STEPS Students Report

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During two months I participated in short-term internship of the program STEPS. It was remarkable experience for me and I want to express big appreciation for this opportunity to facilitators and also to all members of my laboratory, especially Katsumoto-sensei and Takase Shimizu.

Further I present the information about research that I have done.

Electrical control of electron spin is a key element for realizing spin-based quantum information processing in solid-state devices. Quantum Hall edge states, which are the one dimensional electron states at quantum Hall regime, is an ideal electron system for this purpose. In these states, backscattering is prohibited due to their chirality. Therefore, electrons travel in these states keeping high coherent. Thus, our purpose was to manipulate electron spins in quantum Hall edge states electrically by using gates.

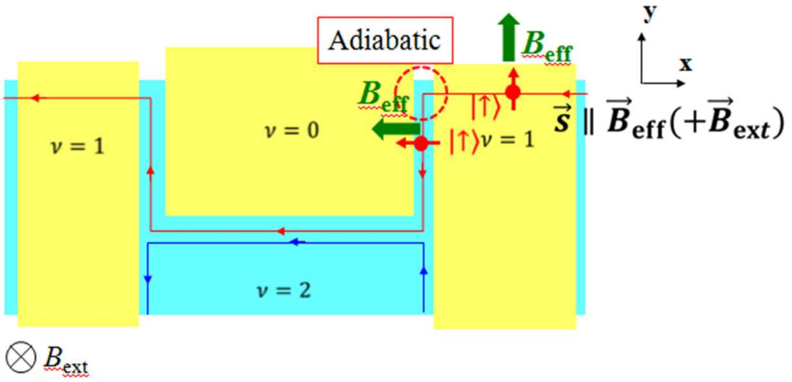


Fig. 1. A schematic image of a device. Initial conditions

The keys are Rashba spin orbit interaction, and adiabatic or non-adiabatic transition at the edge states. On the Fig.1 is depicted a schematic image of our device. When a magnetic field is applied perpendicular to the plane and the filling is 2, and these gates tune the filling below them at 1 and 0, the edge states become like this figure. In this state, when a electron is coming from this side, the electron spin is parallel to the field. The Rashba effective field is now y direction, and the spin is also y direction.

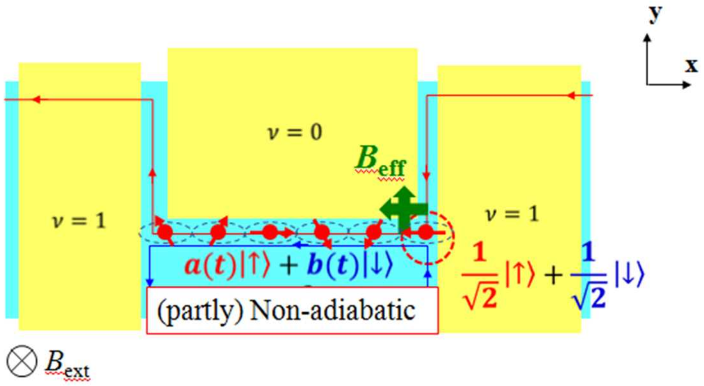


Fig. 2. A schematic image of a device. The electron spin behavior when the electron suddenly changes its momentum.

When the electron get to this edge (see Fig.2), it changes its momentum. At the same time, the effective field direction changes but this change is adiabatic. Then its spin keeps parallel to the effective field. However, at this edge, the electron changes its direction non-adiabatically because there is a down spin edge state. In other words, the electron is always up because the down spin edge state is away from this state.

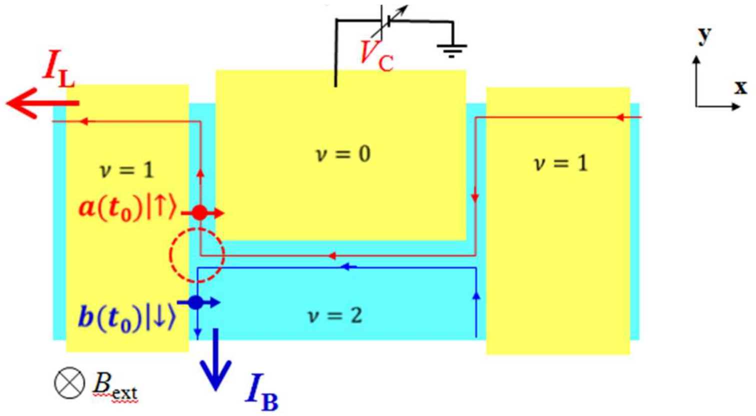
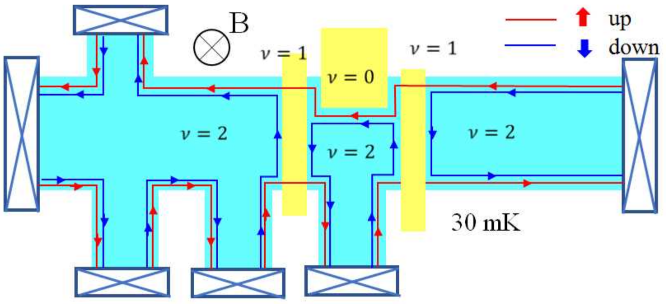
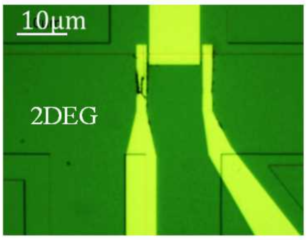


Fig. 3. A schematic image of a device. When edge states are separated.

