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5/2 fractional quantum Hall state in etch defined quantum point contacts.

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A two-dimensional electron system subject to high magnetic fields and lower temperatures exhibit exotic states of matter, for example, the fractional quantum Hall (FQH) effect, owing to electron-electron interactions [1,2]. In recent years, the FQHE state at the even denominator filling-fraction 5/2 has triggered a great deal of theoretical and experimental interests [3–7], due to its possible application in fault-tolerant topological quantum computation [8–11].

In the past a few years, exciting results have been obtained in examining the quasiparticle properties in the 5/2 state [12,13]. Those results are generally obtained in top-gate defined QPCs whose fabrication involves high-energy e-beam lithography. While finer control of the geometrical size of the devices can be achieved, e-beam lithography tends to degrade the material properties. In this work, we utilize an all-optical lithography process to fabricate our device to preserve the heterostructure quality. In this paper we report formation of 5/2 FQH state in a QPC defined on a high mobility GaAs/AlGaAs two dimensional electron gas. Result on tunneling experiments of quasiparticles in this QPC and the temperature and the bias dependence of tunneling conductance will be presented.

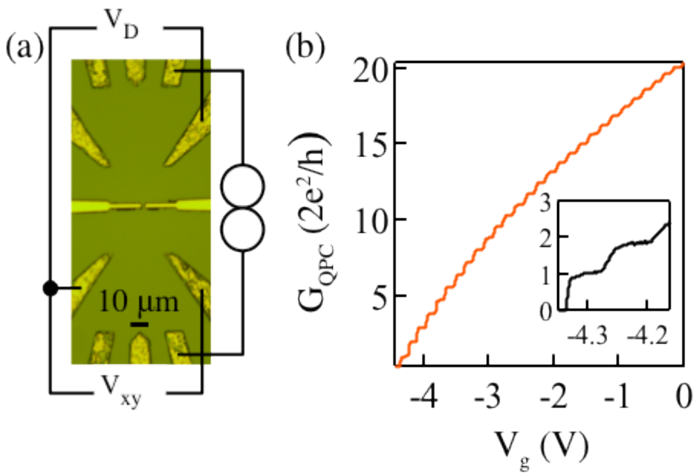

Fig. 1: (a) Optical micrograph of a representative QPC device with a schematic diagram of the measurement setup superposed. (b) G_{QPC} in units of $2e^2/h$ as a function of gate voltage V_g showing well defined quantized conductance plateaus. Inset: enlarged view of the conductance curve in the vicinity of pinch-off.

Our device consists of a QPC formed on a GaAs/AlGaAs heterostructure with a surface carrier concentration $n_s \sim 1.6 \times 10^{11}/cm^2$ and a mobility $\mu \sim 15 \times 10^6\ cm^2/Vs$. Fig. 1 (a) shows an optical micrograph of a representative device. There are five ohmic contacts on either side of the QPC defined by optical lithography followed by Ni/Au/Ge/Ni/Au deposition and high temperature annealing. The QPC gates are defined by optical lithography followed by dry/wet etching and deposition of Cr/Au Schottky gates. The etch defines the constriction without applying any gate voltage. For the width of 1.5 um in our device, the channel width is estimated to be ~ 0.5 µm in the absence of any gate voltage [14].

All the measurements were carried out in the milli-Kelvin temperature range in a dilution refrigerator. Standard four-probe lock-in technique in the AC or AC+DC mode is used for all the measurements. A schematic diagram of the measurement setup is given in Fig. 1 (a). The Hall voltage V_{xy} and the diagonal voltage V_D are measured simultaneously. Fig 1 (b) is a plot of the QPC conductance G_{QPC} as function of gate voltage V_g in the absence of any magnetic field. The inset of Fig. 1 (b) shows an enlarged view of G_{QPC} in the vicinity of the QPC pinch-off. Well formed steps in units of conductance quantum starting from zero gate voltage down to the complete pinch-off of the channel is a signature of a well-defined QPC.

Fig. 2 (a) shows a plot of $R_{D,}$ the diagonal differential resistance across the QPC as a function of magnetic field B normal to the sample showing integer quantum Hall plateaus corresponding to the filling-fractions $\nu = 2$ and $\nu = 3$. The plateau around B = 2.73 T correspond to $\nu = 5/2$ filling-fraction. For a better visibility we take numerical derivative of the data in Fig. 2 (a) and is given in Fig. 2 (b). A well-defined dip at B = 2.73 T corresponds to the formation of 5/2 state.

