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Observation of Two Modes of Edge Magnetoplasmons by Selective Edge Channel Detection

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Abstract. We study the propagation of edge magnetoplasmons by time-resolved current measurements in the quantum Hall regime. Using selective detection of edge states we distinguish two modes of edge excitations propagating with different velocities along the neighboring compressible strips at filling factors close to $\nu = 3$. From the analysis of the propagation velocities of each mode the internal spatial parameters of the edge structure are calculated.

The study of edge magnetoplasmons (EMP's) in a two-dimensional electron system (2DES) has been attracting steady attention for over the last twenty years (for a review, see [1] and references therein). Edge states related EMP phenomena in the quantum Hall regime were studied in experiments on screened 2DES's both in the frequency domain [2] and in the time domain [3]. An inter-edge magnetoplasmon (IEMP) mode [4] represents the excitation of the boundary between two regions with constant but different charge densities. This mode was not identified in any of the experiments with non-classical systems published up to now.

We report here the observation of both EMP and IEMP modes in a degenerate 2DES in the vicinity of the bulk filling factor $\nu = 3$. Using selective detection of edge states we distinguish two wave packets of edge excitations moving with different velocities near the sample boundary (Fig. 1(a)). The faster one propagates along the compressible region formed by two outer compressible strips (CS's) originating from the lowest Landau level. It gives rise to a fundamental EMP mode. The slower wave packet propagates along the inner CS arising from the second Landau level. It represents an IEMP mode.

A schematic view of the experimental setup is shown in Fig. 1(b). An AlGaAs/GaAs heterostructure is patterned into a T-shaped form with a width of 200 μm. The 2DES has a carrier concentration $n_s = 1.8 \times 10^{15}\,\mathrm{m}^{-2}$ and a mobility $\mu = 70\,\mathrm{m}^2$/Vs. A long voltage pulse of 800 ns with ~ 1 ns rise time is applied to the source contact S. With the perpendicular magnetic field pointing into the page it propagates along the upper boundary of the sample to the drain contact D1. A Schottky gate G crosses the entire sample and is situated between S and D1. If the gate G remains unbiased ($V_G = 0$ mV), the local filling factor g under the gate is equal to the bulk value ν and all edge channels (EC's) are transmitted to D1. A negative voltage applied to the gate provides that some fraction of the signal is deflected to the other drain contact D2. Setting $g = 2$ under the gate G we measure the contribution of each Landau level by different drain contacts. The two outer EC's are transmitted to D1 and the innermost EC is deflected to D2. The distances between source S and each of the drain contacts D1 and D2 are equal and amount to $L = 1.56$ mm. In addition, a metallic top gate is deposited on top of the entire sample. The distance d between the top gate and the 2DES is 105 nm. A thin layer of polymethylmethacrylate covering the Schottky gate G isolates the gates from each other in the overlap region. Transmitted pulses are amplified and recorded by a multi-channel digital phosphor oscilloscope (DPO).

The observability of decoupled edge transport depends on the relation between the widths a, l_1, and l_2 of incompressible and compressible strips [see sketch in Fig. 1(a)] and the distance d from the top gate to 2DES. If the condition $d \ll a, l_1, l_2$ is fulfilled, the neighboring CS's

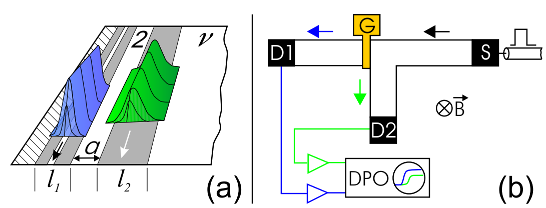

FIGURE 1. (a) Schematic view of two modes of EMP's decoupled by an incompressible strip with filling factor $\nu = 2$. Compressible strips are shown as grey areas, incompressible liquids as white areas, and the hatched region represents a depleted semiconductor at the mesa edge. (b) Sketch of experimental setup. The metallic top gate which covers the whole area of the sample is omitted for clarity.

