Domain wall drag due to dc current injection into ferromagnetic nano-wires

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Abstract

We here experimentally demonstrate the domain wall depinning triggered by injecting the current into the domain wall. The domain wall is pinned at the connection of a large pad and a narrow wire prior to the current injection experiment. The pinned domain wall is freed and pushed into the wire at the critical current, only when the current is injected along the direction of the domain wall propagation. These results imply that the injection of the spin-polarized current into the domain wall causes additional magnetic pressure due to the spin-momentum transfer between the spin-polarized current and the localized magnetic moment.

Spin injection into the ferromagnetic materials induces the torque due to the exchange interaction between the conduction electron spin and the localized magnetic moment \cite{1}. Recently, the magnetization in small ferromagnets was shown to be reversed by spin-angular-momentum transfer from a spin-polarized current \cite{2}. The similar momentum transfer is expected to take place in periodical domain structures whereby magnetic pressure is exerted on the domain wall. We here experimentally demonstrate the domain wall displacement triggered by injecting the DC current.

The 30-nm-thick Ni–Fe wire consisting of a large 1 \times 5 \mu m\textsuperscript{2} rectangular pad and a 250-nm-wide wire, as illustrated in the inset of Fig. 1, was fabricated by a conventional lift-off technique. In this system, a domain wall is generally nucleated in the pad, followed by pinning at the connection between the pad and the wire, and then pushed into the wire \cite{3}. The resistivity measurements were performed at 3 K using a four-terminal DC measurement system in the range of the external magnetic field $H$ from $-1000$ to $1000$ Oe along the wire.

Fig. 1 shows a typical longitudinal magnetoresistance (MR) of the fabricated wire at 3 K. This behavior can be understood as an anisotropic MR effect in association with magnetization reversal. The first small jump at $H \approx 145$ Oe and the second large one at $H \approx 240$ Oe correspond to the magnetization switching of the wide pad and that of the narrow wire, respectively. The first jump is followed by a plateau, indicating that the magnetic state remains between two jumps. The domain wall is therefore considered to be pinned at the connection while the external field $H$ is in between 145 and 240 Oe.

We then studied the influence of the DC current injection on the trapped domain wall. Prior to the current injection experiment, the domain wall was trapped at the connection by setting the bias field at $H = 160$ Oe. Fig. 2 shows the differential resistance
given by \( \Delta R = V_n/I_n - V_{n-1}/I_{n-1} \), as a function of the injecting current at the bias field of 160 Oe. Here \( I_n \) and \( V_n \) are the current and the voltage at \( n \)th measured point, respectively. The current step is 1\( \mu \)A. The change in AMR is 10 m\% much smaller than that of the background resistance which increases by 1\% with the current up to 1 mA because of the Joule heat. Therefore, we plot \( \Delta R \) to find the change in resistance due to the domain wall depinning.

When the current is increased negatively (electrons are injected along the domain wall propagation), the spike is observed at \( I = -0.9 \) mA, as indicated by the arrow in Fig. 2(a). The amplitude of the peak, 200 m\( \Omega \), is the same as the resistance change at the depinning of the domain wall in Fig. 1. Therefore, this peak should coincide with the depinning of the domain wall. In order to confirm above, we measured the MR with sweeping the field from 160 to \(-1000 \) Oe. The MR showed two jumps corresponding to the magnetization switchings of the pad and wire regions. This means that the magnetization of the wire region was reversed by applying DC current under the bias field of 160 Oe.

On the contrary, such a spike does not appear when the current is increased positively up to 2 mA, as in Fig. 2(b). Moreover, the MR curve measured the field swept from 160 to \(-1000 \) Oe after the current shows a single jump corresponding to the switching of the pad region. This means that the positive current injection does not induce the domain wall depinning.

These results imply that the injection of the spin-polarized current into the domain wall causes additional magnetic pressure due to the asymmetric spin-momentum transfer [4] between the spin-polarized current and the localized magnetic moment.

References