Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp780-781

Transmission Characteristics of a Quantum Point Contact for Edge Magnetoplasmons

Kazuhisa Washio[1,*], Masayuki Hashisaka[1,2], Hiroshi Kamata[1,3], Koji Muraki[3], and Toshimasa Fujisawa[1]

[1] Research Center for Low Temperature Physics, Tokyo Institute of Technology,
2-12-1 Ookayama, Meguro, Tokyo 152-8551, Japan
[2] Department of Physics, Tokyo Institute of Technology,
2-12-1-H81 Ookayama, Meguro, Tokyo 152-8551, Japan
[3] NTT Basic Research Laboratories, NTT Corporation,
3-1 Morinosato-Wakamiya, Atsugi, Kanagawa 243-0198, Japan
* E-mail: washio.k.aa@m.titech.ac.jp, Phone: +81-3-5734-2809

1. Introduction

Edge magnetoplasmons (EMPs) in the quantum Hall regime have attracted much attention for their unique properties, such as dissipationless chiral transport [1] and coherent transport [2]. Recently, EMPs are also considered as a source for energy exchange between edge channels associated with different filling factors [3], where Coulomb interaction plays an important role. However, plasmon coupling between edge channels is not well understood both experimentally and theoretically. Here, we investigate transmission characteristics of EMPs at a quantum point contact (QPC) acting as a beam splitter (BS). The transmission amplitude and phase of high-frequency EMPs at f = 0.1 – 1.0 GHz are obtained by using time-resolved detection technique. The gate-voltage dependence of the EMP transmission is similar to the conventional tunneling probability for electrons at low frequencies. However, they disagree with each other at high frequencies. The characteristics can partly be understood by considering capacitive coupling but may involve charge dynamics around a QPC.

2. Experimental setup

The experiments were performed on a device fabricated by standard split-gate technique in an AlGaAs/GaAs heterostructure. All measurements were performed at liquid helium temperature (4.2 K). Magnetic field of 4.5 T, corresponding to the bulk filling factor $\nu_B = 2$, is applied to form well-defined edge channels. EMPs are injected from the source Ohmic contact by applying a sine wave, $V_{inj}(t)$, and propagate along the edge of the device to reach a QPC-BS as shown in Fig. 1(a). The transmission amplitude, denoted as T_{EMP}, can be controlled by the gate voltages, V_{BS1} and V_{BS2}. A fraction of EMPs is transferred to another QPC acting as a detector for EMPs, while reflected EMPs are collected at the ground at the lower-right Ohmic contact. The transmission of the detector QPC is chopped by applying a voltage pulse, $V_{det}(t)$, synchronized with $V_{inj}(t)$ as shown in Fig. 1(b). We measure the average current I at the drain Ohmic contact. The current is measured as a function of the delay time, t_d, of the pulse $V_{det}(t)$ relative to the sine wave $V_{inj}(t)$. The $I(t_d)$ trace provides time-resolved potential induced by EMPs at the detector. Experimental details of time-resolved detection are described in Ref. 4.

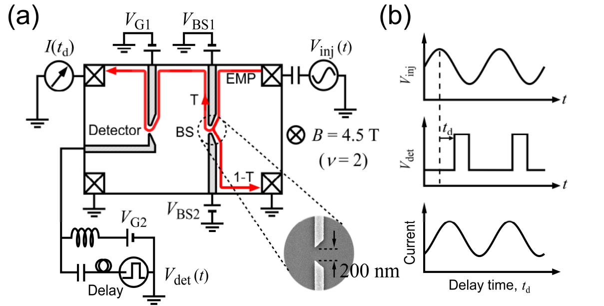

Fig.1 (a) The experimental setup. (b) The applied voltage waveforms, V_{inj} and V_{det}, and expected dc current as a function of t_d.

3. Measurement and analysis

Figure 2(a) shows some $I(t_d)$ traces at f = 1.0 GHz for various gate voltages V_{BS2}. A fixed voltage V_{BS1} = -1.2 V is applied to define the path length (~ 780 μm from the source to the detector). A clear sine wave is obtained at V_{BS2} = 0 V, where T_{EMP} ~ 1 is expected. A peak in $I(t_d)$ appears at around t_d = 0.73 ns, which is corresponds to the average EMP velocity of 1068 km/s at ν = 2. This velocity is consistent with previous experiments for etched edges. As V_{BS2} is made more negative, the amplitude of the $I(t_d)$ oscillations decreases and, at the same time, the peak position shifts to smaller t_d. The most interesting observation here, however, is that the amplitude remains finite even when the transport channel is pinched off (V_{BS2} < -1.1 V). The variations of the amplitude and phase are plotted as a function of V_{BS2} in Figs. 2(b) and 2(c), respectively. The constant amplitude at V_{BS2} ~ 0 V is regarded as full transmission (T_{EMP} = 1) for EMPs. A small phase shift and a plateau in amplitude at V_{BS2} ~ -0.5 V may be associated with the edge channel of the spin-resolved Landau level (ν = 1). The phase shift at the minimum transmission (T_{EMP} ~ 0.1) with respect to the case of full transmission (T_{EMP} = 1) is 110 degree, close to π/2.

