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Spontaneous resistance fluctuations and their evolution near the threshold in o-TaS₃ below the liquid-nitrogen temperature

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Abstract. It is found that below 80 K o-TaS₃ demonstrates spontaneous resistance fluctuations growing when the temperature is decreasing. The average relaxation time, τ_0 , obtained from the noise spectra demonstrates activated behavior, $\tau_0 \propto \exp(W/T)$, $W \approx 1300$ K for $50 < T < 70$ K. In the vicinity of the threshold the average frequency of the fluctuations, f_0 , grows with increasing the voltage, revealing onset of the Fröhlich current. $\log(f_0)$ is found to be proportional to the increase of conductivity. We conclude that the main source of the resistance fluctuations are thermally-assisted jumps of dislocations of the charge-density waves.

The physical properties of quasi one-dimensional conductors with sliding charge-density waves (CDW), such as TaS₃, K_{0.3}MoO₃, below approximately half the temperature of the Peierls transition reveal a number of new features [1]: reduction of the activation energy for the low-field conductivity and disappearance of thermal hysteresis, tremendous growth of anisotropy, growth of the threshold field, E_T , for the CDW depinning and development of nonlinear conductivity at $E < E_T$, hopping conductivity. These features seem to indicate development of a new state of the CDW, probably disordered, or glassy [2]. However, the nature of the transition and the structure of the resulting state remain unclear.

In the present report we demonstrate, that below 75 K o-TaS₃ exhibits spontaneous resistance fluctuations, which increase with further cooling. We show, that the fluctuations can be explained by thermally-assisted climb of dislocations, which develop in the equilibrium state of the CDW at low temperature.

We performed spectral measurements of broad-band voltage fluctuations in samples of o-TaS₃ connected in series with a source of d.c. voltage and a loading resistor. 6 samples with dimensions $(0.4 \pm 1) \text{ mm} \times (1 \pm 20) \mu\text{m}^2$ have been studied. Both 2- and 4-contact configurations were used. The measurements were performed in the frequency range $0.2 \pm 10^3 \text{ Hz}$.

RESULTS

Fig. 1(a) presents typical dependencies of the spectral density of noise on the voltage V applied to the sample at several given

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Fig. 1. a)- Voltage dependence of $S_f(V)$ at different f (indicated in Hz). 4-probe method. $T=53\text{K}$. Background $S_f(0)$ is shown at the right.

b)- $\sigma(V)$ measured simultaneously.

c)-the same as a), 2- probe method

Fig. 2. The spectra multiplied by f at different T (indicated in K). 2-contact method. $V = 40 \text{ mV}$. The broken line corresponds to $S_f(V) \propto \tau_0/[1+(f/f_0)^2]$. The solid lines correspond to distribution of τ_0 : $\delta \ln(\tau_0) = 0.65$.

Fig. 3. The frequencies f_M , at which $S_f(V) \times f$ reaches maxima, vs. $10^3/T$. Data for 2 samples (* correspond to the spectra shown on fig.2).

frequencies (4-probe configuration). The abrupt growth of the noise around $V = 200 \text{ mV}$ corresponds with the growth of conductivity σ (fig. 1(b)). The initial part of the curve ($V \lesssim 200 \text{ mV}$) indicates the voltage range at which $S_f(V)$ is proportional to V^2 (the dashed line). This means that the resistance fluctuations are nearly independent of the electric field applied. This result demonstrates existence of spontaneous resistance fluctuations of pinned CDW.

Fig. 4. $S_f(V) \times f$ vs. f at different V (indicated in mV). 2-probe method (see fig. 1c)

2-probe measurements give analogous curves for this sample (fig.1(c)), though influence of the electric field on fluctuations is observed at $V > 40$ mV, where the fluctuations are partly suppressed.

In all the samples we have observed growth of $S_f(V)/V^2$ at a given frequency by 2.5 ± 4 orders of magnitude beginning from $T \sim 75$ K down to 30 ± 40 K, where $S_f(V)/V^2$ achieved $\sim 10^{-7} \text{ Hz}^{-1}$ at $f = 1$ Hz. 4- and 2-contact curves demonstrate qualitatively analogous temperature dependencies of the noise. Thus, the noise is

of volume origin. However, the 2-probe curves demonstrate more abrupt growth between 70 and 50 K.

In the whole temperature range the dependence $S_f(V)$ on f , when measured by the 4-contact method, can be described as $1/f^\alpha$, $\alpha \sim 1$. The 2-probe method gives, however, pronounced maxima in the frequency dependencies of $S_f(V) \times f$ between 70 and 50 K (fig. 2), while the time domains of voltage demonstrate random switching between two levels. So, it was reasonable to approximate the spectra with a Lorentzian form (fig. 2, dashed line); better fit is achieved if we take into account a distribution of relaxation times, τ_0 (fig. 2, solid lines).

The frequencies f_m corresponding to the maxima of $S_f(V) \times f$, yield the average values of $f_0 \equiv 1/(2\pi\tau_0)$. It can be seen (fig. 2) that f_m is temperature dependent. Fig. 3 shows temperature dependencies of f_m for two samples, giving $\tau_0 = \tau_a \exp(W/T)$, with $W \approx 1300$ K, and $\tau_a \sim 10^{-13}$ s.

