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Spin Valve Effect in Lateral Py/Au/Py Devices

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Spin dependent transport was investigated in lateral Py($Ni_{81}Fe_{19}$)/Au/Py spin valve devices. Clear spin valve effect was observed in conventional four-terminal measurement geometry. Higher resistance was found in anti-parallel magnetization field of two Py electrodes which is determined by anisotropy magnetoresistance (AMR) measurements. The rectangular shape of spin signal together with good agreement of switching field convinces observed spin valve signal is resulted from effective spin injection and detection. The magnetoresistance ratio decays exponentially with channel length by which spin diffusion length of Au channel was estimated to be 76 nm.

Keywords : local spin valve measurement, magnetoresistance, spin injection

1. Introduction

Spin injection into nonmagnetic material from ferromagnetic material has attracted much attention for spintroincs where electron spin is a subject to manipulate to create functionality of electronic devices. Efficient electrical injection of spin-polarized carriers as well as long spin diffusion length in the device are important factors to realize spin field effect transistor [1]. A lot of works have focused on spin injection into semiconductors [2-4], but the results to date are not quite satisfactory. On the other hand, spin injection into a metal [5-9] as well as semimetal [10, 11] has been actively studied in the nanoscale spin valve devices, and successful spin injections have been demonstrated. The successful spin injection in metallic systems can be attributed to the fact that the interface resistance is under the control of the surface treatment by various types of well-developed etching processes. All-metal spin valve devices become more important because they provide a variety of information on spin injection and transport.

In this work, we present measurement of spin injection and detection in Au channel to study spin transport properties by using conventional four-terminal measurement which is called local spin valve measurement. We fabricated nanometer scaled spin device consisting of ferromagnetic metal (Py, $Ni_{81}Fe_{19}$) and normal metal (Au), and measured anisotropy of Py electrode and spin transport signal. The results show magnetic field-dependent transport properties originated from effective spin injection into Au channel. Spin diffusion length and injection polarization in Au channel were evaluated from spin signal as a function of channel length.

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2. Experimental Procedures

The device was fabricated through multilevel photolithography and electron beam lithography followed by lift-off process. A 60-nm-thick Au film was deposited on an oxidized Si substrate by sputtering to form 200-nm-wide Au conducting channel without Ti adhesive layer. 80-nm-thick Py ($Ni_{81}Fe_{19}$) film was sputtered on predefined Au channel to make spin injector and detector following Au channel was carefully cleaned by rf plasma in the 900-mTorr-oxygen atmosphere. Two Py electrodes (Py1: 3×0.5 μm^2, Py2: 0.2×14 μm^2) being separated by an edge to edge distance ranging from 65 nm to 200 nm (center to center distance corresponds to 395 nm and 550 nm respectively) fabricated on the Au transport channel. Hereafter, the channel length is represented by the center to center distance. The shape anisotropy from different aspect ratio of injector and detector yields a different switching field for each Py, and it allows us to manipulate

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the magnetization of the two Py strips by external magnetic field. The electrical measurements were performed by the standard ac lock-in techniques with an bias current ranging from 100 μA to 1 mA in the magnetic field sweeping from −500Oe ~ +500Oe. The resistivity of Au channel of our devices is 4 $\mu\Omega$cm and the interface resistance multiplied by the interface area between Py and Au films is typically 0.11 $\Omega\mu$mm^2 at T=15 K.

3. Results and Discussion

The scanning electron microscopy (SEM) image in Fig. 1 shows one representative Py/Au/Py spin valve device. The device was designed to make a full set of measurements including the anisotropic magneto-resistance (AMR) of both Py electrodes as well as spin transport effects in the local spin valve (LSV) and the nonlocal spin valve (NLSV) geometries.

Fig. 2 shows the AMR curve of two Py electrodes. Sharp decrease in the resistance was observed in the curve. The resistance dip indicates the magnetization switching of Py electrodes upon sweeping up and down the applied magnetic field parallel to the easy axis of Py electrodes. The switching magnetic fields of Py strips are 60 Oe and 200 Oe for FM1 and FM2 respectively. Antiparallel magnetization of two Py electrodes is expected in the field range which can be manipulated by external in-plane magnetic field.

In addition to the voltage drop induced by the charge current, the chemical potential associated with spin accumulation is detected by the voltage terminals. Since the voltage drop due to the charge current does not depend on the magnetization orientation of the ferromagnetic electrode, the contribution of the charge current to the magnetoresistance (MR) appears as a baseline resistance, which reflects the magneto-transport properties of the Au channel. If the external magnetic field is kept within the range in which the magneto-transport properties of Au channel are not modified significantly. The remaining feature in the MR can be attributed to the spin-associated current injected and detected by the two ferromagnetic electrodes.

