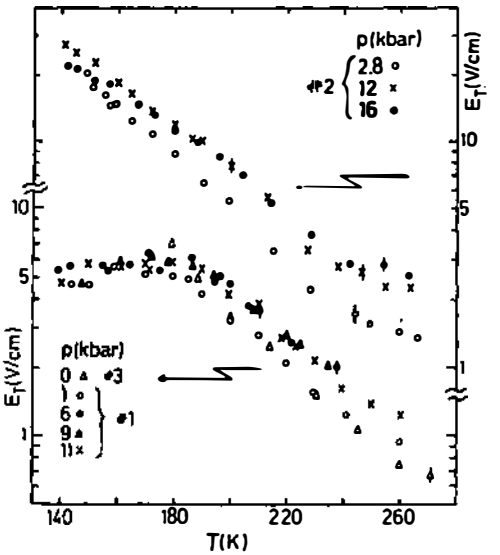

FIG. 4.

As shown in Fig. 2, T_c increases for pressure up to 6 kbar and than begins to decrease, while Δ decreases in the whole pressure interval. It has been suggested[3] that 1d fluctuations can greatly reduce the transition temperature which is in fact determined by the interchain coupling. Under pressure the interchain coupling is enhanced and initially this increases T_c both directly and also indirectly by suppressing 1d fluctuations. The effect of a further increase in pressure gives a more and more pronounced 3d character to the system and T_c decreases, since for 3d materials no Peierls transition exists. On the other hand, stiffening the lattice by pressure hardens the phonon frequencies and Δ decreases.

Previously it has been suggested[4] that the temperature dependence of E_T can be attributed to the increase in screening length associated with the reduction in the normal electron density at lower temperatures. That is at low temperature the screening becomes less effective, the CDW is more strongly pinned and E_T increases. However within this picture one would also expect E_T to decrease under pressure since Δ decreases continuously. As shown in Fig. 4 E_T in fact increases at all temperatures.

Recently some theoretical models have been reported in order to explain the observed exponential temperature dependence of the threshold field in 1d inorganic conductors. K.Maki[5] showed that the inclusion of thermal fluctuations of the phase of the CDW order parameter leads to the following expression for E_T in the strong pinning regime

$$E_T(T)=E_T(0)\ e^{-T/T_0} \qquad (1)$$

where T_0 is a material constant, independent of the impurity concentration and proportional to $(v_1v_2)^2/(v_F^2T_c)$, and $E_T(0)\sim 1/(v_1v_2)^2v_F^2$ (v_1 and v_2 are the Fermi velocities in the two transverse directions perpendicular to the chain).

J.R. Tucker et al[6] modified the argument given by Maki and found that in his strong pinning model, $E_T(0)\sim \Delta/L$ and $T_0\sim\Delta$, where L is the phase correlation length which is assumed to be same as the average impurity spacing along a single chain.

In Fig. 5 we plot the pressure dependence of the parameters $E_T(0)$ and T_0 obtained from fits of our experimental data to equation (1).

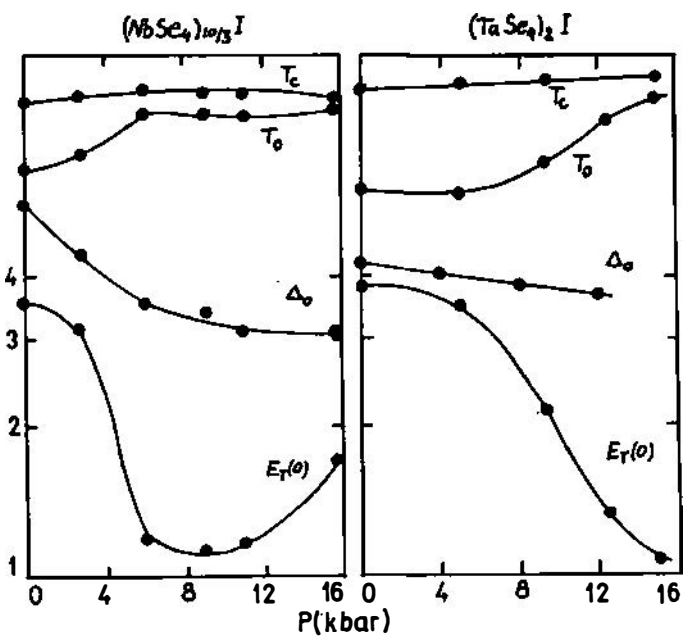

FIG. 5

together with the measured values of T_c and Δ_0. In the same figure

data for $(TaSe_4)_2I$ extracted from references 7 and 4 are also shown. We have found that our data for E_T scales neither with T/T_c nor with T/Δ_0. However there is an obvious qualitative similarity in the behaviour of $E_T(0)$, T_0, Δ_0 and T_c for both compounds. Our data up to ~9 kbar and the data for $(TaSe_4)_2I$ are in qualitative agreement with the predictions of the model given by Maki. Namely $E_T(0)$ decreases while T_0 increases with pressure due to the enhancement of the anisotropy coefficient $\eta = v_1 v_2 / v_F^2$. A more quantitative comparison with theory could be made if the compressibilities of these two compounds were available.

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