Comment on "Distribution of Phase Slip in Charge-Density-Wave Conduction in $NbSe_3$"

Recently, Gill [1] has reported measurements of phase slip in the charge-density-wave (CDW) conductor $NbSe_3$ which are suggested to be inconsistent with previous interpretations. Phase slip is required for conversion between CDW current and single-particle current at current contacts, and is driven by strain in the CDW. In a 1D model [2], this strain is produced by an excess voltage V_{ps} dropped uniformly between current contacts. Significant phase slip occurs only within a length L_{ps} of the current contacts, where the magnitude of the strain is largest.

Gill compared four-probe I-V measurements using the normal (N), transposed (T), and mixed (M) configurations, shown in Fig. 1(a). In terms of the measured current I_{tot}, voltage V, and low-field (single-particle) resistance R_s, the CDW current is defined as $I_{CDW} \equiv I_{tot} - V/R_s$. If the phase slip voltage V_{ps} is dropped uniformly between current contacts, then at a given I_{CDW} there should be an excess voltage (and thus excess single-particle and total currents I_s and I_{tot}) in each of these configurations, proportional to the fraction of the length between current contacts included between the voltage contacts. Since the inner contact pair separation used in Ref. [1] was much smaller than the outer contact pair separation, the voltages V and currents I_{tot} measured at fixed I_{CDW} in the N and M configurations should be comparable, and smaller than measured in the T configuration. Instead, Ref. [1] found a large difference between M and N, roughly one-third the difference between T and N. This difference was interpreted as evidence for an excess voltage drop near the current contacts within the length L_{ps} where phase slip occurs, and was used to calculate the magnitude of L_{ps} as a function of current and temperature.

The interpretation in Ref. [1] was based upon two assumptions: (1) that the voltage contacts were nonperturbing and (2) that the converted CDW current was simply shunted through the single-particle resistivity ρ_s in the phase slip region. Reference [1] used 30 μm wide evaporated indium voltage contacts on a 2 μm thick crystal. We have found that 5 μm wide indium contacts shunt roughly 30% of the total current in 1 μm thick crystals, so that the contacts used in Ref. [1] likely shunted nearly all the current. Below a shunting contact, the electric field is greatly reduced. Consequently, phase stress must accumulate on both sides of the voltage contact to provide enough force on the CDW to keep it moving in this field-reduced region. The mixed voltage thus contains an extra contribution to produce this stress.

To test the effects of field and stress perturbations by voltage contacts, we have performed mixed configuration measurements using both a completely nonperturbing contact ($M1$, an electrically conducting atomic force microscope tip) and a strongly perturbing contact ($M2$, silver paint, 40 μm wide). As shown in Fig. 1(b), the perturbing contact gives results similar to those obtained in Ref. [1], while the nonperturbing contact gives results consistent with V_{ps} being dropped uniformly between the current contacts. Thus, voltage contact perturbations were likely responsible for most of the effects reported in Ref. [1].

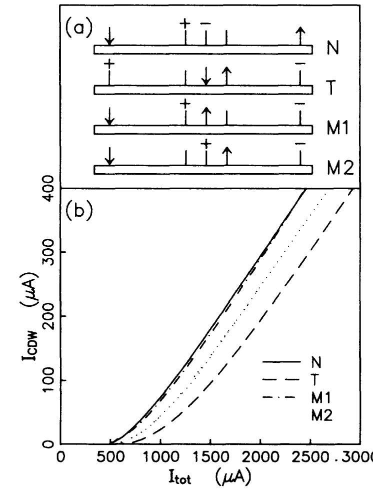

FIG. 1. (a) Four-probe measurement configurations discussed in the text and (b) CDW current I_{CDW} versus total current I_{tot} in $NbSe_3$ at $T=100$ K. The inner pair of contacts used in N and $M1$ are 270 μm apart; the inner pair used in $M2$ are 230 μm apart; the current contacts in $M1$ are 4430 μm apart; and the outermost pair of contacts are 8630 μm apart.

The general validity of the second assumption used in the analysis of Ref. [1] is also uncertain. Although there is at present no two-fluid theory for the phase slip process, it seems unlikely that the converted CDW electrons make no contribution to the total conductivity within L_{ps}. Neglecting this contribution for the $T_P = 145$ K CDW in $NbSe_3$ is reasonable because of the large single-particle density associated with ungapped portions of the Fermi surface. However, in fully gapped materials (e.g., $K_{0.3}MoO_3$) at low temperatures, the single-particle density becomes vanishingly small, so the conductivity associated with converted CDW electrons may be significant.

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