Enhanced Interaction in Closely Spaced Electron-hole Bilayers

by **M. P. Lilly, J. A. Seamons, C. P. Morath, and J. L. Reno**

Motivation—Bilayers of two-dimensional electron systems at zero magnetic field can be well described as individual layers that are weakly coupled. Simply changing the polarity of one of the layers to hole instead of electron leads to completely different physics at low temperature and low density. The ground state electron-hole bilayers (EHBLs) are expected to undergo a transition to strong coupling and ultimately a Bose-Einstein condensation. Our experiments use electrical transport techniques in GaAs heterostructures to explore the strong coupling of EHBLs.

Accomplishment—We have fabricated electron-hole bilayers devices with separate electrical contact to each layer and performed transport measurements that reveal new physics in the strong coupling regime. A cross section of our devices is shown in Fig. 1a. The heterostructure is composed of 18 nm GaAs quantum wells where the 2D layers are formed (white), separated by undoped AlGaAs (gray) layers above, below, and between the quantum wells. The barrier between the wells is small so that the exciton energy is large, but not too small so that recombination rates are small. For the data described here, devices with 20 nm (sample A and B) and 30 nm (sample C) barriers are measured. The electrons and holes are pulled into the quantum wells from the contacts using electric fields generated by top and bottom gates. In addition, a voltage between the layers is required to overcome the GaAs bandgap and create the EHBL. The mobility of the electron and hole layers is shown in Fig. 1b. This demonstrates both the range of density (as low as $3x10^{10}$ cm^{-2}) and high mobility (>10^5 cm^2/Vs) indicating low background disorder for each layer. While device fabrication and operation are quite complicated, these structures achieve our main goals of variable density, high mobility, independent contacts, and narrow barriers.

Our main result is shown in Fig. 2. In an effort to study the coupling *between* the electron and hole layers, we drive a current in the electron layer and measure the voltage that develops in the hole layer. The result of this measurement, called Coulomb drag, is a drag resistivity (ρ_{drag}~V_h/I_e) that depends on scattering mechanisms and interaction between the layers, since no current is actually flowing in the hole layer where the voltage is measured. If the layers are independent, the drag resistivity would be zero. Scattering due to the charge of the carriers leads to weak coupling and a T^2 temperature dependence which can be seen above 0.8 K for the data in Fig. 2a. Strong coupling leads to an increase in the drag signal since electron and hole want to move together. Our drag data for both Samples A and B shows an upturn in the drag at the lowest temperature. The position of the upturn as a function of density is shown in Fig. 2b.

Significance—The increase in drag at low temperature indicates that the interaction between the electron and hole layers gets dramatically strong at low temperature for the narrow barrier devices. Because we do not directly measure coherence, it is difficult to conclusively identify this new regime as exciton condensation, but our results clearly indicate entry into a strong coupling regime, and explanations related to exciton formation, fluctuations above a critical temperature or actual condensation are likely.

Sponsors for various phases of this work include: DOE Office of Basic Energy Sciences and Laboratory Directed Research & Development

Contact: Michael Lilly, CINT Science, Dept. 1132
Phone: (505) 844-4395, Fax: (505) 284-7778, E-mail: mplilly@sandia.gov

