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Three-Terminal Electrical Spin Injection into GaAs from Perpendicularly Magnetized $L1_0$-FePt

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1. Introduction

All electrical spin injection and detection into a semiconductor channel from a ferromagnetic electrode with perpendicular magnetization is one of the important techniques for spintronics devices. For a spin field effect transistor [1] and a spin vertical cavity surface emitting laser [2], a perpendicular magnetized spin injector enables us to operate those potential devices at zero magnetic field. The electrical spin injection from perpendicular spin polarizer has been already investigated by the optical detection [3, 4, 5]. However, its electrical detection is still challenging and is inevitable for the development of future spintronic devices.

We previously reported the preparation of perpendicularly magnetized FePt / MgO / GaAs structure [6]. In this study, we investigated electrical spin injection and detection in a perpendicularly magnetized FePt / MgO / *n*-GaAs structure by three-terminal (3T-) Hanle effect [7].

2. Sample fabrication and measurements

We fabricated a spin injection device from a wafer consisting of 20 nm $L1_0$-FePt / 2 nm MgO / 20 nm n^+-GaAs (n^+ = 2×10^{19} cm^{-3}) / 2 μm *n*-GaAs (n^+ = 3×10^{16} cm^{-3}) / semi-insulating GaAs substrate as shown in Fig.1 (a). The MgO layer acting as a tunnel barrier was deposited at 400ºC by electron beam deposition. The 20 nm $L1_0$-$Fe_{43}Pt_{57}$ layer was grown at 400ºC by magnetron sputtering. Epitaxial growth of the $L1_0$-FePt / MgO / GaAs structure was confirmed by Cu-*Kα* X-ray diffraction. The spin injection device was fabricated using standard photolithography and Ar ion milling. Ferromagnetic (FM) contact B with the area of 80 μm × 80 μm was used for spin injection and detection while an Ohmic contact A and an FM contact C served as reference electrodes. Distances between each contact were sufficiently longer than spin diffusion length in the *n*-GaAs channel.

Figure 1(b) shows magnetic field dependence of Kerr rotational angle measured by polar magneto-optical Kerr configuration at room temperature before the device fabrication process. From the hysteresis loop, the ratio of remanent rotational angle to saturation value was determined to be 0.96. It enables us to inject electron spins polarized perpendicular to the film plane at zero magnetic field.

We used three-terminal Hanle effect (Fig.1 (a)) to probe

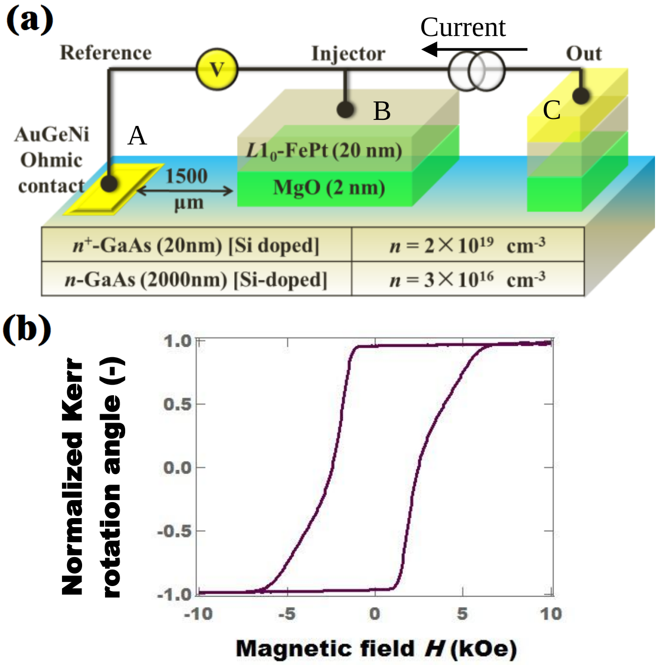

Fig.1 (a) Three-terminal configuration of MR measurement. (b) Polar magneto-optical Kerr measurement of perpendicular magnetization.

