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Spin accumulation in lateral Py/Au/Py spin valves

Janghae Ku[1,2]*, Joonyeon Chang[1], Jonghwa Eom[1,3], Hyun Cheol Koo[1], Sukhee Han[1], and GyuTae Kim[2]
[1]Center for Spintronics Reaserch, Korea Institute of Science and Technology, Seoul 136-791, Korea
[2]Department of Electical Engineering, Korea University, Seoul 136-701, Korea
[3]Department of Physics, Sejong University, Seoul 143-747, Korea

Effective spin injection to nonmagnetic material gives rise to spin accumulation, which is detected nonlocal spin valve (NLSV) measurement [1-4]. The detected signal, for example nonlocal resistance, depends on the magnitude of excitation current, the distance between two ferromagnetic electrodes, the position of voltage probes on the detector, spin transport channel width and thickness. In addition, NLSV signal is largely dependent on the resistivity of NM channel. The resistivity of NM film is subjected to change from sample to sample depending on the deposition conditions so that some fluctuation of the resistivity may lead inconsistent NLSV signal at every samples. Therefore, it is necessary to keep the resistivity as constant as possible. Multi FM electrodes on single channel are preferable in order to minimize the variation of the resistivity. An intervening FM electrode in multi FM devices was reported to significantly suppress the spin accumulation owing to spin current absorption into a connected additional FM [3]. Spin flip resistance in the additional FM is an important measure to judge whether the suppression happens or not. On the other hand, there is a contradictory report that the effect was negligible in the Py/Ag/Py devices [4]. There is still controversy on the effect of intervening FM in spin valve devices. This is an important issue to be addressed for measurement and evaluation of spin transport properties in high accuracy. If injection (detection) occurs homogeneously across the entire width of the sample and the sample film is very thin, then the baseline resistance in the nonlocal measurement is zero. Indeed, all of the fabricated spin valve devices ever reported have shown non-zero base resistance [1-4]. In addition, injected spin current usually produce inhomogeneous spin accumulation which appears to a different magnitude of voltage drop depending on the position of voltage probes on the detector.[5] It is meaningful to investigate the relation between the magnitude of potential drop represented by ΔR and different voltage probe configuration in nonlocal measurement.

In this experiment, we studied on the three issues of spin accumulation in lateral permalloy(Py)/Au/permalloy(Py) spin valves. Three issues are depends on the magnitude of the position of voltage probes on the detector, the spin transport channel width and the effect of an intervening FM. we fabricated Py/Au/Py spin valve devices, where Au

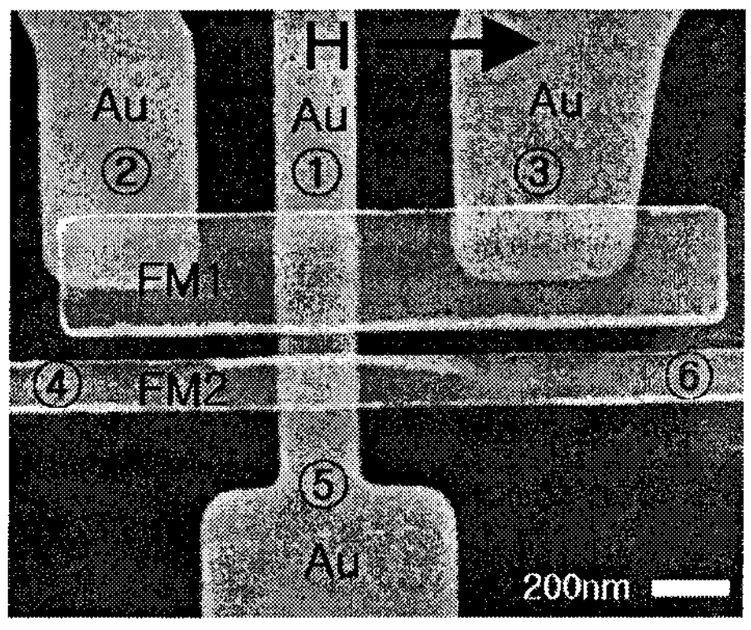

Fig. 1. Scanning electron microscope picture of the lateral Py/Au/Py spin valve devices

