

Coulomb drag in the exciton regime in electron-hole bilayers

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Closely spaced two-dimensional bilayers composed of electrons in one layer and holes in the other layer allow studies of the transition from two Fermi systems to a Bose system when electrons and holes pair to form excitons. One result of exciton formation in these devices is expected to be a Bose-Einstein condensation of the excitons. Our approach to fabricating electron-hole bilayers is to use undoped GaAs/AlGaAs double quantum well heterostructures, and to generate the internal electric fields needed for carriers using gates on the top and bottom of the structure. The electrons in the upper quantum well have self-aligned contacts to the top gate. The holes in the lower quantum well overlap a gate approximately 0.4 micron below the original surface. Processing both sides of the bilayer is accomplished with a flip-chip technique developed at Sandia. With this structure, we can make independent contacts to the electron and hole layers, and densities in each layer can be varied from $4 \times 10^{10} \text{ cm}^{-2}$ to $1.5 \times 10^{11} \text{ cm}^{-2}$. We report Coulomb drag measurements on bilayers with 20 nm and 30 nm $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ barriers. In the drag measurement, current is driven in the electron layer while voltage is measured in the hole layer. For Fermi liquids, Coulomb scattering leads to a T^2 dependence of the drag resistivity at zero magnetic field. We observe quadratic temperature dependence of the drag for the 30 nm barrier. When the barrier is reduced to 20 nm, the high temperature behavior remains quadratic, but below 1K there is a dramatic upturn in the drag resistivity. Increasing drag with decreasing temperature is very unusual, and signals the development of strong coupling between the layers. We compare our results to theoretical predictions of the drag resistivity for an exciton condensate [1,2]. The onset of strong coupling between the electrons and holes for the narrow barrier devices at low temperature suggests the formation of excitons in this system. This work has been supported by the Division of Materials Sciences and Engineering, Office of Basic Energy Sciences, U.S. Department of Energy. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract No. DE-AC04-94AL85000.

[1] Vignale G. & MacDonald, A. H. Drag in paired electron-hole layers. *Phys. Rev. Lett.* **76**, 2786-2789 (1996).

[2] Hu, B. Y. K. Prospecting for the superfluid transition in electron-hole coupled quantum wells using Coulomb drag. *Phys. Rev. Lett.* **85**, 820-823 (2000).