NON-LINEAR CONDUCTIVITY OF MONOCLINIC TaS_3 AT LOW TEMPERATURES

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ABSTRACT

We report on non-linear conductivity of monoclinic TaS_3 between 200 K and 4.2 K in the electric field range of 10^{-2}-5×10^{2} V/cm. Below 50 K measurements reveal two threshold fields with a sharp increase in conductivity by several orders of magnitude above the threshold with the highest amplitude. Mechanisms implying phase slip processes are proposed to explain such a behaviour.

INTRODUCTION

In the past few years there was considerable interest in study of non-linear conductivity of quasi one-dimensional conductors at the helium temperatures. One of the reasons of this interest was the observation of sharp current growth at practically constant voltage in $K_{0.3}MoO_3$ in temperature range $T \leq 20$ K [1-3]. The low damping of CDW motion and fast current response ($\simeq 10^{-8}$ s) has led to suggest that the physical mechanism of CDW motion at low temperatures is radically different from the mechanism at higher temperatures [4]. In this paper we report preliminary results of a systematic study of non-linear conductivity in monoclinic TaS_3 in the wide temperature (300-4.2 K) and electric field (10^{-2} - 5×10^{2} V/cm) ranges. Part of results concerning orthorhombic TaS_3 were published earlier [5,6].

The conductivity measurements were usually carried out in two-terminal configuration, but in several cases we used four terminals. Electrical contacts were made by gold paint or by vacuum deposition of In streeps after appropriate thermal treatment of samples in vacuum. For conductivity and I-V curves measurements the whole range of electric fields was divided on several slightly overlapping regions. For low electric field and low temperatures we used electrometers with high input impedance ($\simeq 10^{16}$ Ohm). In the high electric field range and low temperatures we

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used pulse method in regime of controlled voltage with pulse duration down to ~ 0.1 μs. The I-V curves were obtained by using of dual-channel boxcar integrator and by slowly sweeping the pulse amplitude. The highest measured electric field was governed by the beginning of sample heating which was regularly controlled by observing the pulse form on oscilloscope.

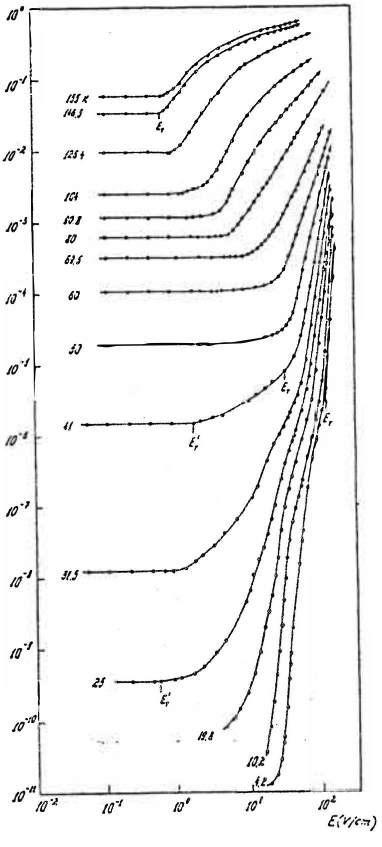

Fig. 1. Dependence of conductivity normalized to its room temperature value on the electric field for monoclinic TaS_3. The temperatures are indicated for each curve.

Fig. 1 shows the set of dependences of conductivity on electric field E for several temperatures. Dependences of $\sigma(E,T)$ for $K_{0.3}MoO_3$ samples obtained in [1] and in some of our experiments also have a similar form. In the range $T > 100$ K the form of I-V curves and their variation with temperature have been well investigated [7,8]. After the electric field exceeds the threshold field E_T the non-linear conductivity appears which can be approximated by $\sigma_n \sim \exp[E_0/E-E_T)]$ dependence [9], where E_0 is some characteristic field.

At decreasing temperature the form of $\sigma(E)$ dependence begins to change. The transition from ohmic to non-ohmic conductivity broadens and we can see two threshold fields E_T' and E_T on $\sigma(E)$ dependence. At the field $E \geq E_T'$ we observed a slight deviation from linear I-V curve and gradual growth of σ_n between E_T' and E_T. With further temperature reduction ($T < 40$-50 K) E_T' value decreases but E_T continues to increase.

At $E \geq E_T$ we observed a sharp growth in conductivity, which enhances with decreasing temperature. At $T < 70$ K many of $\sigma_n(E)$ dependences are close to the power type dependence $\sigma_n \sim (E-E_T)^{\alpha}$, where the value of α increases significantly from $\alpha \simeq 3/2$ ($T \simeq 70$ K) up to $\alpha \simeq 15$ ($T \simeq 4.2$ K). E_T increases from $T_{min} \simeq 145$ K, which corresponds to the minimal value of E_T and continues to increase down to 4.2 K. In this temperature range the $\lg E_T$ dependence on T turns out to be very close to linear one, which agrees with exponential growth of E_T with decreasing temperature :

$$E_T(T) = E_T(0) \exp(-T/T_o) \qquad (1)$$

with $T_o \sim 25$ K.

DISCUSSION

We can give below only a short analysis of our results (for a full discussion see ref. 10). With decreasing temperature below 100 K the number of free carriers decreases significantly and it is probable that the defects in CDW superlattice (as dislocations in the CDW supperlattice, jumps of CDW phase (and amplitude) near strong pinning centers, contacts and sample surfaces) become the main carriers of current with the CDW pinned as a whole. The most probable excitations are the topological 2π-solitons with charge 2e and dissociation energy Δ_S of the order of the value of the interchains interaction energy $\simeq kT_P$ [11].

In the low temperature range $T << \Delta_S$ the thermal activation of solitons is very weak and they become localized in CDW superlattice in a random way. In these conditions the jumps between these localized states become the main mechanism of the current transport in quasi one-dimensional conductors [5,6]. It seems that these processes are similar to hopping conductivity in many disordered systems [12-14].

The dependence of the conductivity on the electric field and temperature ($E < E_T$ and $T \leq 100$ K) can be also explained on the base of mechanism of the hopping motion of the solitons, as obtained in disordered systems [14]. In particular, it was shown that form of $\sigma(E,T)$ dependence is governed by value $\beta = eEl/2kT$, where l is some length which seems to be equal to the average distance between impurities in our case. At E → 0 the conductivity remains finite. With increasing electric field the transition to non-linear region of $\sigma(E)$ dependence occurs at $\beta \sim 0.1$ [14], i.e. at $E \simeq 0.1(2kT/el)$, which can be considered as first threshold field E_T. In this case the value of E_T would be linearly decrease with decreasing temperature, as we have experimentally found.

The sharp growth of σ at $E \geq E_T$ seems to be associated with beginning of rapid increase of the number of solitons induced by electric field and with the beginning of formation of high conductivity channels in the samples. At $E < E_T$ the soliton jumps were uncorrelated in various sample's domains. However, with growth of number of solitons their motion becomes more coherent and it seems to promote the beginning of CDW motion as a whole. The nucleation of 2π-soliton under the action of the temperature and electric field is completely equivalent to phase-slip by 2π which results in reduction of the CDW phase gradient near contacts and centers of strong pinning [15-19].

CONCLUSION

Thus the results reported above suggest evidence for significant contribution of phase-slip processes to CDW depinning and to non-linear conductivity. This mechanism is a common mechanism for CDW depinning either at high temperatures or at low temperatures with however important differences, for instance, in CDW dynamics before and after phase slip.

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