Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp768-769

E-3-2

In-plane magnetic field effect on magnetic focusing in an InGaAs two-dimensional electron gas

Takanori Okayasu, Makoto Kohda and Junsaku Nitta

Graduate School of Engineering, Tohoku University, Sendai 980-8579, Japan

Abstract

We discuss the magnetic focusing in the InGaAs two dimensional electron gas (2DEG) with in-plane magnetic field. By modulating the top gate bias voltage, we can modulate electron carrier density N_s. In this work, we detect the subband energies and their energy shifts when the Fermi energy is occupied in second subband.

1. Introduction

An InGaAs based quantum point contact (QPC) generates a spin polarized current without magnetic fields and magnetic materials [1, 2], which is a promising candidate for future spintronic devices. In order to realize spin functional devices, we need to evaluate the current spin polarization in QPC structures. Magnetic focusing in semiconductor two dimensional electron gas (2DEG) is an attracting method for evaluating the spin polarization in a transport measurement [3]. However, the magnetic focusing of an InGaAs 2DEG is still challenging due to relatively short mean free path in comparison with a GaAs 2DEG system. In this work, we demonstrate the magnetic focusing in an $In_{0.7}Ga_{0.3}As$ / $In_{0.53}Ga_{0.47}As$ 2DEG by using two narrow constrictions (NCs), which contains about twenty channels. By applying a perpendicular magnetic field to the 2DEG plane, electron orbital motion from the emitter NC is modulated due to the Lorentz force and focused to the collector NC, which results in the peak resistance in the collector bias voltage.

2. Experimental results

A wafer consists of an $In_{0.7}Ga_{0.3}As$ / $In_{0.53}Ga_{0.47}As$ structure and was processed into two parallel NCs with a Hall bar structure by electron beam lithography and reactive ion etching as shown in an inset of Fig. 5. Both NCs and the Hall bar were covered with an Al_2O_3 gate insulator (100 nm) and a Cr / Au (40 nm / 80 nm) top gate electrode to modulate the electron mean free path. Magnetotransport measurements were performed at 1.7 K. By applying the positive top gate bias V_{tg}, the induced electrons are occupied not only in the first subband but also in the second subband, which induces the different electron momentum at Fermi energy.

Figure 1 shows the perpendicular magnetic field dependence of the resistance in different V_{tg}. The magnetic focusing is observed as a resistance peak around -0.25 T and -0.45 T at V_{tg} = -2V. By applying a positive V_{tg}, the focusing peaks are shifted to high magnetic field sides. This indicates that the focusing peak is modulated due to the different electron momentums by the change of electron density via the top gate voltage. We plotted the magnetic field at the focusing peak as a function of the carrier density in Fig. 2. By fitting the result with the theoretical peak magnetic field $B_p = (\hbar / e r_c)\sqrt{2\pi N_s}$ induced by the electron cyclotron motion, where B_p is a magnetic field at peak position, $\hbar$ is a Planck's constant, e is an electron charge, r_c is a cyclotron radius, and N_s is the carrier density, we can extract the cyclotron radius of the magnetic focusing. Obtained r_c becomes 0.75 μm, which is consistent to the designed value (0.70 μm) of the spacing between two NCs. As a result, we demonstrated the magnetic focusing in the InGaAs 2DEG and the modulation of focusing peak by the control of electron momentum, $k_F = \sqrt{2\pi N_s}$.

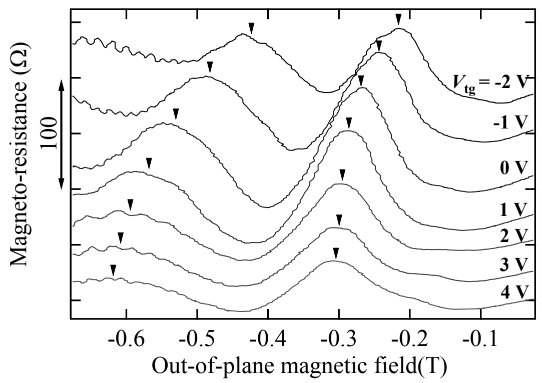

Figure 1: Top gate voltage dependence of focusing peaks.

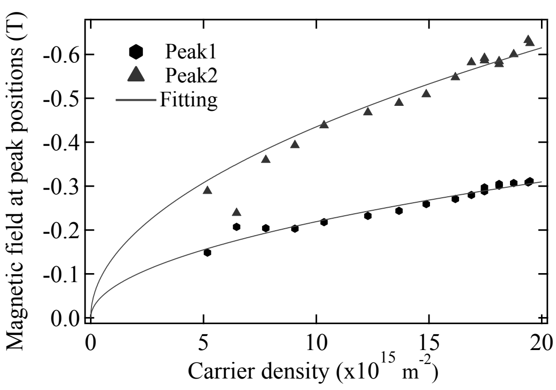

Figure 2: Carrier density dependence of magnetic field of focusing peaks.

