Metal-Insulator and Glass Transitions in a 2D Electron System in Si MOSFETs with a Screened Coulomb Interaction

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Introduction

There is now considerable experimental evidence that suggests that Coulomb interactions are responsible for a variety of phenomena observed in the metallic regime of 2D systems, as well as for the dynamical correlations near the metal-insulator transition (MIT) and in the insulating regime. In order to investigate the role of the range of the Coulomb interactions on the metallic and glassy behaviors, we have performed some transport and noise studies on a 2D electron system (2DES) in Si metal-oxide-semiconductor field-effect transistors (MOSFETs) in which the Coulomb interaction is screened by the metallic gate. Those devices are identical to the very disordered samples that had been used to study glassy dynamics (*e.g.* Refs. [1,2]) except that the oxide thickness is much smaller than the average 2D inter-electron separation in the regime of interest.

Experimental

Measurements of the conductivity σ of a 2DES were carried out on a 1-μm-long, 90-μm-wide n-channel Si MOSFET with the oxide thickness d_{ox} = 7 nm. Similar to previous studies [1, 2], the back-gate bias of −2 V was applied to maximize the 4.2 K peak mobility to ~ 0.04 m^2/Vs. The carrier density n_s was changed at a high temperature $T \approx 20$ K, the 2DES was then cooled to a desired T with a fixed n_s, and σ was measured as a function of time t. The experiment was done in Heliox, a ^{3}He system. The excitation voltage V_{exc} was kept constant and low enough (2-10 μV) to ensure that the conduction was Ohmic.

Results and Discussion

Figure 1 shows the time-averaged conductivity $\langle\sigma\rangle$ as a function of T for different n_s. For the lowest carrier densities n_s, $\langle\sigma(n_s, T)\rangle$ are well fitted to a variable-range hopping law $\langle\sigma\rangle \propto \exp[-(T_0/T)^{-1/3}]$. T_0 decreases linearly with increasing n_s, and vanishes at $n_c = 4.45 \times 10^{11}$ cm^{-2}. On the metallic side of n_c, $\langle\sigma(T)\rangle$ follows a power law, giving a reliable extrapolation of $\langle\sigma(n_s, T=0)\rangle$ and the same value of n_c. The obtained critical exponents are $\mu = 3.04 \pm 0.08$, $x = 1.49 \pm 0.01$, and $z\nu = \mu/x = 2.0 \pm 0.1$. The relative fluctuations $(\sigma-\langle\sigma\rangle)/\langle\sigma\rangle$ were measured at T=0.25 K and their normalized power spectra obey $S(f) \propto 1/f^{\alpha}$. The noise magnitude, the value of α, and the degree of non-Gaussianity are reduced with increasing n_s, and show a sudden change at the glass transition density n_g, providing evidence for the glassy freezing of electrons for $n_s < n_g$ ($n_c < n_g$) as $T \rightarrow 0$, similar to the results on samples with long-range interactions. However, the second power spectra suggest that interacting droplet models, rather than hierarchical pictures of glassy dynamics, might be more appropriate.

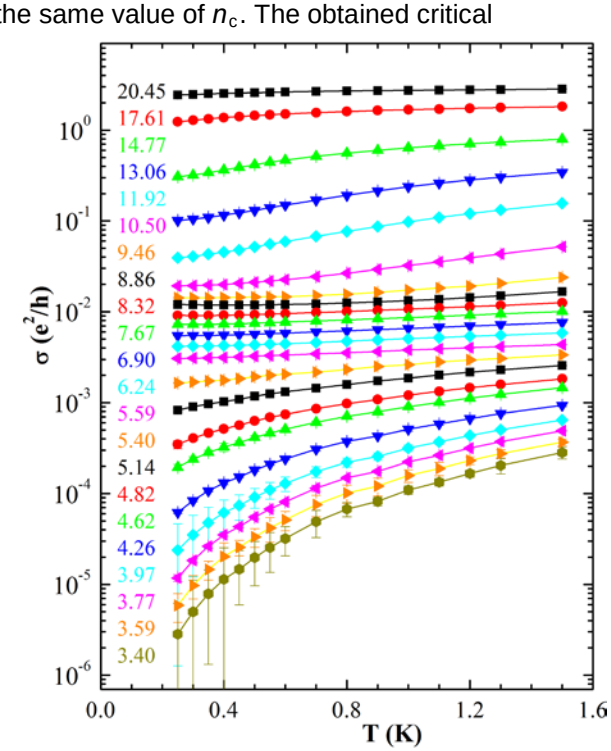

Figure 1: $\langle\sigma\rangle$ vs. T for different n_s (10^{11} cm^{-2}). The error bar shows the size of the fluctuations. Solid lines are guide to the eye.

Conclusions

In a 2DES with a screened Coulomb interaction, we have obtained evidence for the MIT at n_c, and for the glassy freezing for $n_s < n_g$ ($n_c < n_g$) as $T \rightarrow 0$, similar to the results on samples with long-range interactions. The data suggest that here, however, the interacting droplet models might be more appropriate.

Acknowledgements

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References

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[2] Lin, P.V., *et al.*, Phys. Rev. B, **86**, 155135 (2012).