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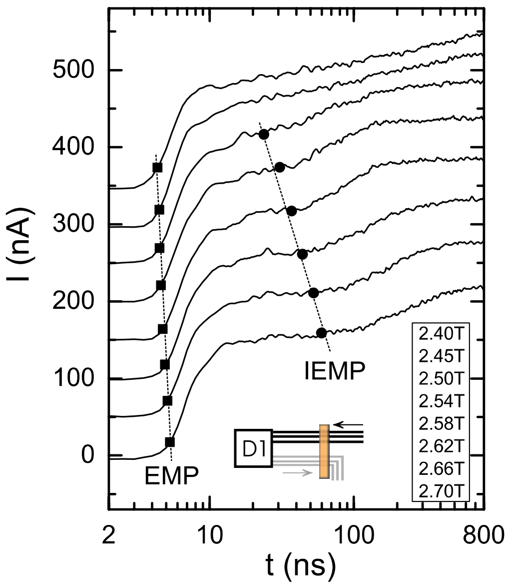

FIGURE 2. Transient currents measured at contact D1 for unbiased gate G ($g=\nu$) for shown values of magnetic field in the filling factor range $\nu = 3.2-2.8$. At $t=0$ s the voltage pulse is applied to the source S. Curves are shifted by 50 nA for clarity. Symbols show the travelling times of each mode. Lines are guides to the eye. The input pulse voltage is $V_{in} = 2.0$ mV.

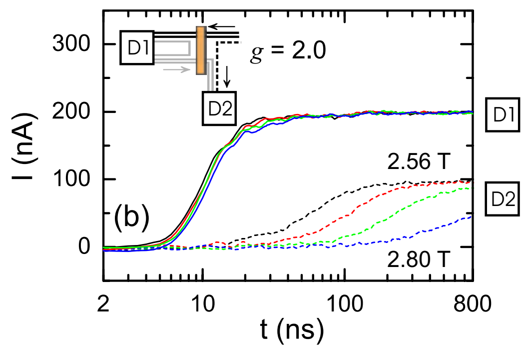

FIGURE 3. Time-dependent current contributions of the outer (D1) and inner (D2) compressible regions attributed to EMP and IEMP modes. Magnetic field is $B = 2.56, 2.64, 2.72$, and 2.80 T ($\nu = 2.99, 2.90, 2.81$, and 2.73) from the upper to the lower curve in each set D1 and D2. $V_{in} = 2.5$ mV.

can be assumed as non-interacting and the electric field within each strip is determined by the gradient of the charge density across this strip [5]. The width of an incompressible strip is substantially smaller than the width of the surrounding compressible ones [6]. From the two incompressible strips at ν close to 3 only the strip with filling factor $\nu = 2$ has a relevant size. It's width a is proportional to the cyclotron gap $\Delta E = \hbar\omega_c$ and is estimated to be broader then 100 nm in our experiment. Thus, it facilitates decoupled transport in two regions l_1 and l_2 attributed to different Landau levels. Figure 2 illustrates a transition from coupled to decoupled edge transport when ν is changing from 3.2 to 2.8. A second slower mode appears distinctly at $B = 2.50$ T and is seen as a second rise in the detected current pulse. This mode propagates along the inner CS and is attributed to an IEMP mode. The two modes have substantially different velocities which are inversely proportional to their travelling times derived from an exponential fit [7] (symbols in Fig. 2). The velocity of the IEMP mode reveals much stronger magnetic field dependence. It changes by a factor of 2.5 in Fig. 2, whereas the velocity of the EMP mode varies only by 20% in the same range of magnetic fields (note the logarithmic scale of t in Fig. 2).

The independent measurement of the EMP and IEMP modes in the decoupled regime is demonstrated in Fig. 3. Each wave packet is represented here by a single rise in the current pulse which is shifted in time with respect to the other one. For a quantitative analysis of the velocities we apply a local capacity approach [5]. There, the group velocity is proportional to $(e^2\Delta\nu/h)(d/l)$ where $\Delta\nu$ is the difference in filling factors of the restricting incompressible regions on both sides of the propagation strip and l is the strip width. For the range of magnetic fields $B = 2.5-2.8$ T we obtain $l_1 = 196-250$ nm and $l_2 = 469-1585$ nm. Here, we used the data from Fig. 3 for the IEMP mode to estimate l_2. Thus, our measurement allows to resolve the internal spatial structure of edge states in the regime where an individual contribution of each EMP mode can be unambiguously identified (for further details see [8]).

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