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Investigating the transport properties of the excitonic state in quasi-Corbino electron bilayers

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Abstract

We investigate two closely spaced 2D electron systems in a quasi-Corbino geometry with independent contacts to both layers. Magneto-transport and drag experiments show that at the systems total filling factor 1 the drive current diminishes with increasing interlayer interaction (parameterized by the ratio of layer separation and magnetic length) while voltages of equal magnitude build up over both the drive and the drag layer. The identity of both voltages is resilient to thermal perturbations which contrasts markedly to the behavior observed in Hall bars.

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Keywords: Total filling factor 1; Quasi-Corbino; Drag; Electron-bilayer

1. Introduction

A novel quantum Hall (QH) state can be observed in double two-dimensional electron gas layers under perpendicular magnetic fields where each layer is at half filling. Its origin is ascribed to Coulomb interactions, where the electrons in the two layers form a strongly correlated many-body state to minimize their exchange energy. The bilayer system at total filling factor 1 ($\nu_T = 1$) can be regarded as an excitonic condensate of quasi-particles by coupling electrons to vacant states from opposite layers [1,2]. The ratio of layer separation d and magnetic length l_B ($= \sqrt{\hbar/eB} = 1/\sqrt{2\pi n_T}$, with n_T as the total density) is commonly used to quantify the relative strength of inter- and intralayer Coulomb interactions. Interlayer drag experiments, where a constant current is passed through one of the layers ("drive layer") and the induced longitudinal and transverse voltage drop in the other layer ("drag layer") is measured [3], have revealed a Hall drag which is quantized to h/e^2 at $\nu_T = 1$. This quantization of the Hall drag implies a superfluid mode of excitons [4] if it is viewed as result of an uniform flow of interlayer excitons, or as a counter flow of electrons in the opposite layers.

In this brief report we present data on transport and interlayer drag measurements performed on a quasi-Corbino electron bilayer. A Corbino geometry allows us to drive a current selectively though the bulk, which excludes the influence of (dissipationless) edge channels. In the standard Hall bar geometry the sample edges always connect source and drain contacts, making their role (and possible edge channels at $\nu_T = 1$) difficult to assess. We observe in a Corbino geometry that upon approaching total filling factor 1, voltages of equal sign and magnitude develop across the drive and drag layer, while the current in the drive layer decreases. In striking contrast to previous results from Hall bars, we find that the identity of the drag and drive voltages is maintained up to high temperatures or large d/l_B where the single layer current flow shows nearly no trace of the $\nu_T = 1$ QH effect.

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2. Double quantum well and geometry

The two-dimensional electron bilayer is confined in two 19-nm GaAs quantum wells, separated by a 9.9 nm superlattice barrier composed of alternating layers of AlAs and GaAs. Each quantum well has an intrinsic electron density of about $4.3 \times 10^{14}\,\mathrm{m}^{-2}$ and a low-temperature mobility of 67 (45) $\mathrm{m}^2/\mathrm{V\,s}$ for the upper (lower) quantum well. Our quasi-Corbino geometry with five contact arms attached to each ring is shown in the inset of Fig. 1. Electrical isolation between the two layers is achieved by applying appropriate negative voltages to the buried back gates and metallic front gates crossing the contact arms (selective-depletion technique [5,6]). The densities in each layer can be adjusted independently by using another set of front and back gates covering the entire active region of the Corbino ring. In a four-terminal measurement, one set of contacts can then be used to pass a current and another one to probe the voltage across the ring. For all samples presented here interlayer tunneling is small; the interlayer resistance (at zero magnetic field and 0.25 K) is of the order 10^7–$10^8\,\Omega$.

