Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 888-889

G-8-2

Resistance Oscillations by Electron-Nuclear Spin Coupling in Microscopic Quantum Hall Devices

Go Yusa[1], Katsushi Hashimoto[2], Koji Muraki[1], Tadashi Saku[3], and Yoshiro Hirayama[1,2]

[1] NTT Basic Research Laboratories, NTT Corporation,
3-1 Morinosato- Wakamiya, Atsugi, Kanagawa 243-0198, Japan
Phone: +81-46-3682 E-mail: yusa@nttbrl.jp
[2]SORST Program, Japan Science and Technology Agency (JST),
4-1-8 Honmachi, Kawaguchi, Saitama 331-0012, Japan
[3]NTT Advanced Technology,
3-1 Morinosato- Wakamiya, Atsugi, Kanagawa 243-0198, Japan

1. Introduction

Nuclear spin is considered to have many applications for quantum information processing and computation. In efforts to control nuclear spin flip processes, hyperfine interactions between conduction electrons and nuclei of their host materials have recently attracted much interest. Electron-spin flips between two spin-resolved states have been investigated in several systems, such as spin-polarized and -unpolarized states of domain structures [1] in Ising quantum Hall (QH) ferromagnets. Transport coefficients of such systems shows hysteresis or monotonic development on a large time scale, reflecting the slow nature of spin-lattice relaxation of nuclei.

2. Experiment

We studied point contact structures in order to examine the local coupling between electrons and nuclear spins. They were fabricated from high mobility GaAs wafers, which contain a 20-nm $Al_{0.32}Ga_{0.68}As/GaAs/Al_{0.32}Ga_{0.68}As$ quantum well [2]. The point contact structures are fabricated by electron beam lithography and defined by the width, W, and the length, L=1 μm. Schematic illustration of the devices is shown in the inset to Fig. 1. We prepared several devices with W<5 μm. The gap between two composite fermion (CF) edge channels at ν=2/3 was locally narrowed in a point contact region, but was sufficiently wide for all edge channels to penetrate the point contact region. We measured the time dependence of the four-terminal longitudinal resistance R_{xx} by constant-current or -voltage mode. The time origin, t=0, is defined as the time at which ν is re-set after the randomization procedure for nuclear spin polarization.

Figure 1 shows time dependence of R_{xx} of a point contact device with W=5 μm. We observed that in the vicinity of spin-transition point at ν=2/3, R_{xx} measured by constant-voltage mode oscillated with a period of several hundreds of seconds for more than fifteen hours.

Time dependence of R_{xx}, of the point contact measured as a function of ν at B=7.5 T and T=200 mK. (Fig. 2) The measurement consists of sequences of a randomization procedure for nuclear spin polarization (-120<t<0 s), re-setting of ν (t=0), and measurement of R_{xx}, as a function of time (t>0). Such oscillations take place only in a limited region of ν; R_{xx} oscillates only for the values of ν between ~0.672 and ~0.687.

We performed time-dependent measurement in the presence of continuous-wave radio frequency radiation (RF) as shown in Fig. 3(a). A resistance minimum at 50.866-MHz in Fig. 3(b) corresponds to nuclear magnetic resonances (NMRs) of ^{75}As nuclei at B=7 T.

3. Discussion

R_{xx} oscillates only in the constant-voltage mode; in the constant-current mode [3], it increases monotonically and saturates, which means that randomized nuclear spins at the local minima are gradually polarized, as observed in wide Hall bar samples [1]. Therefore, we suggest that the average of spin angular momentum of nuclei, $\langle I_z \rangle$, parallel to B, oscillates between randomized ($\langle I_z \rangle$=0) and polarized states ($\langle I_z \rangle$>0). Such self-sustaining oscillations reveal nonlinear nature of electron-nuclear spin coupled systems implemented in microscopic FQH devices.

Acknowledgements

We would like to express sincere thanks to T. Inoshita, Y. Tokura, K. Takashina, and N. Kumada for fruitful discussions.

References

[1] S. Kronmuller, *et al.*, Phys. Rev. Lett. **81**, 2526 (1998).
[2] K. Hashimoto *et al.*, Phys. Rev. Lett. **88**, 176601 (2002).
[3] G. Yusa *et al.*, Phys Rev. B **69** 161302 (2004).

