Magnetic focusing affected by an in-plane magnetic field in an InGaAs two-dimensional electron gas

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An InGaAs based quantum point contact 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 apply the spin functional devices, we need to evaluate the spin polarization under the finite bias condition. Magnetic focusing in semiconductor nanostructures is an attracting method because it enables us to evaluate the spin polarization in a transport measurement [3]. However, magnetic focusing of an InGaAs based nanostructure is still challenging due to relatively short mean free path in comparison with a GaAs system. In this work, we demonstrate magnetic focusing in an $In_{0.7}Ga_{0.3}As/In_{0.53}Ga_{0.47}As$ two dimensional electron gas (2DEG) by using two narrow constrictions (NCs), which contain 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.

A wafer consists of an $In_{0.53}Ga_{0.47}As/In_{0.7}Ga_{0.3}As/In_{0.53}Ga_{0.47}As$ structure and was processed into two parallel NCs with Hall bar structure as shown in an inset of Fig. 2. Both NCs and Hall bar were covered with an Al_2O_3 gate insulator (100 nm) and a Cr/Au (20 nm/150 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 the Fermi energy.

The in-plane magnetic field dependence of the focusing peak under $V_{\mathrm{tg}} = 4.0$ V is shown in Fig. 1. Two resistance peaks are observed around -0.3 T and -0.2 T, which corresponds to the first subband and second subband momentum. However, momentum difference between spin up and down was not detected. This is probably due to the many conductance channels in NCs and low electron mobility of InGaAs 2DEG. In addition, when an in-plane magnetic field is applied, two peaks are shifted to opposite directions. The magnetic field at the resistance peak of the first subband is shown in Fig. 2 as a function of in-plane magnetic fields. In order to understand this peak shift, we consider the diamagnetic effect [4], which increases the subband energy difference ΔE under the in-plane magnetic field. The calculated magnetic field is shown as a blue line in Fig. 2, which is similar dependence to the experimental result. As a result, we can detect the subband energies and their energy shifts by using the transverse magnetic focusing in the InGaAs 2DEG.

[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.*, PRL **89**, 266602 (2002). [4] W. Beinvogl *et al.*, PRB **14**, 4274 (1976).

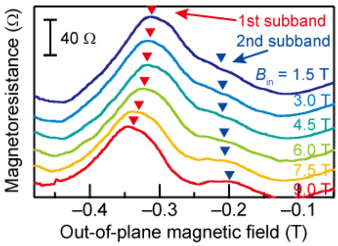

Figure 1: In-plane magnetic field dependence of focusing peaks.

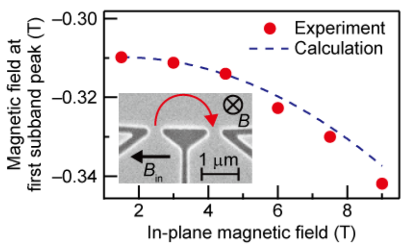

Figure 2: Experimental and calculated results. Inset: SEM image of the device.