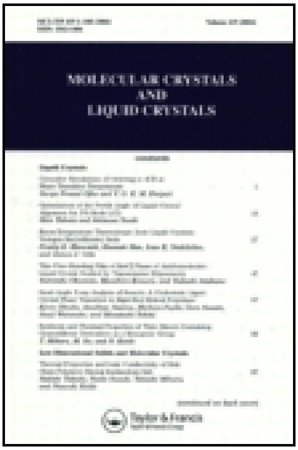

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BROADBAND NOISE IN ORTHORHOMBIC TaS_3

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Abstract We report experimental results on the broadband noise in sliding charge density wave conductor orthorhombic TaS_3. The experimental results are in excellent agreement with a phenomenological model based on fluctuations in threshold field due to deformations of the sliding condensate.

The onset of nonlinear electrical conduction beyond a threshold electric field E_T in charge density wave (CDW) conductors, such as $NbSe_3$ and TaS_3, is known to be caused by the sliding of the CDW which is pinned below E_T by the impurities. The appearance of noise, both narrow-band and broadband, in the nonlinear conduction regime has been studied extensively in recent years.[1,2,3] In this paper we report measurements of the broadband noise in orthorhombic TaS_3.

The measured broadband noise has the following characteristics.(1) Field dependence - The onset of noise is sharp and coincident with the onset of nonlinear conduction as evidenced by a comparison with the differential resistance measurement. (2) Frequency dependence - The noise power has a $f^{-\alpha}$ spectrum with $\alpha = 0.95 \pm .05$ (for 10 Hz $< f < 10^5$ Hz) at 160 K and the spectrum is field independent except very close to the threshold voltage V_T.[4] (3) Sample size dependence - The r.m.s. noise voltage δV scales as $[\ell/A]^{1/2}$ where ℓ is the length and A is the cross-sectional area or, equivalently, $\delta V^2/V^2$ scales as the inverse volume. These results establish that the noise is a bulk (finite size) phenomenon and not associated with contacts.

In order to quantitatively study the behavior we propose the following model. At constant total current, fluctuations in the effective pinning force or V_T, cause fluctuations in the chordal resistance R(= V/I) which is explicitly threshold voltage dependent. Within this model, therefore, the mean squared noise voltage is given by

$$\langle \delta V^2 \rangle = I^2 \langle \delta R^2 \rangle = I^2 \left(\frac{\partial R}{\partial V_T}\right)^2 \langle \delta V_T^2 \rangle \qquad (1)$$

Direct measurement of $\partial R/\partial V_T$ is not possible; so we assume that R is a function of $(V-V_T)$ only, i.e., $\partial R/\partial V_T = -\partial R/\partial V$. The latter is evaluated numerically from the I-V characteristics. Since $\partial R/\partial V$ is only weakly frequency dependent below 100 kHz, the frequency dependence is entirely contained in $\langle \delta V_T{}^2 \rangle$, i.e., $\delta V^2(\omega) = I^2(\partial R/\partial V_T)^2 \delta V_T{}^2(\omega)$.

Figures 1(a) and 1(b) show plots of the field dependence at two temperatures of the noise voltage measured at one frequency (ω = 300Hz, Q = 10) and of the numerically evaluated value of $I(\partial R/\partial V_T)$. Clearly, except very near V_T, they track each other accurately.[4]

It is now known from various experiments[4] that metastable states exist in CDW systems corresponding to long wavelength de-

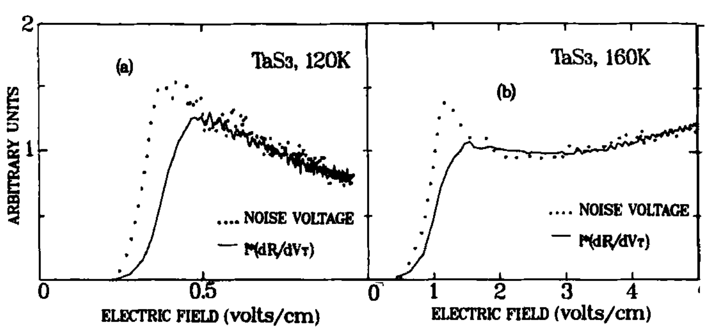

FIGURE 1 Field dependence of the broadband noise $\langle \delta V^2 \rangle$ measured at 300 Hz and $I^2(\partial R/\partial V_T)^2$.

