Melting of a Quantum 2D Wigner Crystal: Evidence for a Microemulsion Phase

X.P.A. Gao, R.L.J. Qiu, N.J. Goble (Case Western Reserve University); A. Serafin, L. Yin, J.S. Xia, N.S. Sullivan (NHMFL, UF Physics); G.S. Boebinger (NHMFL, FSU Physics); L.N. Pfeiffer, K.W. West (Princeton University)

Introduction

Transport of strongly interacting 2D holes in high mobility GaAs quantum wells was studied to investigate the WC-liquid melting against tuning parameters: temperature, hole density and magnetic field. The melting of a two-dimensional crystal of carriers in this clean semiconductor is found to trigger the formation of an intermediate phase between electron crystal and liquid.

Experimental

Two dimensional (2D) electronic systems are expected to form a quantum Wigner crystal (WC) ground state in the most strongly interacting regime. How this 2D WC melts into liquid and whether there are new phases between WC and liquid is an outstanding problem in condensed matter physics. Low frequency magneto-transport measurements using lock-in technique were primarily performed on high mobility GaAs quantum well (QW) samples from wafers grown on (311)A GaAs. Al0.1Ga0.9As barriers and Si delta doping layers were placed symmetrically at a distance of 195 nm away from the 10 nm thick GaAs QW. All the samples have density $p \sim 1.3 \times 10^{10}/cm^2$ and mobility μ=2-5×10^5 cm^2/Vs without gating. A back gate was placed approximately 150-300 mm underneath the sample and used to tune the hole density.

Results and Discussion

The RIP (reentrant insulating phase) due to WC formation at low *B* has been observed (1,2) as related to the strongly interacting character of the dilute 2DHS and high sample quality. This RIP connects with the *B*=0 metal insulator transition at r_s~37, as expected for the 2D WC-liquid transition phase diagram in the clean limit. The transport properties of this low field RIP over extended temperature and density ranges showed the melting of 2D WC in a system with intrinsically large r_s and low disorder strength. Data strongly suggest that the 2D WC-liquid transition gives its way to phase separation and forms a new intermediate phase where WC bubbles coexist with metallic fluid.

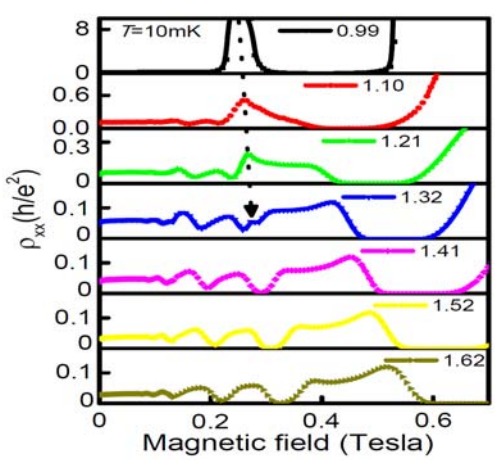

Figure 1. Magnetoresistivity of QW 5A at *T*=10mK for densities *p* = 0.99, 1.10, 1.21, 1.32, 1.41, 1.52, and 1.62. The dash line illustrates the evolution-melting of a 2D Wigner crystal while increasing the density *p*. For density *p* = 0.99, the reentrant insulating phase (RIP) has peak resistivity ρ peak two orders of magnitude larger than the peak resistivity ρ(B=0T) at zero field.

Conclusions

We found strong evidence that the melting of a clean 2D WC induces a new intermediate phase, as predicted in the theory of micro-emulsions where the crystal and liquid coexist. The observation of this new phase provides insights to the understanding of interaction effects on phase transition in low dimensions.

Acknowledgements

The NHMFL High B/T Facility is supported by the National Science foundation DMR-1157490 and the State of Florida. X.P.A. Gao also acknowledges funding support from the NSF via DMR-0906415.

References

[1] R. L.J. Qiu, X. P.A. Gao, L. N. Pfeiffer, K. W. West, *Phys. Rev. Lett.* **108**, 106404 (2012).
[2]. R. L.J. Qiu, X. P.A. Gao, *Phys. Rev. Lett.* **110**, 249702 (2013).