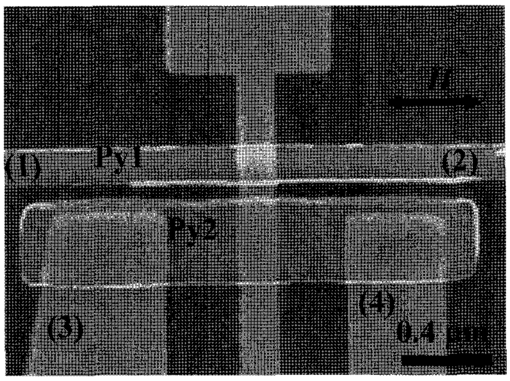

Fig 1. Scanning electron micrograph of a Py/Au/Py spin valve device. FM1 and FM2 separated by center to center distance of 450 nm were patterned on top of Au channel.

The spin valve signal was measured by local spin valve configuration where the voltage between (3) and (4) is measured when the current flows from (1) to (6) in Fig. 1. Although the local spin valve signal may contain other spurious effects such as local Hall effect, AMR of Py electrodes and interface resistance, it is still useful for evaluation of spin dependent transport and for the application of the practical devices. Fig. 3 shows the local spin valve signal of the device with different channel length of 395 nm and 550 nm respectively. When the injected spins were aligned anti-parallel to the detector magnetization, the device was in high resistance state of the local spin valve. The rectangular shape in the spin valve signal

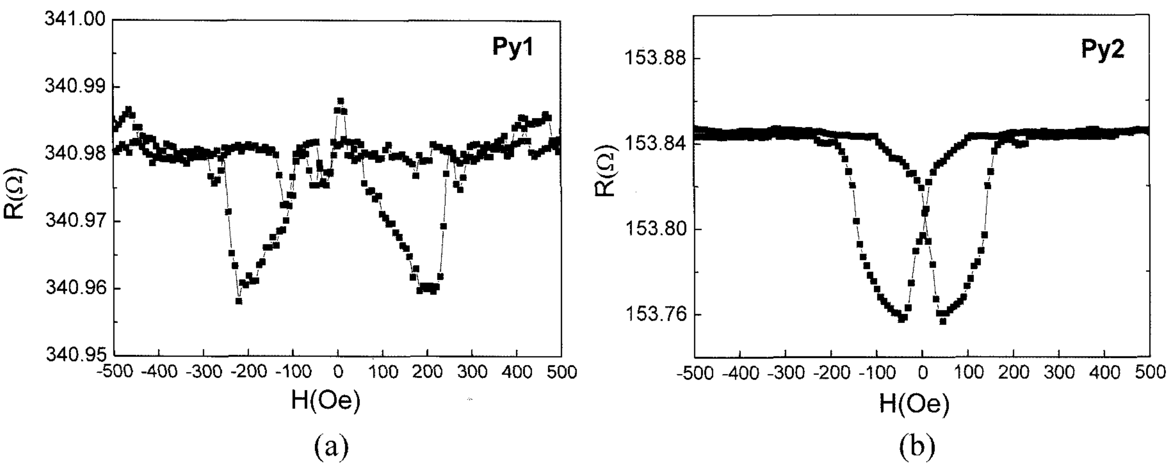

Fig. 2. AMR curve of two Py electrodes indicating different magnetic switching field of each Py owing to shape anisotropy.

