Critical Behavior of Si:P at the Metal-Insulator Transition

The apparent value of the conductivity exponent $\mu = 0.5$ at the $T=0$ metal-insulator transition in Si:P has remained a puzzle for over a decade [1]. Stupp *et al.* [2] recently have proposed a reanalysis of the data which gives $\mu \approx 1.3$. The two approaches involve different sets of assumptions regarding the definition of the critical region. In our high-resolution, uniaxial stress-tuning study of the transition [3,4], we did not fit the data for conductivity $\sigma(T\rightarrow 0) < 5(\Omega\,\mathrm{cm})^{-1}$ because of concerns about irreproducibility. Stupp *et al.* assume that this region contains the salient physics, with a new critical donor density n_c smaller by 6%.

As noted in our original paper, the criterion of 5 $(\Omega\,\mathrm{cm})^{-1}$, corresponding to $n/n_c - 1 \approx 0.001$, denoted the point where the data no longer repeated from sample to sample. We plot explicitly in Fig. 1 results at $T=3$ mK on two pieces of Si:P from different regions of the same boule, illustrating the extremes of behavior which we observe. The solid line is a least squares fit by a critical form with $\mu = 0.48 \pm 0.07$. We believe that the sample-dependent rounding reflects macroscopic, nonrandom density variations in the P dopant distribution. We argue against stress inhomogeneity as a major factor because the results repeat over the entire range in S for the same sample repositioned in the stress cell.

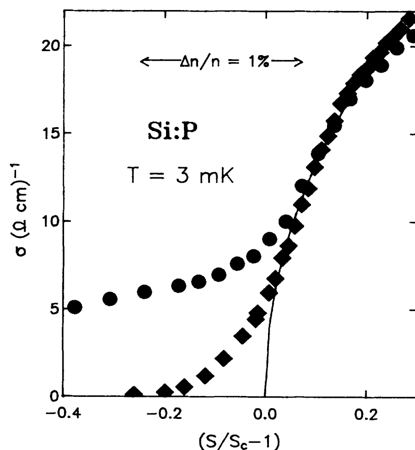

FIG. 1. Electrical conductivity σ as a function of uniaxial stress S at $T=3$ mK for two crystals of Si:P (circles and diamonds), indicating the reproducibility that leads us to identify the region of intrinsic behavior. The solid line is a fit to the data in this region, leading to a critical exponent $\mu = \frac{1}{2}$. Extrapolation to $T=0$ of the reproducible data does not change the exponent (Ref. [3]). The critical stress values defined by the fits, S_c, differ by 10% for the two samples because the donor densities, n (the zero-stress points), of the samples differ. We have obtained the range of relative densities, as shown by the arrows, by a separate determination of the critical density, n_c, vs S.

A second reason why we did not include the low S "tail" in the critical analysis is the attendant need to lower n_c. Measurements of the divergence of the dielectric constant as a function of uniaxial stress in the insulator [4] on independently calibrated Si:P samples show clear insulating character as close as 1% to the n_c determined from the metallic conductivity. Hence, the 6% smaller n_c required by Stupp *et al.* to raise μ would not permit a self-consistent treatment of the observed critical behavior on both sides of the metal-insulator transition.

In summary, we argue that the new critical regime proposed by the Karlsruhe group [2] is dominated by a nonrandom impurity distribution and should not be compared with the usual theories of critical phenomena.

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