Capacitance and Coulomb Drag in GaAs/AlGaAs Electron-Hole Bilayers

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We present electrical transport measurements on electron-hole bilayers (EHBs), realized in the GaAs/AlAs material system, at very low, balanced carrier densities. Such a structure is predicted to host excitonic phases at sufficiently low densities, temperatures, and interlayer distances [1]. In particular, the possibility of an excitonic Bose-Einstein condensate has motivated the investigation of GaAs-based EHBs for decades, but conclusive experimental evidence of this phenomenon has not yet been demonstrated [2].

Our heterostructures include two bulk-doped layers (p- and n-type), serving as gates. They are separated by an intrinsic layer of GaAs with a thin (10-40 nm) $Al_{0.8}Ga_{0.2}As$ barrier in the center. The formation and carrier density of 2D charge layers on either side of the barrier can be controlled with high precision by tuning the gate voltage.

We observe a sharp peak in the interlayer differential conductivity, which coincides with a large step and subsequent shoulder in the capacitance [3], see Fig.1. Both parallel and perpendicular magnetic fields enhance this conductivity peak and cause it to shift to higher biases/densities. While the behaviour in parallel fields is inconsistent with Josephson-like tunneling, it does not rule out the formation of excitonic phases. Two additional peaks appear along with steps in the capacitance as the parallel field is increased. We associate the first peak with the formation of a dilute 2D layer of electrons at the barrier [4], while the second peak marks the accumulation of holes and the creation of an excitonic system. The third peak then indicates the transition to an electron-hole Fermi gas. The parallel field enhances these peaks by opposing charge movement in the growth direction.

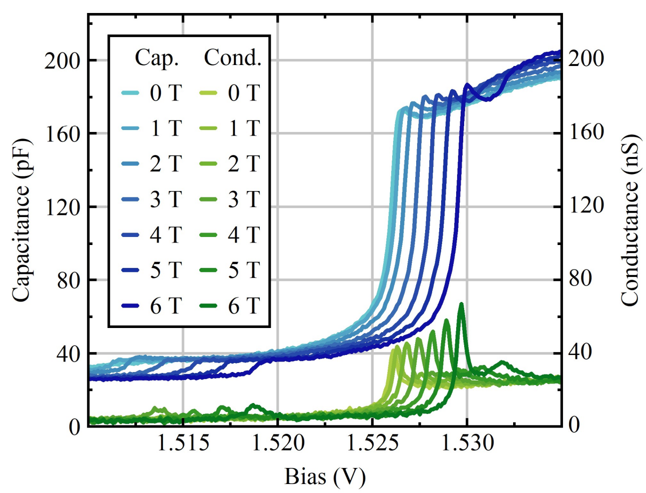

Fig.1. Capacitance and conductance of a 10 nm barrier device with different parallel magnetic fields and at a temperature of around 30 mK.

We also produced devices with several ohmic contacts to each 2D system in order to investigate intralayer characteristics in the excitonic regime. Coulomb drag experiments show exceptionally high drag resistivities at small densities (below $4 \cdot 10^{10}$ cm^{-2}). Interestingly, this resistivity shows a distinct dependency on magnetic field. In parallel fields, the drag resistivity initially increases in magnitude, up to a field of around 1.5 T. Further increasing the field then results in a suppression of the resistivity and a shift of its maximum to higher biases.

To further explore the physics of EHBs in the excitonic regime, new devices are under preparation with even thinner barriers, with the aim of increasing the interlayer interaction strength.

References

[1] M. M. Fogler et al. Nat. Commun. **5**, 4555 (2014).

[2] M. Combescot et al. Rep. Prog. Phys. **80**, 066501 (2017).

[3] M. L. Davis et al. Phys. Rev. Lett. **131**, 156301 (2023).

[4] R. Engel-Herbert et al. J. Appl. Phys. **108**, 124101 (2010).