20p-C15-3

Bias dependent spin detection sensitivity in spin-Esaki diode structures

Dept. Materials Science, Tohoku Univ.[1], Univ. of Regensburg[2], IMR, Tohoku Univ.[3]

°J. Shiogai[1], M. Ciorga[2], T. Nojima[3], D. Schuh[2], M. Kohda[1], D. Bougeard[2], D. Weiss[2], and J. Nitta[1]

E-mail: j.shiogai@s.tohoku.ac.jp

Spin injection from a ferromagnet into a semiconductor channel is one of the key technologies for realizing novel spintronics devices. After solving the conductance mismatch issue in spin injection experiments by inserting a tunneling barrier between a ferromagnet and a semiconductor [1], a next argument is a role of the localized states within the band gap at the tunneling interface. Recent experiments in Hanle effect using three-terminal geometry, where spin injection and detection are done by a single ferromagnetic contact, have revealed that interface states trap the spin polarized electrons and amplify the electrical signal [2]. Our previous comparison experiments between three-terminal (3T) and four-terminal (4T) Hanle effects using spin-Esaki diode structures pointed out that the 3T Hanle signal is most enhanced when the current-voltage (*IV*) characteristic shows negative differential resistance, that indicates spin signal is enhanced due to the mid-gap localized states. In this study, we demonstrated the spin injection into the bulk conduction band in *n*-GaAs by the non-local geometry and signal amplification using localized states.

A spin injection device is patterned into 50-µm-wide mesa from an epitaxial wafer consisting of semi-insulating (001) GaAs substrate, 300 nm GaAs buffer layer, 500 nm AlGaAs / GaAs superlattice, and 0.8-µm-thick *n*-GaAs with $n = 2.5 \times 10^{16}$ cm^3, followed by 0.2-µm-thick n^+-GaAs, 15 nm GaAs with linearly graded doping $n^+ \rightarrow n^{++}$ with $n^+ = 5.0 \times 10^{16}$ cm^3 and $n^{++} = 6.0 \times 10^{18}$ cm^3, 8 nm n^{++}-GaAs, 2.2 nm AlGaAs diffusion barrier and finally 50 nm (Ga,Mn)As by photolithography and wet chemical etching. The mesa of *n*-GaAs layer, oriented along the [110] GaAs direction, is used as a transport channel. Then, ferromagnetic (Ga,Mn)As / *n*-GaAs spin Esaki contacts along [1-10] are defined by electron beam lithography, Au/Ti evaporation and wet chemical etching. They constitute spin injection and detection contacts. The distance between two ferromagnetic contacts is 5 µm. All measurements are carried out at 4.2 K.

In order to explicitly measure the bias dependent spin detection sensitivity, non-local voltage is measured by ac lock-in technique. The alternating spin injection current modulated at 17Hz is applied from the injector to the ground while non-local voltage is measured between the detector and the reference electrode. At the same time, dc bias V_{dc} is applied to the detector to tune the band structure. Spin detection sensitivity is evaluated by non-local spin-valve effect. Non-local spin-valve signal ΔV is defined as non-local voltage difference between parallel and anti-parallel magnetization configurations. In the standard theory, ΔV_{NL} can be expressed as

$$\Delta V_{NL} = P_{inj} P_{det} I_{inj} \lambda_{sf} \rho_N / S \exp(-L/\lambda_{sf}), \qquad (1)$$

with $P_{inj(det)}$ being spin injection (detection) efficiency, I_{inj} spin injection current, λ_{sf} spin relaxation length, ρ_N and S resistivity and cross-sectional area of the *n*-GaAs channel, respectively. In the present measurement configuration, P_{inj} is fixed at constant value and P_{det} is expected to vary with dc bias V_{dc}.

Figure 1 shows the non-local voltage as a function of the external magnetic field when different dc bias voltage is applied to the detector. As clearly seen, both amplitude and sign of the spin-valve signal ΔV_{NL} strongly depend on V_{dc}. Figure 2 summarizes V_{dc} dependent ΔV_{NL} and the corresponding dc current applied from the detector to the channel. With increasing positive V_{dc}, ΔV_{NL} is most enhanced at V_{dc} = 0.33 V where the negative differential resistance is observed in the *IV* characteristic. On the other hand, with increasing the negative V_{dc}, ΔV_{NL} is suppressed and changes its sign below $V_{dc} = -0.1$ V. The observed bias dependence is very similar to that obtained by 3T Hanle measurements carried out in the same device (to be shown in the talk).

In this talk, we are going to discuss the correlation between the three-terminal Hanle effect and the bias dependent spin detection sensitivity and the origin of the signal amplification in terms of localized states within the forbidden gap.

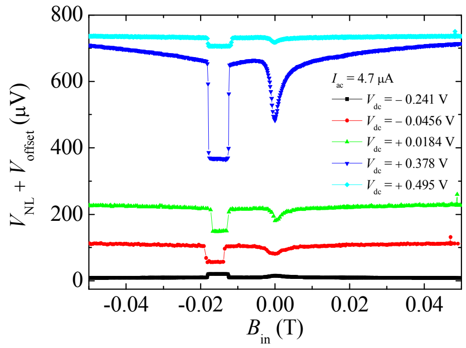

Figure 1 Non-local voltage as a function of in-plane magnetic field B_{in}. An ac exciting current is 4.7 µA and V_{dc} is varied from − 0.241 V to + 0.495 V. Offset is added to the raw data for clarity.

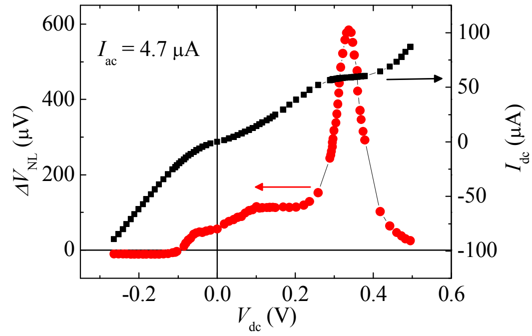

Figure 2 Non-local spin-valve signal ΔV_{NL} as a function of applied dc bias V_{dc} (red filled circles, left axis) and the corresponding dc current (black squares, right axis).

[1]E. Rashba Phys. Rev. B **62**, R16267 (2000). [2]M. Tran *et al.*, Phys. Rev. Lett. **102**, 036601 (2009)