NONEXPERIMENTAL RELAXATIONS IN A 2D ELECTRON SYSTEM IN SILICON

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Introduction

The relaxations of conductivity have been studied in a strongly disordered 2D electron system (2DES) in Si after excitation far from equilibrium by a rapid change of carrier density $n_i$, controlled by the gate voltage $V_{g,i}$, at low temperatures $T$. The observed nonequilibrium dynamics strongly suggests the existence of a glass transition at $T=0$ in the range of $n_i$ that spans both the insulating regime and the unconventional conducting regime where $k_F l < l$ ($k_F$ - Fermi wave vector, $l$- mean free path).

Experimental

Measurements were performed on a 2DES in Si (the peak 4.2 K mobility $\mu = 0.06$ m$^2$/Vs with the applied substrate bias of $-2$ V) with the sample dimensions $1 \times 90$ and $2 \times 50 \mu$m$^2$. The samples and the measurement technique have been described in more detail elsewhere [1]. The experimental procedure was as follows. The sample was cooled from 10 K to the place on the metallic side of the metal-insulator transition, albeit in the regime where 2D electrons play a dominant role in the observed out-of-equilibrium dynamics. The onset of glassy dynamics takes both the insulating regime and the unconventional conducting regime where $n_i V_{g,f}$ and $T$ were measured. By warming up to 10 K and cooling down again to $T$ with the $V_{g,f}$ applied, the equilibrium conductivity $\sigma_0(V_{g,f}, T)$ corresponding to the given $V_{g,f}$ and $T$ was obtained. At the end of the run, the sample was warmed up to 10 K, gate voltage changed back to the same $V_{g,f}$, and the experiment was repeated at a different $T$ for the same $V_{g,f}$. Finally, the whole procedure was repeated for different values of $V_{g,f}$.

Results and Discussion

Figure 1 shows the relaxations of conductivity, $\sigma(t, V_{g,f}, T)$, normalized to the corresponding $\sigma_0(V_{g,f}, T)$ for different $T$ and a fixed $V_{g,f}$. It is striking that $\sigma(t)$ first overshoots its equilibrium value, goes through a minimum, and only then approaches $\sigma_0$.

The minimum in $\sigma$ shifts to longer times with decreasing $T$ until, at sufficiently low $T$, it falls out of the time window of the measurements. A detailed and careful analysis of the data for times before the minimum in $\sigma(t)$ reveals [2] that the relaxations are strongly nonexponential: $\sigma(t,T)/\sigma_0(T) \propto t^\alpha \exp(-t/\tau) \sim 0<\alpha<0.4$ and $0.2<\beta<0.45$, where $\tau \propto \exp(\gamma n_s^{1/2}) \exp(E_d/T)$, $E_d \approx 20$ K. These results are consistent with the continuous phase transition occurring at $T_d=0$. At times above the minimum in $\sigma(t)$, the system equilibrates via a simple exponential process with a characteristic time $\tau \sim \exp(E_d/T)$, where $E_d \approx 57$ K independent of $n_i$. The data show that, even though the system is, strictly speaking, glassy only at $T=0$, at low enough $T$ ($i.e.$ $< 1$ K) the dynamics is glassy on all experimentally accessible time scales.

Conclusions

The dramatic and precise dependence of the relaxations on $n_i$ and $T$ strongly suggests (a) the transition to a glassy phase as $T \to 0$, and (b) the Coulomb interactions between 2D electrons play a dominant role in the observed out-of-equilibrium dynamics. The onset of glassy dynamics takes place on the metallic side of the metal-insulator transition, albeit in the regime where $k_F l < l$. These results support our earlier conclusions [1] based on the noise measurements, and exhibit many similarities to the behavior of other glassy materials.

Acknowledgements

This work was supported by NSF Grant No. DMR-0403491 and the NHMFL.

References