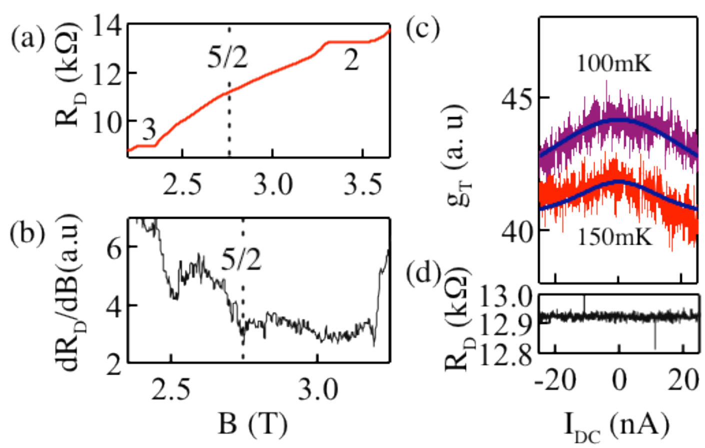

Fig. 2: ν =5/2 FQH state in QPC: (a) R_D vs B field showing the ν =3, 5/2 and 2 plateaus. (b) Numerical derivative of the data shown in (a) vs B field. The dip at B = 2.73 T correspond to 5/2 FQH state. (c) g_T vs DC source drain bias current I_{DC} for 100 mK (violet) and 150 mK (red) sample temperatures. Blue curves represent the global fit to the data using the weak-tunneling formula. (d) R_D vs I_{DC} for B = 3.25T corresponding to the 2^{nd} Landau level.

Weak tunneling between counter-propagating edge-channels in constrictions has been proposed as a tool to study quasiparticles properties [15,16] and, has been experimentally studied in the recent past [13,17]. According to the theory, the tunneling conductance g_T is a strong function of the potential difference between the counter propagating edge-states and also of the temperature and is given by the formula

$$g_T = g_T^0 + AT^{(2g-2)} F\left(\frac{e^* V_D}{k_B T}, g\right).$$

Where, $$F(x,g) = B\left(g + i\frac{x}{2\pi}, g - i\frac{x}{2\pi}\right)\left\{\left\{\pi\cosh\left(\frac{x}{2}\right) - 2\sinh\left(\frac{x}{2}\right)\mathrm{Im}\left[\Psi\left(g + i\frac{x}{2\pi}\right)\right]\right]\right\}.$$

A is the amplitude, V_D is the potential difference between the counter propagating edge states, T is the temperature, Ψ is the digamma function and, B is the beta function.

Next, we discuss quasiparticle tunneling experiments in the QPC at $\nu = 5/2$ filling-fraction. In these experiments both the Hall resistance R_{xy} and the diagonal resistance R_D across the QPC are measured simultaneously as shown in Fig. 1 (a). The tunnel conductance $g_T = R_D - R_{xy}/R_{xy}^2$ reflects the contribution to the total conductance due to the quasiparticles tunneling between the edge channels at the constriction. Fig 2. (c) represents g_T as a function of DC source-drain bias current at B = 2.73 T, corresponding to the $\nu = 5/2$ FQH state, at 100 mK (violet) and 150 mK (red) sample temperatures. The peak centered at zero bias is a signature of quasiparticle tunneling. Fig 2. (d) represents a similar measurement of R_D at B = 3.25 T, on the $\nu = 2$ integer quantum Hall plateau. The absence of any peak for $\nu = 2$ and the presence of a zero bias peak at $\nu = 5/2$ implies that the tunneling is due to the quasiparticles [17].

The tunneling I-g_T curves in Fig. 3 (c) are consistent with the expression for weak tunneling of quasiparticles. A global fit to the data using the expression is also given in Fig. 3 (c) [blue curves]. We note that, in order to reduce the fitting ambiguity, in our fits,

e^* is fixed to be $e/4$ and A, g and g_T^0 are kept as free parameters where, e is the electronic charge. From the fits we obtain a Coulomb interaction parameter of g = 0.7 for this sample.

In conclusion we have fabricated QPC devices on a high mobility GaAs/AlGaAs heterostructure. We observe well-defined quantized plateaus in the QPC conductance. We have observed FQH plateau corresponding to the $\nu = 5/2$ filling-fraction and, conducted tunneling experiments enabling us to characterize the quasiparticles properties.

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