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Generation and Detection of Edge Magnetoplasmons in a Quantum Hall Edge Channel Using a Photoconductive Switch

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Edge magnetoplasmons (EMPs) are unidirectional charge density waves travelling in an edge channel of two-dimensional electron gas (2DEG) in the quantum Hall regime. We present both generation and detection schemes with a photoconductive switch (PCS) for EMPs. Here, the conductance of the PCS is modulated by irradiating a laser beam modulated at a radio frequency (RF). When the PCS is used as a generator, the RF current from the PCS can be injected into the edge channel to excite EMPs. When the PCS is used as a detector, RF voltage induced by EMPs can be multiplied by the PCS conductance modulated at the reference RF signal to constitute a phase-sensitive measurement. For both experiments, we confirm that the time of flight for the edge channel increases with the magnetic field in agreement with the EMP characteristics. Combination of the two schemes would be useful in investigating EMPs at higher frequencies.

1. Introduction

Injection of a nonequilibrium charge into a quantum Hall system can excite edge magnetoplasmons (EMPs), which propagate along the edge of the two-dimensional electron gas (2DEG) in a direction determined by the orientation of the magnetic field, B. Since the EMPs are fundamental low-energy excitations in QH states, the transport characteristics such as velocity, dispersion relation, and dissipation are important in understanding the nonequilibrium edge states [1-3]. Lots of attentions both in theories and experiments have been paid to study the EMPs. In most of the experiments, EMPs have been investigated by using radio frequency (RF) techniques, for example by applying a short voltage pulse or a sinusoidal voltage to a gate electrode or an ohmic contact of the sample [4]. Alternative generation/detection schemes with a photoconductive switch (PCS) are desirable for studying high-frequency EMPs beyond the RF regime [5,6].

Here we report both generation and detection of EMPs in a 2DEG in a standard AlGaAs/GaAs herterostructure by using a PCS fabricated on a separate semi-insulating GaAs wafer. As prototype experiments, a generation scheme and a detection scheme are separately demonstrated with a single PCS driven by a laser beam.

2. Experimental setup with a PCS

We have fabricated a PCS by patterning interdigitated electrodes with the effective area of about 120 μm^2 on a standard undoped semi-insulating GaAs wafer. Irradiation of a laser beam (λ = 780 nm) on the PCS modulates the conductance G_{PCS}. For a typical bias voltage V_{PCS} = 10 V at 1.5 K, the saturated current through the PCS reaches I_{PCS} = 20 μA under irradiation. In a magnetic field B, the cyclotron motion decreases the photocurrent to about 2.5 % of the original value at 8 T, in agreement with a typical mobility of GaAs. For RF modulation, when the PCS is directly connected to a 50-Ω load, the frequency cutoff of our device was about 1 GHz, which is close to the value determined by the lifetime (~ 1 ns) of photo carriers in undoped GaAs [7].

We used a quantum Hall device with four ohmic contacts, and investigated time of flight of EMPs from one contact to the neighboring contact. The length of the edge channel for the time of flight is about 800 μm. The PCS has been connected to an ohmic contact with a gold bonding wire. Although the parasitic capacitance in this connection restricts the operation frequency, we have successfully demonstrated the generation and detection schemes with the PCS.

3. EMP Generation

Figure 1(a) shows the measurement setup, where the biased PCS under irradiation of a laser beam modulated at frequency f generates RF current at a contact c_1 and excites EMPs in the edge channel. The EMPs propagate along the edge channel and reach the next ohmic contact c_2, which is terminated at 50 Ω for RF. The RF voltage with the amplitude V_{det} and the phase ϕ_{det} is measured with an RF amplifier and a vector network analyzer (VNA). We have also measured dc current I_{dc} between c_1 and c_2 at a small bias (0.5 mV) by using bias tees (not shown in the figure).

Figure 1(b) compares the magnetic field dependence of V_{det} for EMP transport and I_{dc} for dc transport. The two-terminal dc current decreases with increasing $|B|$ in a step-wise manner reflecting the depopulation of Landau levels. Similar step-like structures are also seen in the V_{det} trace, but only in the positive B region where the propagation direction is from c_1 to c_2. In the negative B region, the injected EMPs are effectively grounded at other ohmic contacts c_3 and c_4 through a parasitic capacitance, and thus V_{det} becomes very small. The remaining signal could be induced by the electromagnetic crosstalk. Note that significant reduction of V_{det} (plotted in a log scale) at positive B (> 0) as compared to the I_{dc} trace (in a linear scale) comes from the magnetoconductance of the PCS stated above.

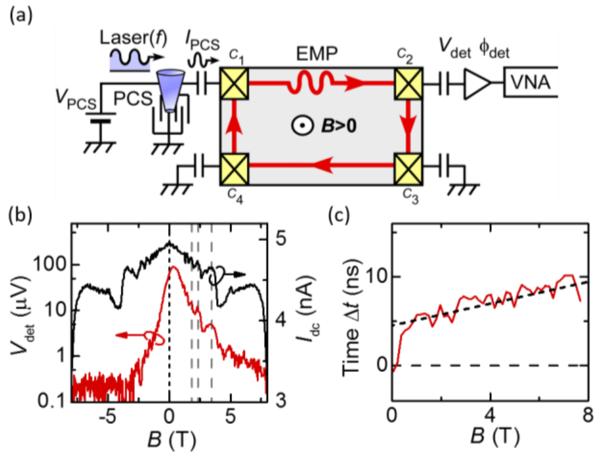

Fig. 1 (a) A schematic experimental setup for generating EMPs. The PCS is made of three metal fingers for each electrode. (b) Magnetic field dependence of V_{det} and two-terminal dc current I_{dc}. (c) The time of flight Δt of the EMPs plotted as a function of magnetic field. The data in (b) and (c) were taken at V_{PCS} = 6 V and T = 1.5 K.

