Capacitance Measurements of 2D Hole Gas in Magnetic Fields at Ultra-Low Temperatures

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Introduction

The mechanism of the putative metallic state and metal-insulator transition in two dimensions has presented a long-standing unsolved problem in condensed matter physics, as the 2D metallic state challenges the well-established one parameter scaling theory of localization [1]. In order to shed light on this system, we have probed the field-dependence of the density of states be measuring the junction capacitance of a 2D hole gas (2DHG) in the form of a hole doped 10nm GaAs quantum well [2] down to millikelvin temperatures.

Experimental

We have carried out measurements of a 2D metallic system by measuring the capacitance between the top gate and conduction plane of a 2DHG. A reactive component of 79 Hz alternating current (typically 1 nA or less) superposed with static DC gate voltage was measured by ultra-low noise lock-in amplifier and converted to capacitance. The 2DHG was cooled by immersing the sample in liquid helium-3 that was thermally linked to the cooling stage of a high-circulation rate dilution refrigerator. The capacitance provides direct information about localized and extended states. The carrier density can be varied from several times 10^9 to 10^{11} cm^{-2} by changing the gate voltage.

During measurements temperature was fixed by temperature controller while sweeping magnetic fields and / or the gate voltage.

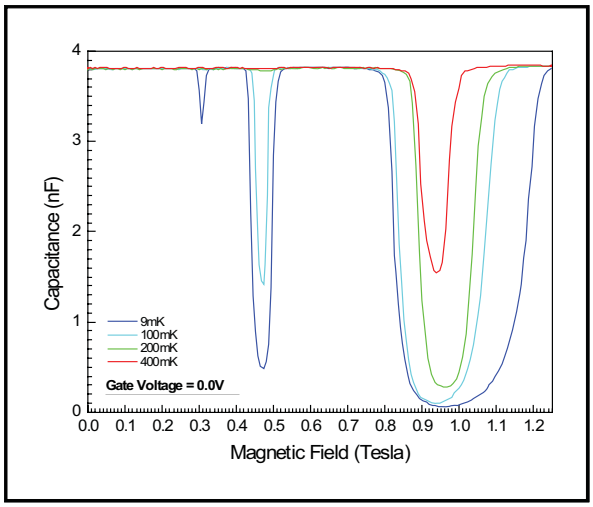

Figure 1. Variation of the capacitance of a GaAs quantum well as a function of magnetic field for 9<T<400 mK.

Results and Discussion

Fig. 1 shows the observed variation of the capacitance of the junction of GaAs quantum well as function of magnetic field. The capacitance is observed to oscillate between the quantum hall states and exhibit a dramatic reduction around the integer Quantum Hall plateau. The non-localized states show a behavior nearly independent of carrier density and consistent with estimated geometrical value of about 3.8 nF. In zero field at 9 mK capacitance reduction as well as resistance increase were observed below the critical density of metal-insulator transition (MIT) in transport [2]. Temperature was also found to have strong effect on gate capacitance around the MIT.

Conclusions

The results show that capacitance can be used to measure the density of states of dilute 2D hole system and support the view that the Quantum Hall States are localized except edge currents. The density and temperature dependences of capacitance at zero field in the context of MIT need further theoretical understanding.

Acknowledgements

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References

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