By applying in-plane magnetic field, we try to detect difference of electron momentum between spin up and down arising from Zeeman effect. However, splitted focusing peaks were not observed due to NC's many coductance channels and short mean free path of InGaAs. In addition, focusing peak is not affected by in-plane magnetic field at first subband state as shown in Fig. 3. Figure 4 shows the in-plane magnetic field dependence of focusing peak when both first and second subbands are occupied with electrons. Two resistance peaks are observed around − 0.3 T and − 0.2 T, which corresponds to the first subband and second subband momentums. When the in-plane magnetic field is applied, these two peaks are shifted to opposite directions. In order to understand these peaks shift, we consider the diamagnetic effect [4], which increases the subband energy difference ΔE under the in-plane magnetic field and induces a rearrangement carrier density between first and second subbands. The perpendicular magnetic field at the focusing peak of the first subband is shown in Fig. 5 as a function of the in-plane magnetic field. The calculated magnetic field by taking into account the diamagnetic effect is shown as a solid line in Fig. 5, which reproduces the experimental shift. As a result, we can detect the subband energies and their energy shifts by using the transverse magnetic focusing in the InGaAs 2DEG.

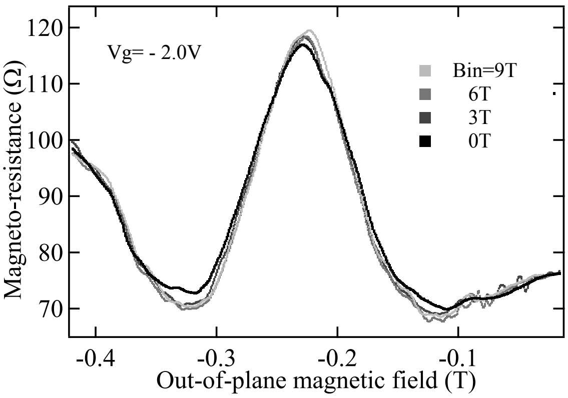

Figure 3: In-plane magnetic field dependence of focusing peaks at first subband.

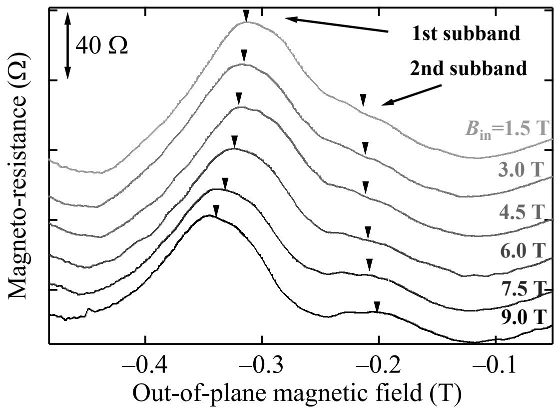

Figure 4: In-plane magnetic field dependence of focusing peaks at first and second subbands.

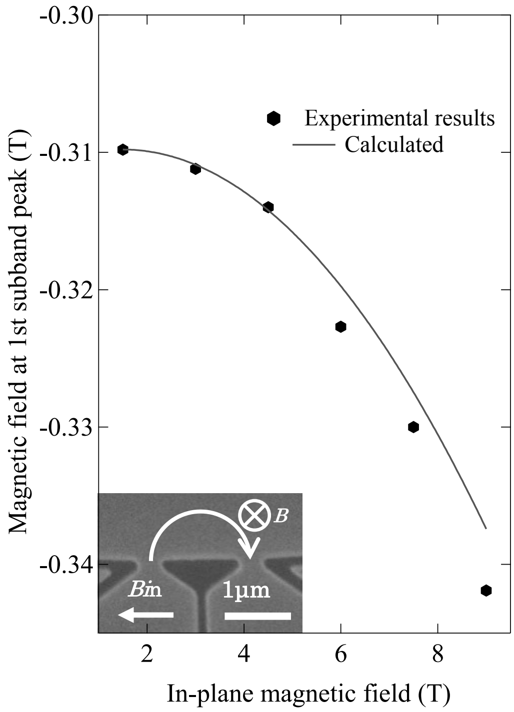

Figure 5: Experimental and calculated results of the peak shift under in plane magnetic feild and an SEM image of the device.

3. Conclusions

We demonstrate the magnetic focusing in the InGaAs 2DEG. Although, spin resolved magnetic focusing peaks were not observed in the present samples, we could expect spin splitted peaks by using NCs with a single channel. Such a magnetic focusing device is the possible candidate for evaluating the spin polarization in InGaAs based QPCs and the great importance for establishing the spin functional devices in the future.

Acknowledgements

This work was supported in part by the Japan Science and Technology Agency (JST), by Grant-in-Aids from Japan Society for the Promotion of Science, by a grant for Advanced Industrial Technology Development from NEDO and by the Mayekawa Foundation.

References

[1] P. Debray *et al.* , Nat. Nanotech. **4**, 759 (2009).
[2] M. Kohda *et al.*, Nat. Commun. **3**, 1082 (2012).
[3] R. M. Potok *et al.*, Phys. Rev. Lett. **89**, 266602 (2002).
[4] W. Beinvogl *et al.*, Phys. Rev. B. **14**, 4274 (1976).