The time of flight Δt for EMPs can be investigated from the relation, $\phi_{det} = 2\pi f \Delta t$, where the reference ($\Delta t = 0$) is taken from the data at $B = 0$. Neglecting the low field data where the edge channel is ill defined, Δt increases linearly with B as shown in Fig. 1(c). This is consistent with the EMP velocity $v_{EMP} \propto 1/B$. This result manifests the excitation of EMPs with this scheme.

4. EMP Detection

The EMP detection was performed on the same device at negative magnetic field. As shown in Fig. 2(a), where the layout has been rotated for the signal flow from the left to the right, EMPs were excited by applying an RF square wave $V_{ex}(t)$ to c_2, and the EMP signal $V_{det}(t)$ at c_1 is detected with the PCS. The PCS conductance, $G_{PCS}(t)$, is modulated by the laser beam with the same waveform as the excitation, but a tunable delay time, t_d, is introduced as depicted in Fig. 2(b). This produces a net dc current $I_{det} = \int G_{PCS}(t) V_{det}(t) dt$, averaged over the period of the square wave. As illustrated in Fig. 2(c), a saw-tooth signal $I_{det}(t_d)$ is expected for square waves $G_{PCS}(t)$ and $V_{det}(t)$ with a phase shift ϕ_{det}. This provides a phase sensitive measurement of EMPs.

Actually, I_{det} is superimposed on a large driving current through the PCS with the bias V_{PCS} = 6 V and V'_{PCS} = −1.5 V. Therefore, we used a lock-in amplifier to retrieve I_{det} by switching $V_{ex}(t)$ on and off at a low frequency (141 Hz). We have successfully observed that I_{det} oscillates as a function of delay time t_d as shown in Fig. 2(d), from which we can evaluate the amplitude A_{det} and the phase ϕ_{det} of the signal. The time of flight Δt for EMPs can also be obtained from the relation, $\phi_{det} = 2\pi f \Delta t$.

The magnetic field dependences of A_{det} and Δt are summarized in Fig. 2(e) and 2(f), respectively. They are consistent with the results in Fig. 2(b) and 2(c). Particularly, the obtained linear B dependence of Δt at higher field ensures that

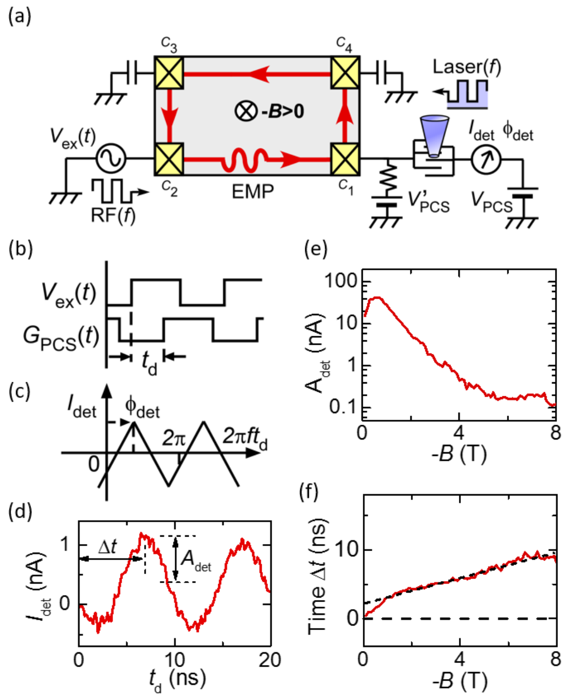

Fig. 2 (a) A schematic setup for detecting EMPs using a PCS. Two bias voltages, V_{PCS} = 6 V and V'_{PCS} = -1.5 V, are used to compensate the unwanted bias at c_1. (b) Square waveforms for $V_{ex}(t)$ and $G_{PCS}(t)$. (c) Expected detector current I_{det} as a function of delay time t_d. (d) Experimental results of $I_{det}(t_d)$ at f = 50 MHz and $-B$ = 4 T. Corresponding A_{det} and Δt are indicated. (e) The extracted amplitude A_{det} and (f) the time-of-flight Δt of EMPs plotted as a function of magnetic field. The data were taken with the amplitude of V_{ex} being 100 mV and at T = 1.5 K.

the signal is attributed to the propagation of EMPs rather than other artifacts like electromagnetic cross talk.

5. Conclusions

In this way, we have demonstrated that the EMPs can be generated and detected with a PCS. The results encourage us to integrate two PCSs and a quantum Hall device on the same substrate so as to investigate EMPs at higher frequencies. The scheme could be exploited further to investigate the novel QH edge states in higher frequency domain and in more integrated devices.

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