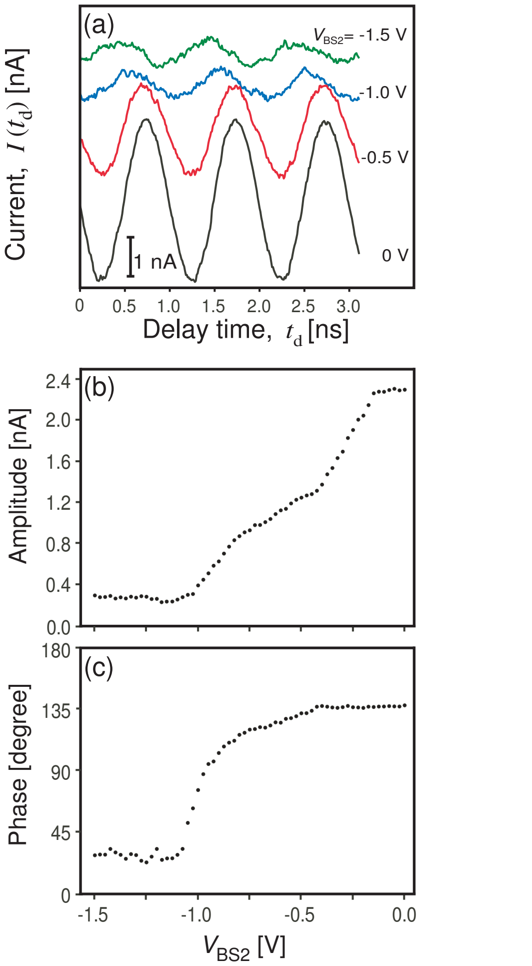

Fig.2 (a) $I(t_d)$ traces at f = 1.0 GHz for various gate voltages V_{BS2}. (b) Amplitude and (c) phase of the oscillations in (a).

These observed data can be understood by considering capacitive coupling between edge channels as illustrated in Fig. 3. The two edge channels (the filling factor ν = 1 for the outer and ν = 2 for the inner edge channel) are fully transmitted at V_{BS2} = 0 V [Fig. 3(a)]. When the QPC is pinched off, a finite capacitive coupling gives finite transmission for EMPs [Fig. 3(c)]. When only one edge channel is fully transmitted, both direct and capacitive coupling coexist [Fig. 3(b)]. In the intermediate regions between them, tunneling processes are involved. The simple capacitance model explains the general feature qualitatively.

Figure 4 shows the V_{BS2} dependence of T_{EMP} at f = 1.0 GHz (solid circles) and 0.1 GHz (open circles) together with the tunneling probability T_{tun} (solid line) obtained from two-terminal dc conductance ($G = 2e^2 T_{tun}/h$). While the low-frequency T_{EMP} at f = 0.1 GHz is very close to the T_{tun} curve, the high-frequency T_{EMP} at f = 1.0 GHz deviates from T_{tun}. The increase at the pinch-off region (V_{BS2} < -1.1 V) is consistent with the capacitance model for electromagnetic coupling. However, the decrease at V_{BS2} ~ -0.6 V cannot be explained by the simple model. Detailed analysis and further experiments for EMPs are required for full understanding of the transmission characteristics.

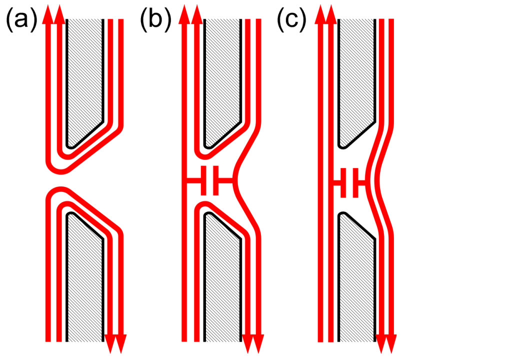

Fig.3 Illustrations of edge channels around the QPC, (a) the two edge channels (ν = 1 and 2) are fully transmitted through the QPC. (b) Only one edge channel (ν = 2) is fully transmitted, where both direct and capacitive coupling coexist. (c) A finite capacitive coupling gives finite transmission for EMPs.

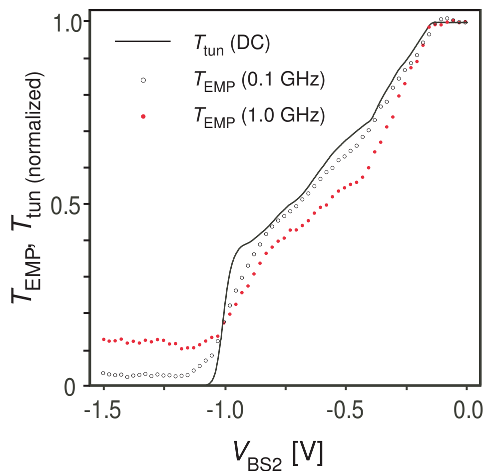

Fig.4 V_{BS2} dependence of T_{EMP} at f = 1.0 GHz (solid circles) and 0.1 GHz (open circles) together with the tunneling probability T_{tun} (solid line) obtained from two-terminal dc conductances.

4. Conclusion

We investigate transmission characteristics of a QPC for high-frequency EMPs, which is different from conventional tunneling characteristics. The EMP transmission amplitude can be controlled by the gate voltage, which can be used as a tunable beam splitter for EMPs.

Acknowledgments

This work was partially supported by a Grant-in-Aid for Scientific Research (21000004, 21810006) from the MEXT of Japan, and the Global Center of Excellence Program from the MEXT of Japan through the "Nanoscience and Quantum Physics" Project of the Tokyo Institute of Technology.

References

[1] R. C. Ashoori *et al.*, Phys. Rev. B **45**, 3894 (1992).
[2] Y. Ji *et al.*, Nature (London) **422**, 415 (2003).
[3] P. Degiovanni *et al.*, Phys. Rev. B **81**, 121302 (R) (2010).
[4] H. Kamata *et al.*, Phys. Rev. B **81**, 085329 (2010).