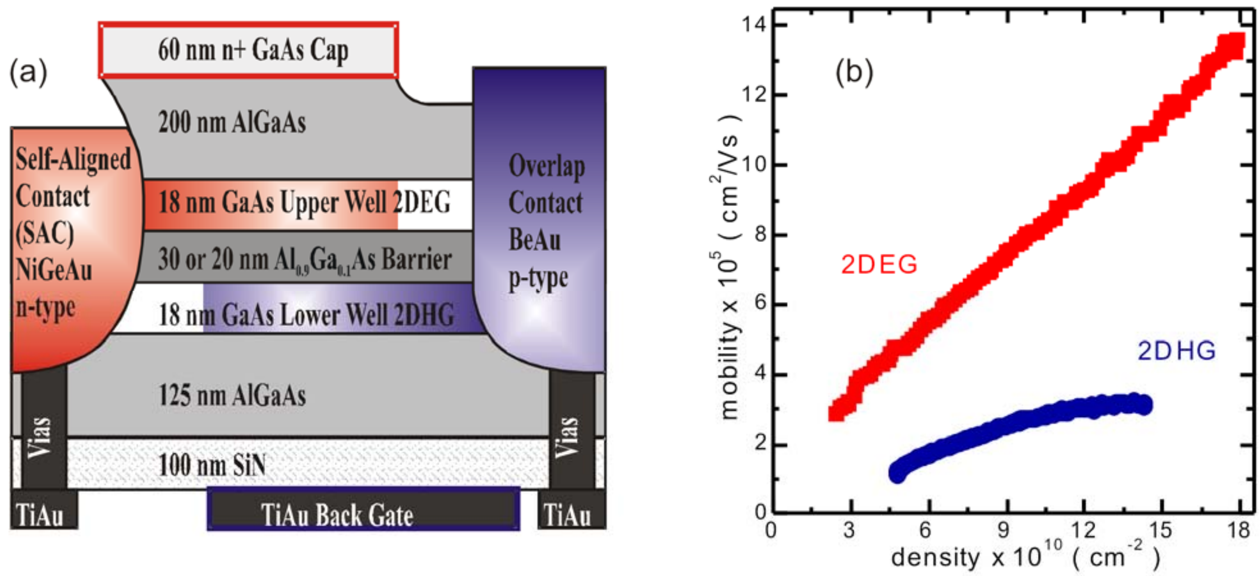

Figure 1. (a) Cross section of electron-hole bilayers device. Operation requires both top and back gate voltages, as well as a voltage between the electron and hole layers. (b) Mobility of electron and hole layers at T=0.3K for sample C. Carrier density in each layer can be independently controlled.

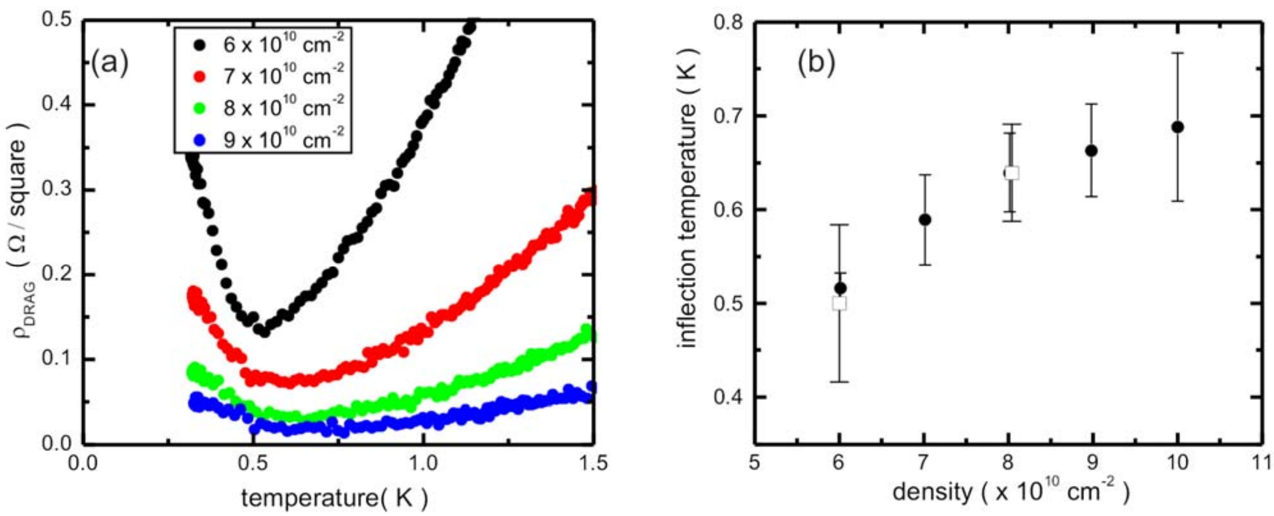

Figure 2. Coulomb drag results on sample A as a function of temperature for several matched densities (n=p) indicated in the legend. The T^2 behavior at high temperature is expected for independent 2D systems. The increase in drag at low temperature arises from strong coupling between the layers at low temperature. (b) The minimum in the drag resistivity for sample A (solid circles) and sample B (open squares) as a function of carrier density maps the transition from independent electrons and holes (upper left) to strongly coupled layers (lower right). The strong coupling region may indicate exciton condensation or it may signal the onset of condensate fluctuations above the critical temperature.