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Enhancement of nonlocal spin-valve signal using spin accumulation in local spin-valve configuration

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We propose a nonlocal spin-valve measurement combined with a local spin-valve structure to enlarge spin signal. The probe configuration consists of a lateral spin valve with three Ni–Fe wires bridged by a Cu wire. The advantage is that the spin polarization in the Cu wire induced by the spin injection can be enhanced compared to the conventional method. © *2004 American Institute of Physics*. [DOI: 10.1063/1.1829772]

The devices utilizing spin information have great advantages over the conventional electronic devices because of additional spin functionalities. Recently, a class of spintronic devices, such as spin battery,[1] spin-torque transistor,[2] etc., have been proposed. Understanding the spin-dependent transport properties is essential to realizing such spintronic devices. Vertical structures are suitable to observe spin-dependent transport phenomena because the actual traveling length for spin is much shorter than the spin-diffusion length. However, recent nanofabrication techniques make it possible to realize laterally nanostructured ferro-/nonmagnetic (F/N) hybrid devices with dimensions in the order of spin-diffusion length enough to keep spin information. Such lateral structures can be applied to develop multiterminal spintronic devices which enable us to perform more detailed studies on spin-dependent transport than vertical structures. However, it has been difficult to detect spin-dependent signals in lateral structures because spurious magnetoresistance tends to smear intrinsic signals of interest. Recently, Jedema *et al.*[3,4] proposed the nonlocal spin-valve (NLSV) measurement technique to extract only spin current from the spin-polarized charge current. They succeeded in detecting the clear spin-accumulation signal even at room temperature using lateral F/N hybrid structures. More recently, we have detected the clear spin-accumulation signal without any spurious magnetoresistance effect not only in the NLSV configuration but also in the local spin-valve (LSV) configuration by reducing the dimension of ferromagnetic wires and the resistance of nonmagnetic layer.[5]

Obtaining large magnetoresistance or spin signal by spin injection is one of the main issues for realizing such spintronic devices. We also found that the obtained spin signal in the local configuration is about twice as large as that in the nonlocal configuration because of the efficient spin accumulation. However, the large background resistance, caused by the ohmic resistance of the Cu wire, exists in the LSV configuration where the induced spin splitting in the antiparallel configuration is larger than that in the parallel configuration, as shown in Fig. 1.[5] To maintain the continuity of the chemical potential in the nonmagnetic layer, the large spin splitting can be induced both in the local nonmagnetic region with the charge current and in the nonlocal region without the charge current. We can thus expect much larger spin signal than a conventional NLSV measurement once the NLSV is combined with the above mentioned local current injection.

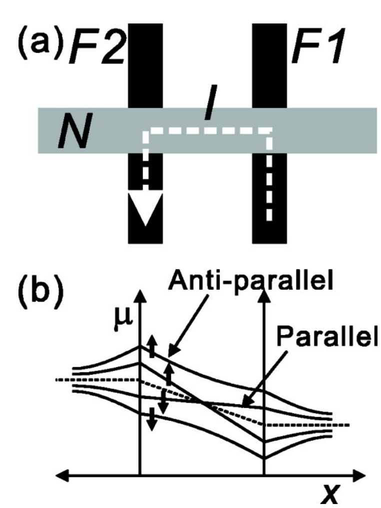

FIG. 1. (a) Schematic illustration of the local spin-valve measurement configuration. (b) Spatial distribution of the spin-dependent chemical potential in the N layer at the parallel and antiparallel state at the local current injection.

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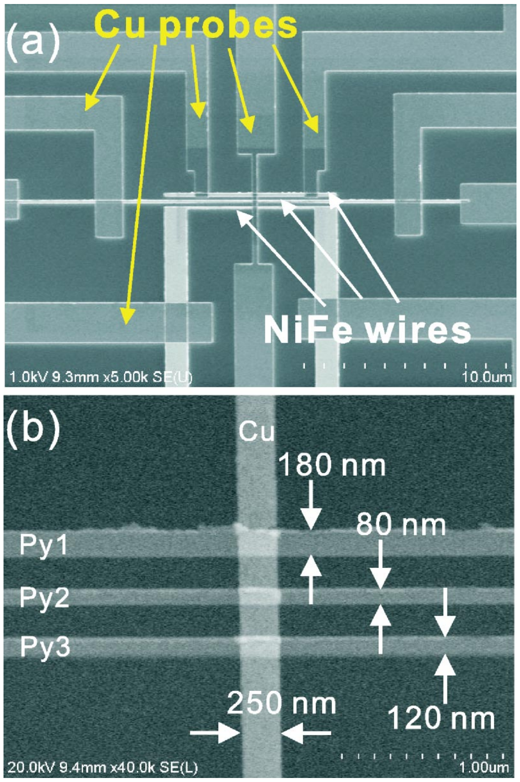

FIG. 2. (a) SEM images of the fabricated lateral spin device consisting of three Py wires bridged by a Cu wire and (b) magnified image around junctions.