Appendix

URL: http://www.brl.ntt.co.jp/people/yusa/

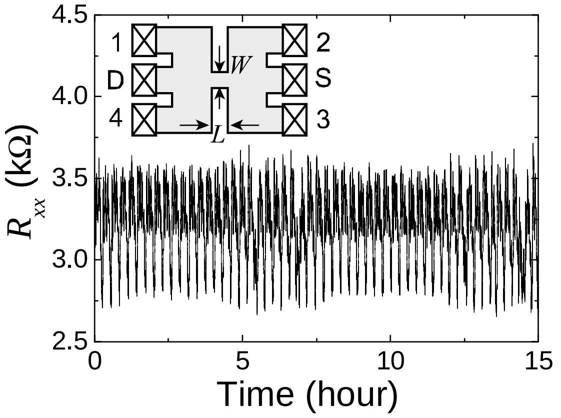

Fig. 1: Time dependence of the longitudinal resistance, R_{xx}, of a point contact device. The measurement was performed at the spin-transition point of ν=2/3 at B=7.5 T, and at T=250 mK. (Inset) Schematic illustration of our device.

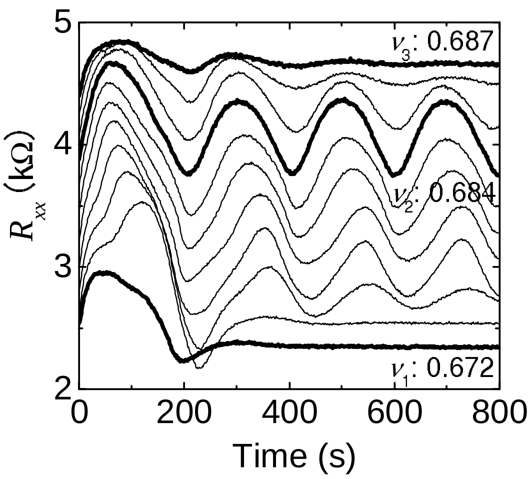

Fig. 2: The resistance oscillations for ν between 0.672 and 0.687 at 7.5 T and at 200 mK. We confirmed that the transition point between the spin-polarized and -unpolarized states was in the vicinity of ν ~0.69 at this magnetic field by obtaining the dependence of R_{xx}, on B and ν

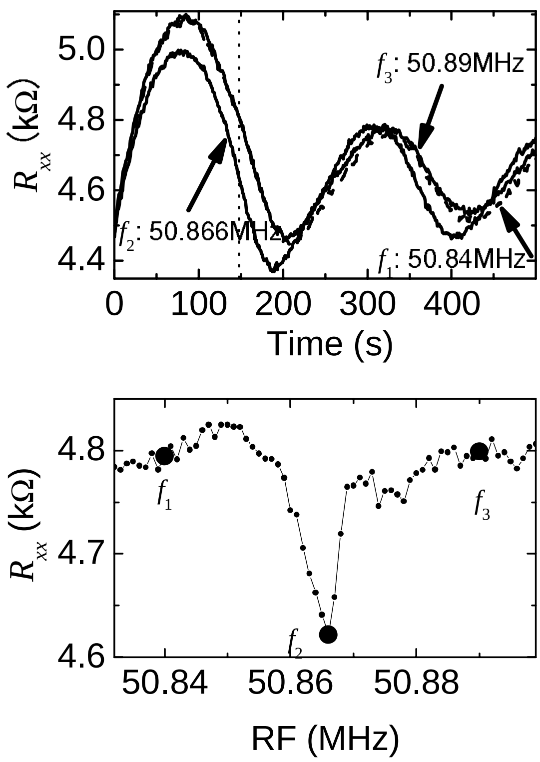

Fig. 3 (a) Time dependence of R_{xx} at 7 T and at 200 mK in the presence of RF radiation off resonance with f_1=50.84 and f_2=50.89 MHz, and at resonance with f_3 =50.866 MHz. (b) f_{RF} , dependence of R_{xx} at t=150 s. Three solid dots correspond to f_1, f_2, and f_3.