

Transport experiments on electron-hole bilayers

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The possibility of excitonic phases in semiconductors was first raised in the 1960s[1]. At that time it was thought that since excitons are charge neutral objects, transport based experiments would not be of much relevance for such phases. Certain key experimental advances have radically changed this perspective. The advent of quantum well based structures and the ability to make independent contacts to closely spaced wells with steady state, controlled populations of electrons and holes have made a transport based approach possible. Of fundamental importance to transport based approaches to bilayers is a technique of measuring the interlayer interaction via the “drag voltage” [2].

We have made independently contacted bilayers in which the 2DEG and the 2DHG are separated by an $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ barrier 10-25nm wide, but with extremely low leakage. The 10nm barrier is smaller than the excitonic Bohr radius of GaAs ($a_B \approx 12\text{nm}$) and the densities are sufficiently low such that the interlayer (electron-hole) interaction can dominate over the intralayer (electron-electron or hole-hole) interaction. Measurements of drag voltage over a wide range of densities[3], spanning matched ($n=p$) or unmatched ($n < p$ or $n > p$) regimes show certain features that cannot be explained within the purview of a Fermi liquid picture. At low temperatures ($T < 1\text{K}$), the “drag” voltage measured on the hole layer (with a current flowing in the electron layer) shows an upturn, followed by a downturn and then changes sign. The effect is either absent or present much more weakly for drag measured on the electron layer, even though the system is clearly in the linear response regime. This lack of symmetry is *very surprising* because it appears to contradict Onsager’s reciprocity theorem as applied to four-terminal resistance measurements. The basis of this theorem is thermodynamic and it is not expected to be affected by the internal complexity of a system.

Secondly we find that the proximity of one layer (in 10nm devices) mutually induces an insulating temperature dependence ($d\rho/dT < 0$) in the single-layer resistance of the other layer, in the same temperature range where the anomalous drag is seen. Even when the individual layer mobilities are very high and $k_{Fl} \sim 10 - 100$ in each layer, below $T \approx 1\text{K}$ the layers acquire insulating character. If the first layer is fully depleted the sign of $d\rho/dT$ changes allowing us to unambiguously attribute this effect to interaction and not disorder. In both the experimental results mentioned here, it appears that the point of equal densities ($n=p$) is not special - rather contrary to initial expectations. It is possible that the small, residual anisotropy in the in-plane dispersion $E(k_{||})$ of the holes preventing strong dipolar pairing interaction. In which case it may be necessary to go to quantum well widths significantly less than $\sim 15\text{-}20\text{nm}$, that is used in experiments at present.

References

- [1] J.M. Blatt, K.W. Boer and W. Brandt. *Phys. Rev.* **126**, 1691 (1962). L.V. Keldysh and Y.V. Kopayev, *Sov. Phys. Solid State* **6**, 2219 (1965)
- [2] P.J. Price, *Physica* 117B, 750 (1983), M.B. Pogrebinsky, *Sov. Phys. Semiconductors*, **11**, 372 (1977), T.J. Gramila, J.P. Eisenstein, A.H. MacDonald, L.N. Pfeiffer, and K.W. West, *Phys. Rev. Lett.* **66**, 1216 (1991)
- [3] A.F. Croxall *et al*, arXiv:0807.0134 (2008), J.A. Keogh *et al*, *Appl. Phys. Lett.* **87**, 202104 (2005)

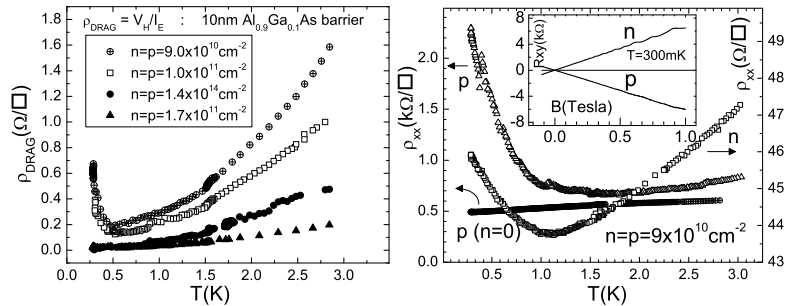


Figure 1: Coulomb drag (left) and single layer resistivities (right) in an electron-hole bilayer with 10nm $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ barrier. The drag voltage, when measured on the electron layer, did not show the upturn. At $T=1\text{K}$, the electron and hole mobilities at $9 \times 10^{10}\text{cm}^{-2}$ were $1.5 \times 10^6\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ and $1 \times 10^5\text{cm}^2\text{V}^{-1}\text{s}^{-1}$