Coulomb Drag of Electron-hole Bilayers in the Exciton Regime

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Motivation—Two-dimensional (2D) bilayers composed of electrons in one layer and holes in the other are expected to exhibit Bose-Einstein condensation (BEC) of excitons at zero magnetic field. Recent progress in quantum Hall [1] and optical [2] systems has demonstrated evidence for exciton condensation using both electrical and optical techniques. One system where exciton condensation is expected is the electrically generated 2D electron and 2D hole bilayer at zero magnetic field. Our experiments examine transport in electron-hole bilayers.

Accomplishment—We have fabricated undoped electron-hole bilayer (uEHBL) 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 the uEHBL is shown in Figure 1a. Three devices from two different GaAs/AlGaAs heterostructures are discussed here: Sample A with a 30 nm barrier (EA1286) and Samples B and C with a 20 nm barrier (EA1287). Electron (n) and hole (p) densities are measured using the Hall resistance and adjusted independently. Here we present results for matched (n=p) density only.

Coulomb drag measurements were taken by sending a current through the electron layer while measuring the voltage induced in the hole layer (Figure 1b). The ratio of the voltage to current scaled for geometry is the drag resistivity, ρ_{DRAG}. For the larger barrier Sample A, the temperature dependence of the drag for three densities is shown in Figure 1c. As expected for Coulomb scattering in Fermi systems, the drag is approximately proportional to T^2 and lower densities result in larger ρ_{DRAG}. The red lines in Fig. 1c are T^2 best fits to ρ_{DRAG} over the range from T = 0.3 K to 10 K. Independent theory calculations [3] find excellent agreement between the data and Boltzmann transport calculations based on realistic device structures.

In Fig. 2b, the drag resistance for all three devices is shown $n = p = 8 \times 10^{10}$ cm^{-2}. The quadratic behavior of the data above 0.5 K indicates the 2D electrons and holes behave as Fermi liquids, but below 0.5 K in Sample B and Sample C a significant deviation develops. At a critical temperature the drag reaches a minimum, and for lower temperatures there is a pronounced *upturn* of the drag where ρ_{DRAG} increases with decreasing temperature. The increase in drag indicates the development of a strong coupling between the electron and hole layers, and may be caused by the formation and/or condensation of excitons in uEHBLs.

Significance—Temperature dependent Coulomb drag measurements are presented as a function of matched densities for electron hole bilayers with two different center to center separations. For the larger barrier, the drag resistance can be well described by interlayer Coulomb scattering between fermions. For the narrow barrier device, we observe an increase in the Coulomb drag as the temperature is lowered. The increased coupling suggests pairing of electrons and holes and formation of excitons in electrically generated electron-hole bilayers.

[1] J. P. Eisenstein and A. H. MacDonald, Nature **432,** 691 (2004).

[2] J. Kasprzak, *et al.*, Nature **443,** 409 (2006); R. Balili, *et al.*, Science **316,** 1007 (2007).

[3] E. H. Hwang and S. Das Sarma, Phys. Rev. B **78**, 075430 (2008).

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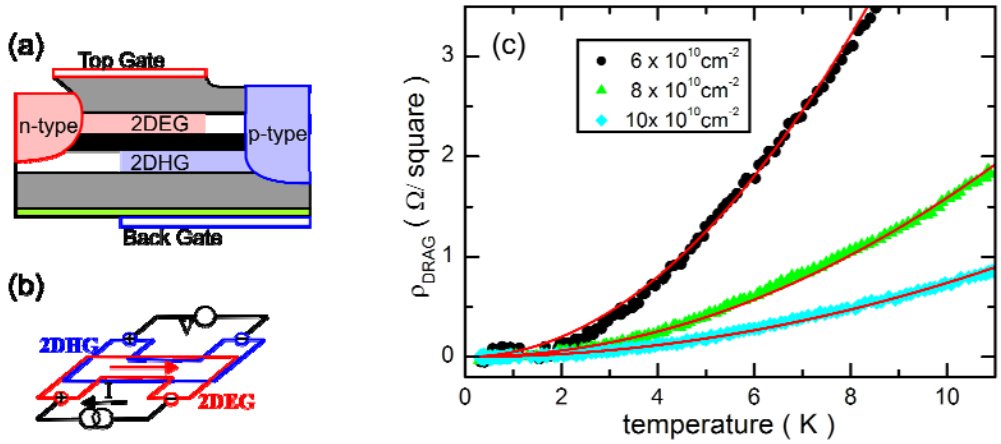

Figure 1. (a) Schematic cross section of the uEHBL sample: the conducting areas of the 2DEG (2DHG) are in red (blue), the $Al_{0.3}Ga_{0.7}As$ ($Al_{0.9}Ga_{0.1}As$) barriers are in grey (black), and an insulating SiN layer is shown in green. (b) Coulomb drag measurement where current flows in electron layer while voltage is measured in the hole layer. (c) Drag resistivity for 30 nm barrier at matched electron and hole densities is typical for Fermi systems. The red lines are T^2 best fits.

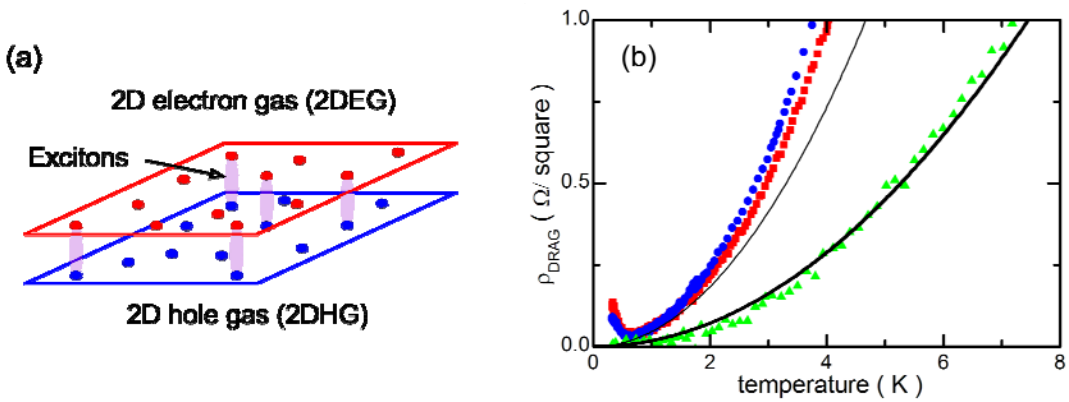

Figure 2. (a) Formation of excitons occurs as electrons and holes pair in opposite layers. (b) ρ_{DRAG} at $n = p = 8 \times 10^{10}$ cm^{-2} for three devices. Sample A, 30 nm barrier, (green triangles), Sample B, 20 nm barrier, (red squares), and Sample C, 20 nm barrier, (blue circles). The thick line is a T^2 best fit for an uEHBL with a 30 nm barrier. The thin line is the expected scaling for reducing the barrier from 30 to 20 nm.