On the Fig.3 these edge states are separated. Then up spins transmit to the left contact and down spins transmit to the bottom. Then if we tune the Rashba field by gate voltage, we can manipulate the spin precession and we can measure the spin state via current transmitted to the left or bottom contact.

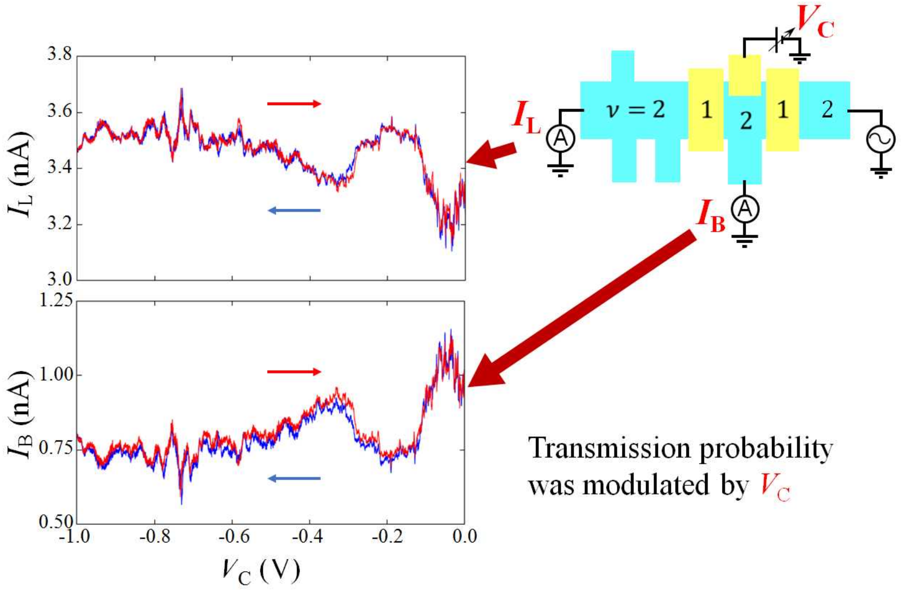




$n = 4.42\times10^{11}\ \mathrm{cm}^{-2}$
$\mu = 9.6\times10^{5}\ \mathrm{cm}^2/\mathrm{VS}$

Fig. 4 The sample configuration and the optical micrograph

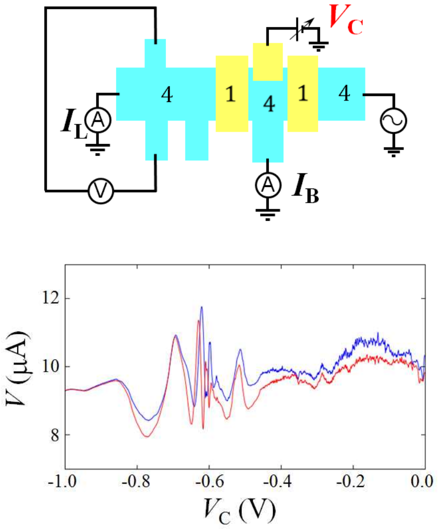
The sample configuration of our device is depicted on the Fig.4. The sample was made by means of electron-beam lithography. The yellow color indicate the titanium/gold top gate and light blue parts are two dimensional electron gas in AlGaAs/GaAs heterostructure as shown here. Also an optical micrograph of the device around gates is shown here.



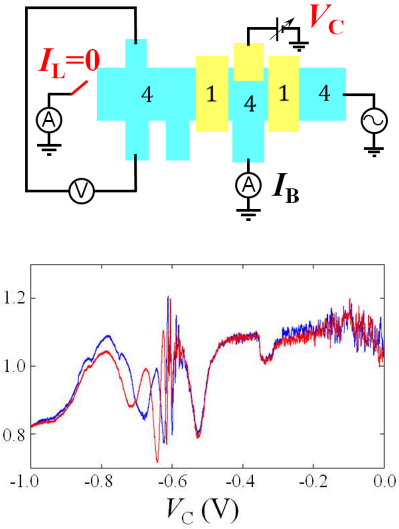
Transmission probability was modulated by V_C

Fig. 5. Currents measurements

For the filling factor=2 AC voltage was applied at around zero bias and measured the current at left and bottom electrodes. The results is depicted on the Fig.5.It is clear that left and bottom current exhibit opposite oscillation. This means that by keeping total current constant and only the tunneling rate were tuned by the center gate. Especially at around -0.7V, there is a periodic oscillation.



Measured voltage is Hall voltage ($V = I_L R_H$)



Non-local voltage (net current is zero)

Fig. 6. Voltages measurements

Finally, voltages was measured (see Fig.6). This is the voltage between these two terminals. This result is very natural in this configuration because this voltage is Hall voltage, namely proportional to the current. Then the same signal as the previous slide. After that, we remove the connection at the left. In this configuration, no current flows to the left then no voltage was expected. However, clear voltage oscillation was observed. This means that the non-local appears in quantum Hall state.

As a result, I got a lot of experience and knowledge, working at the Katsumoto Laboratory. In addition, I received useful skills such as a sample creating by means of a electron-beam lithography, for instance. It was exciting to me to discover as much as possible about Japan. I have visited a lot of places, not only Tokyo but Osaka, Kyoto, Kamakura and I also have seen Fuji mountain very close. Moreover, I met wonderful people who always were very friendly and help me a lot of.