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Electron Spin Depolarization in Non-equilibrium Quantum Wires Accompanied with Dynamic Nuclear Polarization Detected by the Noise Measurement

Kensaku Chida[1], Masayuki Hashisaka[1,†], Yoshiaki Yamauchi[1], Shuji Nakamura[1,‡], Tomonori Arakawa[1], Tomoki Machida[2,3], Kensuke Kobayashi[1] and Teruo Ono[1]

[1] Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan
Phone: +81-774-38-3105 E-mail: chida@scl.kyoto-u.ac.jp
[2] Institute of Industrial Science, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
[3]Institute for Nano Quantum Information Electronics, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan and
[†]Present address: Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[‡]Present address: The National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

1. Introduction

Dynamic nuclear polarization (DNP) is useful method for initializing the nuclear spins before computation [1]. The phenomenon is caused by nuclear-electron spin-flip scattering, or hyperfine-mediated spin transfer from electrons to nuclei. As a result, electron spin depolarization is accompanied by DNP. We performed noise measurement to observe the nuclear-electron spin-flip scattering and derived electron spin depolarization [2].

2. Experimental setup

Figure 1(a) shows the measurement setup with the scanning electron micrograph (SEM) image of our quantum wire (QW) fabricated on the two-dimensional electron gas (2DEG) with electron density of 2.3×10^{11} cm^{-2} and electron mobility of 1.1×10^{6} cm^2/Vs in the AlGaAs/GaAs heterostructure. 4.5 Tesla magnetic field was applied perpendicularly to the 2DEG for making ν = 2 quantum Hall (QH) state. We define the QW by applying negative voltages (V_g and V_{cg}) to the two electrodes on the 2DEG. The conductance of the QW (G) at a finite source-drain bias (V_{sd}) was measured by a standard lock-in technique. The current noise at 2.5 MHz defined by the resonant (inductor-capacitor) circuit was measured through the homemade cryogenic amplifier. The measurement was performed in the dilution refrigerator with base temperature of 20 mK [3].

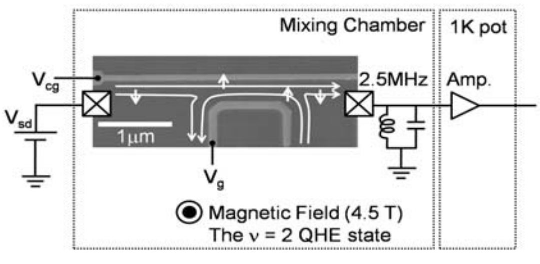

Fig. 1 Schematic diagram of the measurement setup with SEM image of the sample fabricated on the GaAs/AlGaAs 2DEG. At conductance plateau at e^2/h, only the outer edge channel transmits electrons while the inner edge channel is reflected. The two channels are spin polarized as schematically shown by↑and ↓.

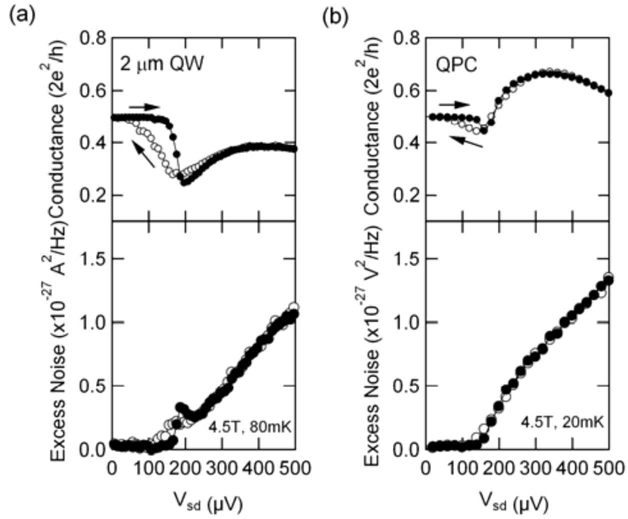

Fig. 2 Typical differential conductance and the excess noise of (a) 2 μm long QW and (b) QPC at the conductance plateau at e^2/h as a function of V_{sd}.

3. Results and discussion

Figure 2(a) shows typical differential conductance and excess noise of 2 μm long QW with conductance of e^2/h (on a conductance plateau) as a function of V_{sd}. With V_{sd} smaller than the zeeman energy (~ 180 μV at 4.5T), the conductance is quantized as e^2/h and excess noise is strongly suppressed because of the dissipation-less edge channel transport of the QH state. With larger V_{sd} than the threshold value, the conductance deviates from e^2/h and finite excess noise is generated. The excess noise is proportional to V_{sd} which is characteristics of the shot noise [4]. We conclude that the excess noise is generated by the nuclear-electron spin-flip scattering by combining experiments with resistive detection nuclear magnetic resonance [2]. An evidence of the scattering is hysteresis of the conductance around V_{sd} ~ 180 μV, which is caused by effective magnetic field created by DNP. We have performed the same experiments for a 1 μm long QW and a quantum point contact (QPC), obtaining similar behavior of the conductance and the excess noise. QPC conductance and excess noise is shown in Fig.2 (b).

