Comment on "Size Effects and Charge-Density-Wave Pinning in $NbSe_3$"

The recent Letter by McCarten *et al.*[1] contains the most complete information to date on how the threshold field E_T for charge-density-wave (CDW) conduction in $NbSe_3$ depends on the Ta impurity content and cross-sectional dimensions of the crystal. The size-dependent contribution to E_T, which Yetman and I observed[2] in thin crystals and attributed to pinning associated with surfaces, proves to be proportional to the concentration n_i of impurities. The bulk E_T, measured in thick crystals, is found to vary approximately as n_i^2. This behavior is qualitatively consistent with the pinning being distributed throughout the crystal, provided that it is of the "weak" type defined by Fukuyama, Lee, and Rice.[3] Size dependence then appears as the lateral phase-coherence length of the CDW approaches one or both of the cross-sectional dimensions. Although we rejected the possibility on the grounds repeated below, McCarten *et al.* accept that the size dependence arose in this way, and claim that their results establish that CDWs in Ta-doped $NbSe_3$ are weakly pinned.

While their argument is internally consistent, its conclusion that lateral phase-coherence lengths L_x in $NbSe_3$ are typically a few μm is in obvious conflict with other experimental evidence. Direct observation in the electron microscope[4] has revealed lateral coherence only on a scale ~ 0.02 μm. As this is substantially less than the crystal thickness (~ 0.05 μm), which necessarily was very small, there is no compelling reason to expect the lateral coherence to be much greater in larger crystals. Unfortunately its direct measurement in larger crystals by x-ray diffraction[5] has not been possible, on account of mosaic structure in the very thick (~ 100 μm) specimens then needed. However, further indications, albeit indirect and model dependent, that coherence lengths are much smaller than McCarten *et al.* propose are provided by transport measurements, notably of narrow-band current noise and high-frequency conductivity.

In view of this the case for weak pinning should not be accepted as proved, especially as McCarten *et al.* do not inquire how else the dependence of E_T on n_i might have arisen.

One possibility, suggested by recent experiments[6,7] in this laboratory and elsewhere, is that E_T arises from the pinning of edge dislocations in the CDW structure. In the case of $NbSe_3$, the spread of disturbance along the moving CDW appears consistent with its being governed by the glide of edge dislocations, present intrinsically at boundaries between the bulk CDW and surface layers of slightly different wave vector.[7] The presence of such dislocations, which carry a dipolar charge[8] and are easily pinned by impurities, would readily account for a size-dependent component of E_T proportional to n_i.

Further, it is not impossible that edge dislocations form also throughout the bulk of the CDW, as a result of strains caused by the presence of impurities. Defects induced by impurities have recently been observed in the CDWs in certain dichalcogenides,[9] where they appear in numbers proportional to the impurity concentration. If dislocations in $NbSe_3$ behave in an analogous way, and are present with density proportional to n_i, their pinning might well result in a bulk E_T varying as n_i^2.

It is not suggested that this proves that the pinning of dislocations was the source of E_T in the $NbSe_3$ specimens measured by McCarten *et al.* It should, however, serve to point out that their results, whose attribution to weak pinning is in obvious conflict with other observations, may well be explicable in quite different terms.

J. C. Gill
H. H. Wills Physics Laboratory
Tyndall Avenue
Bristol BS8 1TL, England

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