Spin manipulation by spin-momentum locking in an InGaAs-based two-dimensional electron gas

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Spin-momentum locking, which constrains spin orientation perpendicular to electron momentum, provides a basic concept to control electron's spin and charge flow in variety of material systems such as topological insulators, semiconductors, and heavy metals. Induced helical spin texture at the Fermi surface allows us to efficiently generate and detect spin polarization without an external magnetic field or magnetic materials [1-4].

While spin generation and spin detection using spin-momentum locking have been intensively explored at Rashba interfaces and topological surface states [1-4], spin manipulation has yet to be demonstrated: it remains the missing ingredient towards full set of spin control by spin-momentum locking. Here, we experimentally manifested spin manipulation by spin-momentum locking in a magnetic focusing device [5]. In a two-dimensional (2D) system with strong spin-orbit (SO) interaction, spin orientation is preferentially directed toward the SO-induced magnetic field and remains focused in this direction due to spin-momentum locking.

We employ an InGaAs/InGaAsP heterostructure which shows strong SO-induced effective magnetic field over 10 T. Such a large SO field generates and detects in-plane spin-polarized electrons by combining with lateral quantum point contacts (QPCs) [6]. As shown in Fig. 1, weak out-of-plane external magnetic field B_{op} focuses ballistic electrons from emitter to collector QPC by Lorentz force. Focusing time from emitter to collector only takes a few psec by moving with Fermi velocity, minimizing influence of spin relaxation [7]. Two QPCs allow us to polarize and detect electron spin along in-plane orientation due to strong SO interaction. Figure 2 shows the focusing signal detected in collector QPC with different conductance in emitter (N_e) and collector (N_c) QPCs with unit of ($2e^2/h$). Enhanced signal is observed around for B_{op} = 0.3 T with (N_e, N_c) = (0.5, 0.5) condition, *i.e.* spin polarized magnetic focusing regime. This indicates that the spin orientation in focused electrons have taken the opposite direction from that of the emitted spins. Electron spin rotates in a circular orbital motion while spin orientation is locked towards the SO field due to the spin-momentum locking.

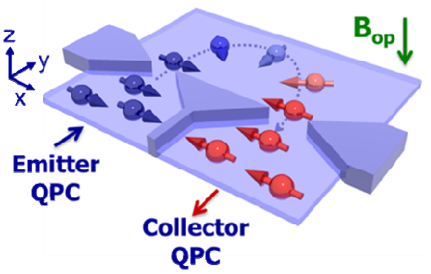

Fig. 1. Spin-momentum locked spin manipulation under transverse magnetic focusing.

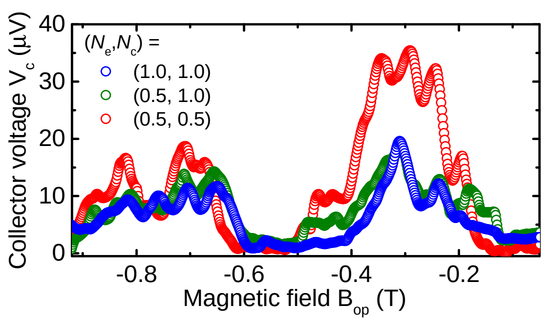

Fig. 2. Focusing signal with different conductance in emitter (N_e) and collector (N_c) QPCs with $2e^2/h$.

Reference: [1] V. Sih *et al.*, Nat. Phys. **1**, 31-35 (2005). [2] J. C. Rojas Sánchez *et al.*, Nat. Commun. **4**, 2944 (2013). [3] C. H. Li *et al.*, Nat. Nanotech. **9**, 218-224 (2014). [4] J. C. Rojas Sánchez *et al.*, Phys. Rev. Lett. **116**, 096602 (2016). [5] M. Kohda *et al.*, Sci. Rep. accepted (2019). [6] M. Kohda *et al.*, Nat. Commun. **3**, 1082 (2012). [7] R. M. Potok *et al.*, Phys. Rev. Lett. **89**, 266602 (2002).