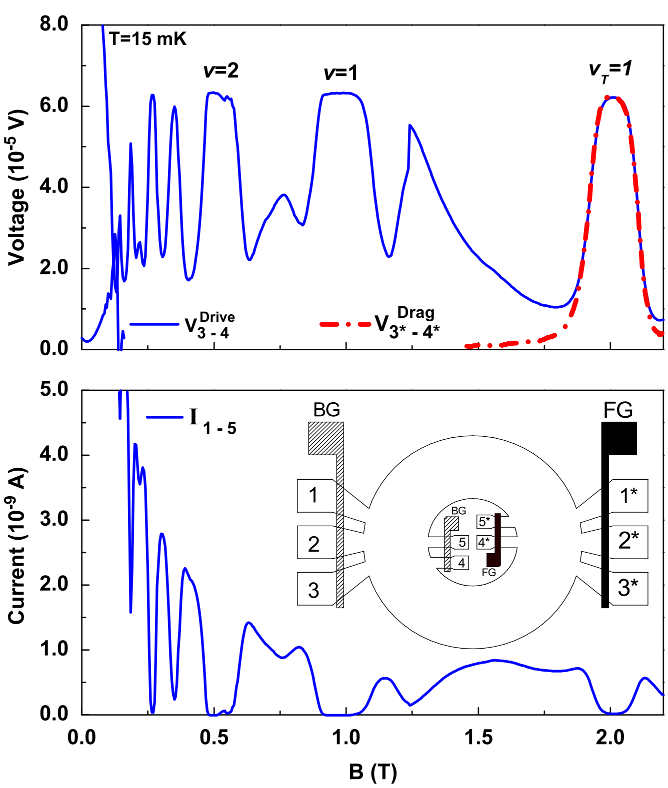

Fig. 1. Top panel: measured drive (solid line) and drag (dash-dot line) voltages at $T_{\mathrm{bath}} = 15\,\mathrm{mK}$. The (integer) filling factors $\nu \leqslant 2$ and $\nu_{\mathrm{T}} = 1$ ($d/l_{\mathrm{B}} = 1.62$) are labeled. Bottom panel: measured current in the drive layer. Inset: schematic view of the Corbino geometry used in this experiment. Application of appropriate voltages to the back gates ("BG") and front gates ("FG") will lead to contact separation.

3. Experiment

Transport measurements were performed by using a standard lock-in technique with the sample mounted at the cold finger of a dilution refrigerator or a ^{3}He system. For all measurements the electron densities in the two layers were adjusted to be equal. A small excitation voltage (60–65 μV, 3–5 Hz) was applied radially across one layer (the drive layer) through an isolation transformer for DC decoupling and the induced current through this layer was measured with a small resistance connected in series. Since the voltage dropping over the drive layer changes in response to the current that oscillates as a function of the magnetic field, the voltage across the drive layer was also monitored using a separate pair of contacts together with the induced voltage in the drag layer. This excludes also the effects of the finite resistances of the ohmic contacts and the contact arms. The measurements were reproducible upon interchanging contacts and upon interchanging drive and drag layer.

Fig. 1 presents data measured on sample B (outer diameter $d_{\mathrm{O}} = 780\,\mu\mathrm{m}$, ring width $w = 230\,\mu\mathrm{m}$) at $T_{\mathrm{bath}} = 15\,\mathrm{mK}$ and a total electron density of $n_{\mathrm{T}} = 4.8 \times 10^{14}\,\mathrm{m}^{-2}$. The bottom and top panels plot the measured current in the drive layer and the corresponding drive and drag voltages as a function of the magnetic field. Below 1.5 T, the current oscillates in a $1/B$-fashion reflecting the different filling factors. At total filling factor 1 which occurs here at 2.0 T, we observe a strong minimum in the current as well. As a result, the voltage drop over the drive layer almost equals the source voltage (top panel). The vanishing conductance at $\nu_{\mathrm{T}} = 1$ we observe is in common with the normal integer QH states at lower magnetic fields, where the Corbino ring is in an incompressible state. However, only over the region of the correlated $\nu_{\mathrm{T}} = 1$ phase, a large drag voltage develops which is identical in sign and magnitude to the one across the drive layer. In previous drag experiments using Hall bars, identical Hall voltages in the drag and drive layers were considered to be signaling the underlying excitonic superfluidity. In our Corbino geometry the large drag voltage exists in the absence of the external driving current. This suggests that the drive voltage sets up a circling current which by the excitonic coupling produces a current of the same size in the drag layer leading to identical voltages across both layers. Supported is that notion by the fact that the contacts of the drag layer in our geometry are located at opposite sides of the ring.

However, owing to the high impedance of the drive layer at total filling factor 1 the occurrence of the drag voltages could equivalently be explained in terms of tunneling between the edges of drive and drag layer. Earlier reports have shown that at $\nu_{\mathrm{T}} = 1$ the tunneling is resonantly enhanced [7]. Our interlayer tunneling experiments also indicate that at total filling factor 1 the interlayer resistance and the drive layer resistance are comparable and of the order of several MΩ. Interestingly, at elevated