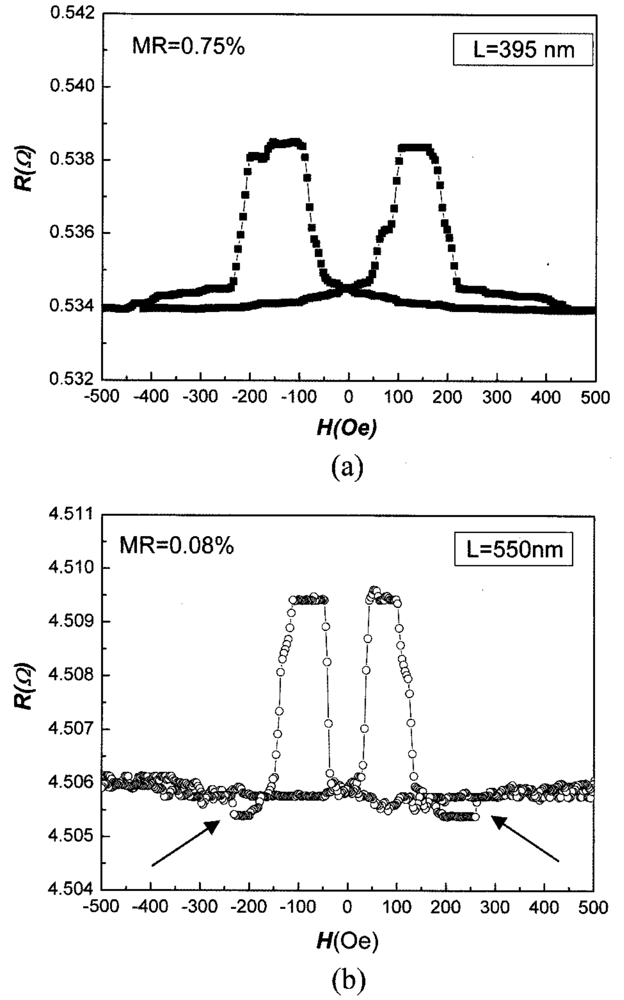

Fig. 3. Spin valve signals of the device with channel length of (a) 395 nm and (b) 550 nm measured at 15 K under bias current of 0.5 mA.

observed at antiparallel magnetization of both Py electrodes clearly implies the accumulation of spins injected from the spin source although it may contain the spurious effect. Small dips in the resistance marked as an arrow in (b) may be affected by AMR of Py1. Switching field of local spin valve signal is quite well matched to that of AMR measurement. The magnitude of spin signal ($\Delta R = R_{high} - R_{base}$) decreases as the channel length increases. Since the baseline resistance fluctuated from sample to sample, it is desired to present MR ratio defined by the equation $MR(\%) = \Delta R/R_{base} \times 100(\%)$. MR ratio is also dependent on the channel length.

The dependence of MR ratio on the center to center separation was plotted in Fig. 4. As the separation gets larger, ΔR decays exponentially in the characteristic length of spin diffusion. Assuming that the spin valve effect in the lateral spin valve is fully determined by spin accumulation, the measured MR can be described with the following equation, [6, 12]

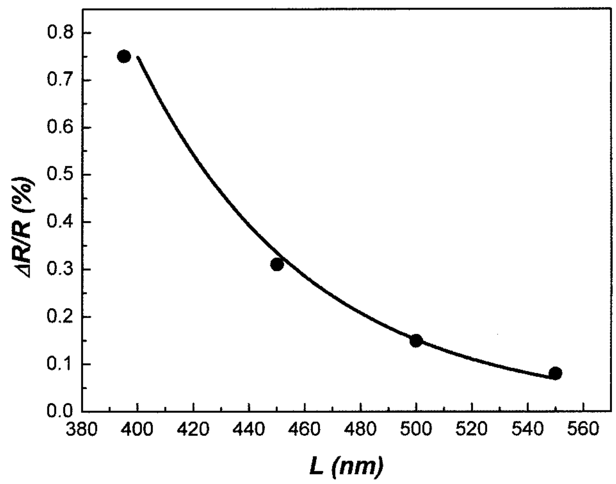

Fig. 4. Dependence of the spin valve signal ($\Delta R/R$) on the center-to-center distance (L) of Py injector and detector at T=15 K. The solid line is a fit of the data to Eq. (1).

$$\frac{\Delta R}{R} = \frac{\eta^2 \lambda_s}{L} \exp(-L/\lambda) \qquad (1)$$

where η is spin polarization of current crossing the Py/Au interface, L is the center to center distance and λ_s is the spin diffusion length of Au. The solid line in Fig. 4 was obtained by fitting the obtained data to Eq. (1). From the fitting result, we calculate the spin diffusion length in the Au film is estimated to be $\lambda_s \approx 76$ nm with an error of ± 10 nm at 15 K.

In local spin valve measurement, the injected spins accumulated in Au channel lead to an additional chemical potential that is detected by the ferromagnetic electrode. As the channel length increases, detection of spin accumulation becomes more difficult because of a lot of scattering events happened when spins spreading out to the detector. For sufficiently large distances between two Py electrodes longer than spin relaxation length, the spin valve signal decays exponentially.

4. Conclusion

In conclusion, we have investigated the spin valve effect in lateral Py/Au/Py devices with different channel length. AMR measurement of Py electrodes gives an antiparallel magnetization switching field of the device. A clear spin accumulation signal was detected by using a conventional four-terminal geometry. The typical MR ratio of lateral Py/Au/Py spin valve device is 0.75% at 15 K for the channel length of 395 nm. The spin diffusion length in the

Au film is estimated to be $\lambda_s \approx 76$ nm with an error of ± 10 nm at 15 K.

Acknowledgements

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