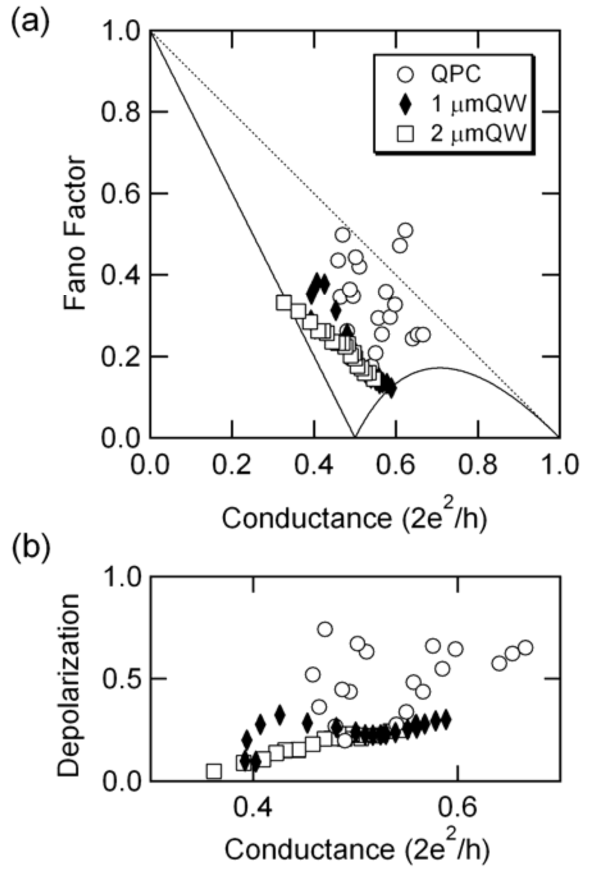

Fig. 3 (a) Fano factor and the non-equilibrium conductance of QW with various length. The dashed curve in the figure is the theoretical Fano factor expected for two spin degenerated channels, and the solid curve is for the fully-polarized case [2, 5]. The grey region in a Fano factor - non-equilibrium conductance plane bounded by the two curves shows the region realizable in the present two-channel model, and the fact that the obtained Fano factor falls in this region indicates the validity of our analysis. (b) Electron depolarization as a function of the non-equilibrium conductance.

Figure 3(a) shows Fano factor as a function of non-equilibrium conductance. Fano factor and non-equilibrium conductance is derived from the conductance and the excess noise in the range of V_{sd} = 250-500 μV. In this V_{sd} range, conductance is agreeably constant and the excess noise is proportional to V_{sd}. Fano factor depends on wire width and length, indicating that the excess noise is originated to inside and vicinity of the QWs. Hence, we treat the excess noise as the shot noise generated by the QW and deduce the spin-polarization (P) from the Fano factor and the non-equilibrium conductance as follows.

When the energy-dependence of the transmission is neglected, the conductance of the QW is represented as $G = e^2/h\ (\tau\uparrow + \tau\downarrow)$. Here, $\tau\uparrow$ ($\tau\downarrow$) is the transmission of the outer (inner) edge channel. In this case, F equals to $((1 - \tau\uparrow)\tau\uparrow + (1 - \tau\downarrow)\tau\downarrow) / (\tau\uparrow + \tau\downarrow)$ [4]. When P is defined by $|\tau\uparrow - \tau\downarrow|/(\tau\uparrow + \tau\downarrow)$, $P = ((1 - F)(2e^2/h) / G - 1)^{1/2}$ holds [2, 5]. For example, the observation of $F = 0$ with $G = e^2/h$ evidence that the electron transport through the QW occurs via the single edge channel with P = 100 %, which realize in the QWs with V_{sd} smaller than the Zeeman energy. This is consistent with the fact that the measurement is done at sufficiently low temperature for the spin-degeneracy of electrons to be lifted-up. In the same way, we can express the non-equilibrium conductance and Fano factor by using $\tau\uparrow$ and $\tau\downarrow$, which are defined at the incident electron energy and the spin polarization deduced from $P = ((1 - F)(2e^2/h) / G_{neq} - 1)^{1/2}$ as shown in the Fig. 3(b), where G_{neq} is the non-equilibrium conductance. While P equals to 100 % with V_{sd} smaller than the Zeeman energy, P is reduced in the non-equilibrium. In other words, the spins in the QWs are depolarized as DNP occurs. Hence, observed excess noise is the shot noise generated by the electron-nuclear spin-flip which accompanies with DNP.

4. Conclusions

We observed the electron-nuclear spin-flip scattering by the shot noise measurement. As a result, nuclear spins are dynamically polarized and electron spins are depolarized. The present result tells that the shot noise measurement is a powerful tool to address the electron dynamics of dynamic nuclear polarization, where both the electron spins and the nuclear spins are essentially relevant.

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References

[1] K. R.Wald *et al.*, Phys. Rev. Lett. 73, 1011 (1994); T. Machida *et al.*, Appl. Phys. Lett. 80, 4178 (2002); G. Yusa *et al.*, Nature (London) 434, 1001 (2005); A. Córcoles *et al.*, Phys. Rev. B 80, 115326 (2009).
[2] K. Chida *et al.*, Phys. Rev. B **85**, 041309(R) (2012).
[3] M. Hashisaka *et al.*, Rev. Sci. Instrum. 80, 096105 (2009).
[4] Y. M. Blanter and M. Büttiker, Phys. Rep. 336, 1 (2000).
[5] L. DiCarlo *et al.*, Phys. Rev. Lett. 97, 036810 (2006).; S. Nakamura *et al.*, Phys. Rev. B 79, 201308(R) (2009).

Appendix

E-mail: chida@scl.kyoto-u.ac.jp
URL: http://www.scl.kyoto-u.ac.jp/~ono/onolab/public_html/indexj.html