formations of the phase of the CDW condensate. Such deformations alter the distribution of phases at impurity sites and therefore the pinning force exerted by the impurities on the sliding condensate. We suggest that this is the source of the threshold field fluctuations. If the transition between metastable states is thermally activated, then a distribution of barrier heights leads to a distribution of relaxation times. Even if the barrier height distribution is sharply peaked at an energy $E_p \gg k_B T$, one still[5] obtains a $f^{-\alpha}$ power spectrum for the noise, so long as the distribution function is slowly varying within $k_B T$.

We propose that the fluctuation in $E_T = V_T/\ell$ is coherent within a "coherent volume," λ^3. The net threshold voltage fluctuation across the entire sample of length ℓ and cross-sectional area A is the incoherent addition of these fluctuations. Assuming that the fluctuation in the pinning field, $\langle \delta E_T^2 \rangle$, is proportional to E_T^2, we obtain

$$\langle \delta V^2(\omega) \rangle = I^2 \left(\frac{\partial R}{\partial V_T}\right)^2 \cdot E_T^2 \cdot \lambda^3 \cdot \frac{\ell}{A} S(\omega,T) \qquad (2)$$

where $S(\omega,T)$ is the spectral weight function. Equation (2) produces the experimentally observed sample dimension dependence.

In Fig. 2(a) we plot the temperature dependence, for $V = 2V_T$, of $\delta V^2(\omega)$ measured at 300 Hz. It grows rapidly below T_c and has a pronounced peak near 150K where an incommensurate-commensurate transition is thought to occur.[6] Figure 2(b) shows the temperature dependence of $I^2(\partial R/\partial V_T)^2 V_T^2$ measured directly. This quantity also grows rapidly below T_c and shows a pronounced peak at 150 K.

In Fig. 2(c) we plot the temperature dependence of the ratio of these two quantities i.e., $\delta V^2(\omega)/[I^2(\partial R/\partial V_T)^2 V_T^2]$. This, according to equation (2), reflects the temperature dependence of $\lambda^3 S(\omega,T)$. This grows below T_c and saturates gradually. The peak disappears. Several issues remain unresolved. First, we do not

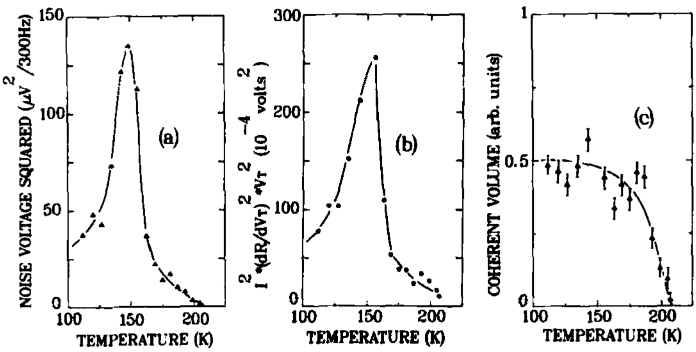

FIGURE 2 Temperature dependence of (a) $\langle \delta V^2 \rangle$ (300 Hz) (b) $I^2(\partial R/\partial V_T)^2 V_T^2$ and (c) $\lambda^3 S(\omega,T)$.

know what relation λ bears to the Lee-Rice length, nor to the dynamic coherence length ξ in ref. 7. A more microscopic theory is desirable. Second, a model for the temperature dependence of $S(\omega,T)$ is needed.

To conclude, we have demonstrated that a phenomenological model of threshold field fluctuations can accurately describe the broadband noise in sliding CDW conductors. It will be interesting to see if analogous models can be constructed for noise generation in other systems, such as charge transfer salts.

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