spin accumulation at the interface of the GaAs channel beneath the FM contact B where the constant electric current I_{inj} was applied from contact B to C while the voltage was measured between contacts A and B. the negative and positive current directions correspond to the current flows when electron spins are injected into and extracted from *n*-GaAs channel, respectively. At zero magnetic field, electron spins along out-of-plane direction are accumulated in *n*-GaAs. Under the application of in-plane magnetic field, electron spins precess along the field with Lamor frequency ω_L. As a result, the spin accumulation decays as a function of the in-plane magnetic field as follows [8];

$$\Delta V(B) = \frac{\Delta V(0)}{1+(\omega_L\tau_{sf})^2} = \frac{\Delta V(0)}{1+\left(\frac{g\mu_B B\tau_{sf}}{\hbar}\right)^2} \quad (1),$$

where g is the electron g-factor, μ_B is the Bohr magneton, $\hbar$ is Planck's constant divided by 2π and τ_{sf} is the spin flip time which can be determined from full width at half maximum (FWHM). Figure 2(a) shows magnetic field

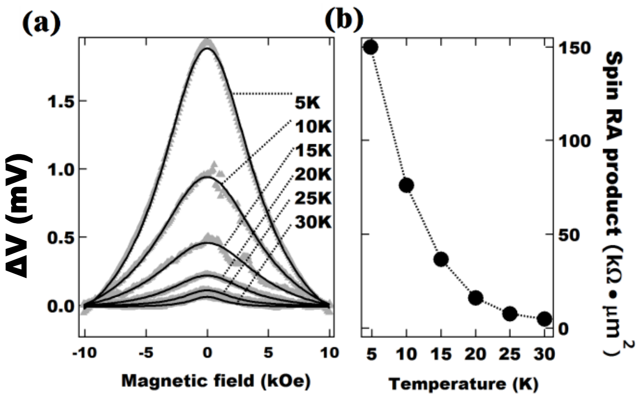

Fig.2 (a) Temperature dependence of Hanle signals under the injection bias = +100 μA and (b) their RA products.

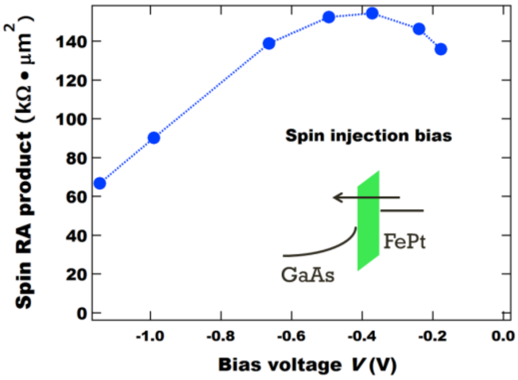

Fig.3 Bias current dependence of spin-RA product of Hanle signals under the spin injection biases at 5.0 K.

dependence of the 3T-voltage at I_{inj} = +100 μA at various temperatures after subtracted background signal. As can be seen, the experimental results were well fitted by Eq. (1). It is known that the product of spin resistance $\Delta V(0) / I$ and FM junction area A (spin-RA product) is proportional to square of the tunnel spin polarization (TSP) [9]. Thus, thermal variation of the signal should be discussed in terms of spin-RA product. As shown in Fig. 2(b) the spin-RA decayed with increasing the temperature, which reflects that spin injection efficiency monotonically decreases with the temperature increase in our device. From FWHM of the Hanle curve, the spin flip time was obtained to be τ_{sf} = 100 ps at T = 5.0 K.

Figure 3 shows spin-RA product measured at 5.0 K with the I_{inj} varying from -700 μA to -10 μA. With increasing bias current, the signal decreased. Such a bias dependence can be explained by the bias voltage dependence of injected spin polarization in the density of state of FePt with a hot-electron like behavior of the injected spins at high bias voltage. The spin flip time decreased with increasing bias voltage.

3. Conclusions

We achieved the electrical spin injection and detection into GaAs from perpendicularly magnetized $L1_0$-FePt using 3T-Hanle effect. It was found that the spin-RA product decreased with increasing temperature and bias current. These experimental results are interpreted by thermal and bias voltage variations of the TSP.

Acknowledgements

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