Though the 4-probe spectra did not demonstrate similar maxima, we found that the average slope, α , of $\lg(S_f)$ vs. $\lg(1/f)$ is changing from $\alpha < 1$ to $\alpha > 1$ with cooling the samples in the same range of T . From this we conclude that the average value of τ_0 also decreases.

Fig.4 shows the same measurements as fig.1(c) displayed as a set of $S_f(\delta V/V) \times f$ vs. f at different V . At low voltages a maximum corresponding with fig.2 is seen. Its form looks voltage independent. No qualitative changes are observed until around 180 mV extra noise appears at the lower frequencies. Then a maximum appears at $f = f_0(V)$, f_0 increasing with V . The same voltage dependence of f_0 can be obtained from the curves $S_f(\delta V/V)/V^2$ vs. V at given f , if one marks V corresponding to the first maximum (fig.1(c)). 4 - probe measurements yield similar growth of f_0 with V , though the maxima of $S_f(\delta V/V) \times f$ are less pronounced.

DISCUSSION

At low T the screening of the defects in the volume is reduced due

to freezing out of the quasiparticles. This can give rise to resistance fluctuations: growth of $1/f$ -type noise could be described by the semi-empirical Hooge relation [3] working well for semiconductors and metal films of different kind: $S_f(V)/V^2 \times f = \gamma/N_c$, where N_c is the total number of the free current carriers, and $\gamma \sim 2 \times 10^{-3}$. However, it gives the growth of $S_f(V)/V^2 \propto R(T)$, which is slower than we have observed. Also, $S_f(V)/V^2$ appears at least 3 orders of magnitude lower than the experimental value. This discrepancy seems to indicate that the fluctuations have collective nature.

We suppose that the resistance fluctuations are caused by thermally-assisted motion of dislocations of the CDW. The role of dislocations, whose excitation energy (per one electron) is low in comparison with the over-gap excitations [1,4], should increase at low T . The abrupt growth of noise below 75 K indicates that in this temperature range some extra defects develop in the volume of the CDW. Such defects are supposed to develop due to the reduction of screening of the CDW deformations [5,6] providing strong pinning [2]. Growth of E_T below 90 K and reduction of the dielectric constant [2] indicate decrease of the coherence volume. At the same time, $T > 50$ K appears high enough to provide thermal-assisted climb of dislocations between pinning centers, corresponding to the phase-slippage (PS) of the CDW. In this case, dislocation lines would cross CDW chains adding (or removing) 2 conducting electrons per chain, and giving rise to the fluctuations of conductivity [7]. The activation energy for $\tau_0(T)$, 1300 K, characterizes the barrier for the climb of the dislocations. The underlying microscopic processes giving rise to this barrier remain unclear. Corresponding to the whole width of the Peierls gap, W is still smaller, than the activation energy for the PS observed at higher T [7]. We believe, that at $T < 50$ K the dislocations become immobile, forming the glassy state [2] and providing the relief for hopping conductivity.

The gradual growth of $f_0(V)$ at $V \sim V_T$ (fig. 4) indicates onset of the CDW current. The observed values of f_0 are too low to reveal the Fröhlich current directly. However, we found proportionality between $\delta\sigma$ and $\log(f_0)$, which corresponds to progressing PS activation with the deformation of the CDW. This result is in agreement with the logarithmic decay of metastable states in this temperature range [6].

One can see, that the relaxation times are better defined in the 2-contact configuration, which is evidently due to the synchronization of PS acts. In this case, nonuniform electric field near the current terminals, and, probably, the injection (or extinction) of free carriers by the terminals [4], affect the conditions of PS.

In conclusion, we have observed spontaneous resistance fluctuations at $T < 80$ K associated with thermally-assisted jumps of equilibrium dislocations of the CDW.

- [1]. G. Grüner Rev. Mod. Phys. 60 (1988) 1129; P. Monceau 1985 in: Electronic Properties of Inorganic Quasi-one-dimensional Compounds, Part 2. Ed. by P. Monceau. Dordrecht: D. Reidel Publ. Sump.
- [2]. F. Ya. Nad' and P. Monceau Solid. State. Commun., in press
- [3]. F. N. Hooge Phys. Lett. A 29 (1969) 139.
- [4]. S. Brazovskii, S. Matveenko J. Phys. I France, 2 (1992) 409; *ibid* 2 (1992) 725
- [5]. V. Ya. Pokrovskii and S. V. Zaitsev-Zotov Synthetic Metals, 29 (1989) F439; *ibid* 32 (1989) 321
- [6]. S. V. Zaitsev-Zotov Synthetic Metals 41-43 (1991) 3923
- [7]. D. V. Borodin, S. V. Zaitsev-Zotov and F. Ya. Nad' Zh. Eksp. Teor. Fiz. 93 (1987) 1394; [Sov. Phys. JETP 66 (1987) 793]