bonding pad was first patterned on an oxidized Si substrate by standard photo lithography. 60 nm thick Au film was patterned to define various wide Au channel by electron beam lithography followed by lift off process. 80 nm thick Py ($Ni_{81}Fe_{19}$) electrodes with a different aspect ratio being separated by a center to center distance ranging from 420 to 750 nm are fabricated on a pre-patterned Au channel. Py ($Ni_{81}Fe_{19}$) was deposited in the electron beam evaporating system. Junction area on Au transport channels was carefully cleaned by rf plasma in the 900 m Torr oxygen environment prior to Py deposition in order to have good Ohmic contact. The resistivity of Au channel is 4 uΩcm and the interface resistance multiplied by the interface area is 0.11 Ωum^2 at 15 K. The NLSV measurements were carried out at different voltage probe configurations by the standard ac lock-in techniques at 15 K with an excitation current value of 1 mA in the magnetic field sweeping from -600 to + 600 Oe . The magnetization of the Py film can be oriented either parallel or anti-parallel to the easy axis of Py film by the external magnetic field. Due to the shape anisotropy, two Py electrodes with different aspect ratio show distinct switching field.

In the study, we performed nonlocal measurement with different voltage and current probe configurations on the lateral Py/Au/Py spin valve devices in order to address the cause of non zero base resistance as well as a large difference of non local signal depending on the location of injecting or detecting probes. Since there is no net current between electrodes in the NLSV, the voltage represented by resistance (Δ)is only sensitive to the chemical potential originating from spin accumulation in Au channel. We measured the non local spin valve (NLSV) signals in two different probe configurations. Voltage probe between 4 and 5 is called "A" configuration and contacting 5 and 6 is "B" configuration when the current flows from 1 to 2. For "A" configuration where the current and the voltage probe locates at the same side on the border of Au channel, Δ is 2.6 mΩ while for "B" Δ is 1.9 mΩ. We have done the same measurement for 10 devices with different Au channel gap and width in total and obtained the consistent result that "B" configuration is always lower than "A" in the magnitude of Δdepending on the channel length as well as gap between injector and detector. Spin diffusion length of Au channel with 4 Ωcm resistivity is evaluated to be 170 nm [2]. We believe this is mainly attributed to both factors: first, the point contact forms between the injector and Au channel producing inhomogeneous spin injection, and second, effective spin travel length starting from the point contact affects observed Δ in two measurement configurations of "A" and "B". In the last work, we fabricated Py/Au/Py spin valve devices with multi Py electrodes and measured series of nonlocal signal in various distances of Pys with or without an intervening Py electrode aiming at clarifying the uncertainty. For NLSV measurement, distinguished dips on sweep up and down can be found in every combinations of multi FMs. We have compared data for samples taken with intervening FM and without FM. Samples with four Py electrodes connecting Au channel make possible to measure various distances of injector and detector by using different combination of injector and detector under constant Au resistivity. Our results clearly show that intervening FM electrode dose not suppresses the spin accumulation. Comparison of our results with previous works and the controversy in multi FM devices will be discussed.

In conclusion, inhomogeneous spin accumulation initiating from the point contact between an injector and Au channel induces the different distribution of spin accumulation flowing into a detector. In addition, the typical magnitude of clear spin injection signals is $\Delta R = \Delta V/I = 0.7$ mΩ at 15 K for the electrode center to center distance of 0.7 μm with Au width 0.2 μm. The Au width increases, NLSV signal decreases. The channel width dependence of ΔR is largely attributed to the diffusive transport behavior at the Au channel length longer than spin relaxation length. Also, we conclude that accumulation effect in the Au channel is enhanced reducing cross-section. Since intervening Py electrodes in multi FM devices dose not affect NLSV signal, simultaneous fabrication of multi Py electrodes with different separations on a spin channel is more favorable to evaluate consistent spin accumulation, spin diffusion length and injection polarization by fixing Au channel resistivity.

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