Preliminary Exploration of Wigner Crystallization Effects in HIGFET Devices

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Introduction

New quantum phenomena emerge in response to strong electron-electron interaction. To probe interaction-driven phenomena, it is crucial to study ultra-dilute electron systems in which the disorder must be suppressed to avoid the occurrence of Anderson Localization. We have fabricated undoped two-dimensional hole systems in GaAs/AlGaAs FETs (grown by Loren Pfeiffer) in which the charge concentration can be tuned below $1x10^9$ cm^{-2}. The goal for this project is to study the temperature and density dependence of the sheet resistance to seek evidence of interaction-driven [1] characteristics and signatures for a possible phase transition.

Experimental – Hall Measurement and temperature dependence of the resistivity

The transport measurement of HIGFET samples are performed at the MicroKelvin Lab High B/T facility (at Williams Hall, UF). The samples are Hall-bar devices mounted inside a helium-3 emersion cell which is cooled down to 10 mK temperature. Upon condensing 3He gas inside the cell, the sample reaches thermal equilibrium with the liquid 3He bath. Then, the sample is turned on through biasing the top gate above the turn-on threshold. Hall measurement is first performed to characterize the charge densities and the mobility. Then, for each fixed charge density, the temperature dependence of the resistivity is measured by heating the bath to ~700 mK and detect the resistivity variation as the sample is cooled at a controlled slow cooling rate. Varying the charge density from ~$1x10^{10}$ cm^{-2} down to ~$1x10^9$ cm^{-2}, we measure temperature dependence of the sheet resistance corresponding to the metal-to-insulator transition across a critical density. Then, DC-VI measurement will be performed in the insulating regime in order to obtain evidence of interaction-driven characteristics and the dynamical response of a possible Wigner Crystal, i.e. through nonlinear threshold behaviors.

Results and Discussion

The cooling of the HIGFETs is a fragile process since the gate is easily damaged by the electrostatic charges induced during the cooling. The first few attempts of cooling failed until we recently adopted a more rigorous grounding procedure and we are now measuring a working device. The Hall and temperature (T) dependence measurement has been performed for a series of densities. Fig.1 is an example of the magnetoresistance (MR) measured in B-fields for a charge density of $3.5x10^9$ cm^{-2}. Despite the ultra-low density and the insulating nature (indicated by the resistivity well above the quantum resistance h/e^2), the dip at filling factor (ν) 1 is clearly developed. Right above ν=1, a reentrant insulating phase appears, consistent with an interaction-driven scenario. Moreover, the low-field (<0.03T) MR exhibits a surprising negative sign, in contrast to the positive MR for higher densities in the metallic regime due to the spin-orbit effect. The T-dependence of the resistivity (not shown here) for the insulating cases is nonactivated.

Conclusions

MIT is observed in *p*-channel HIGFET sample at a low critical density around $4.2x10^9$ cm^{-2}. The nonactivated transport in the insulating regime is consistent with an interaction-driven effect. The negative sign of MR in the insulating regime indicates a sign change occurring around the critical density, and the negative sign derives a qualitatively different origin than that for the weak localization effect. Further study of the T-dependence of the negative MR is needed in addition to the DC-VI measurement.

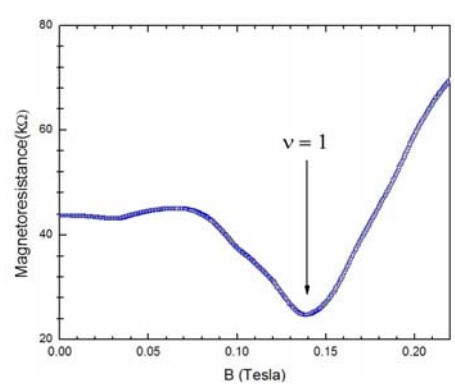

Fig.1 Magnetoresistance vs. B-field for a carrier density of $3.5x10^9$ cm^{-2}.

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References

[1] Jian Huang et al, Phys. Rev. B 85, 041304 (Rapid Comm.) (2012).