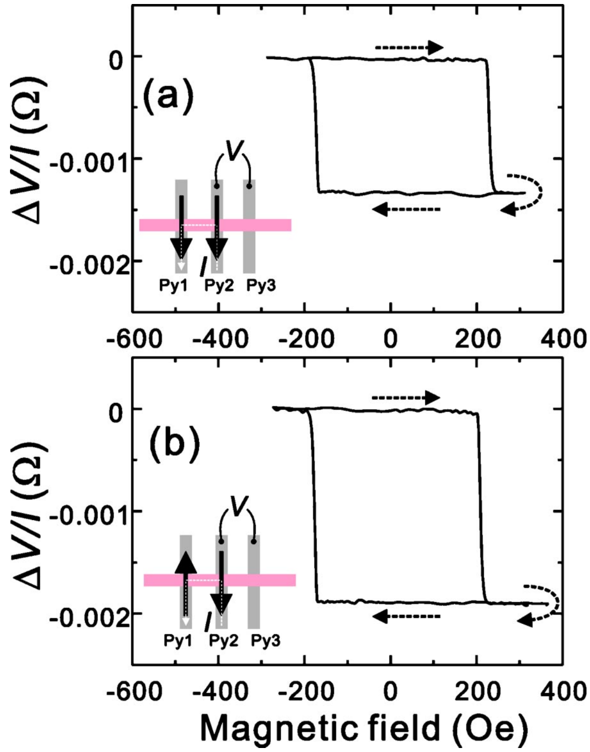

FIG. 3. Minor loops of nonlocal spin-valve measurements with the local current injection: (a) at the parallel state and (b) at the antiparallel state. The insets shows the probe configuration for the measurement and the magnetization orientation.

To realize this idea, we fabricated a lateral spin-injection device consisting of three F wires bridged by a Cu wire by means of electron-beam lithography and lift-off technique. Figure 2 shows a scanning electron microscope (SEM) image of a fabricated device. There are three permalloy (Py) wires with different widths, denoted as Py1, Py2, and Py3. To obtain different switching fields among the Py wires, the widths and edge shapes are designed appropriately as follows. Widths of Py1, Py2, and Py3 are 180 nm, 80 nm, and 120 nm, respectively. Py3 is connected to the large pad while Py1 and Py2 have flat ends. These results in the smallest switching field for the Py3 wire. The thickness of the Py wires is 30 nm. The spacing between each Py wires is 200 nm. The dimensions of the Cu wire are 250 nm in width and 80 nm in thickness. The details of the sample preparation are described elsewhere.[5,6] The resistivities of Py and Cu wires are, respectively, 18.2 $\mu\Omega$ cm and 1.44 $\mu\Omega$ cm at 4 K. The measurement was performed at 4 K in the magnetic field applied along the wire by using conventional lock-in technique. The switching fields of Py1, Py2, and Py3 wires were found 400 Oe, 450 Oe, and 200 Oe, respectively. Magnetic orientation of Py wires can thus be controlled by setting the magnetic field between different switching fields of three Py wires.

Before demonstrating above enhancement effect, the condition of each junction was examined by measuring the conventional NLSV. The obtained spin signal in the NLSV configurations using Py1 and Py2 with the Cu probes is 0.8 mΩ, and that using Py2 and Py3 with the Cu probes is 1.0 mΩ. The difference in the spin signal between two measurements is due to the different width of the F wires.[6]

We performed a NLSV measurement with the local current injection either in the parallel or in the antiparallel configuration as follows. The current flows from Py1 to Py2 wires and the voltage difference between Py2 and Py3 wires was measured, as shown in the inset of Fig. 3. Before starting the measurement, the magnetization orientation between Py1 and Py2 was set either in the parallel or in antiparallel state. We then swept the magnetic field between −300 Oe and 300 Oe, meaning that the magnetization directions of Py1 and Py2 are fixed, while the magnetization of Py3 is switched during the measurements.

Figures 3(a) and 3(b) show the NLSV minor loops measured with Py1 and Py2 in parallel and antiparallel, respectively. As explained above, we can induce large spin polarization in the nonmagnetic layer when the local current injection is performed with Py1 and Py2 in the antiparallel configuration. As shown in Fig. 3, the obtained spin signal in the antiparallel configuration increases to 1.9 mΩ whereas that in the parallel configuration is 1.3 mΩ. Thus, the spin signal in the NLSV configuration can be increased by changing the magnetization configuration for the local spin-current injection.

In the present study, to detect the spin polarization of the nonmagnetic layer, we used the F wire in ohmic contact. However, as mentioned in our previous paper, such a F wire induces the reduction of spin accumulation due to the small spin–flip resistance.[7] An efficient way to detect the above enhancement should be the usage of a F wire in contact with the N wire through a tunnel junction.[4]

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