Current-induced domain wall nucleation and its characteristics at a notch in a spin valve stripe

Beongki Cho[1,2], Youngman Jang[2] and Seungha Yoon[2]

[1]Department of Nanobio Materials and Electronics, [2]Department of Materials Science and Engineering, Gwangju Institute of Science and Technology (GIST), Gwangju 500-712, Korea

Introduction

The manipulation of domain walls (DWs) in ferromagnetic nanowires has attracted much technological attention primarily due to their possible applications in memory and prospective logic devices.[1,2] In these devices, information is recorded and read in the magnetic states of domains in lithographically patterned nanowires. DW motion along the wires allows for the access and manipulation of the stored information.

While field-driven magnetization reversal is widely used in the data writing, current-driven magnetization reversal provides a promising and alternative method. The spin torque drives the change of magnetic structures, which include the magnetic DW, through a transfer of the spin angular momentum. Furthermore, it was recently reported that a high density spin-polarized current can give rise to spin-wave and thermal excitation in a ferromagnetic nanowire, perturbing the uniformly magnetized state to nucleate a domain and DWs.[3]

In this study, we report a current-induced domain wall nucleation in a submicron CoFe/Cu/CoFe spin-valve stripe. And it was also found that the domain was nucleated at a temperature, which is lower than Curie temperature of CoFe layer.

Experimental Details

The nanowires in this study, which are 250 nm wide and 200 μm long, were patterned by electron-beam lithography using a lift-off technique. The spin valves, deposited by sputtering, consist of the layers in the following sequence: Ta(30)/Cu(20)/IrMn(120)/CoFe(80)/Cu(120)/CoFe(80)/Ta(50), where the number in parenthesis is the nominal thickness of each layer in Å. The CoFe layers below and above Cu layer are the pinned and free layers, respectively. Contact lines of Ta/Au were subsequently deposited on the top of spin-valve nanowires. A diamond-shape pad was attached to one end of nanowire for easy nucleation of DW at low fields, and the other end of nanowire was tapered to a sharp point. A scanning electron microscopy (SEM) image of a typical nanowire is shown in Fig. 1(a). While the current was injected between pads 1 and 4, the voltage was measured using pads 2 and 3.

Results and Discussion

Fig. 1(b) shows a normalized giant magneto resistance (GMR) curve of the submicron spin-valve stripe, where an in-plane magnetic field was applied along the long axis of spin-valve stripe. The GMR ratio of spin-valve stripe is about 1.73% with the low and high resistance corresponding to the parallel (P) state and antiparallel (AP) states of spin-valve stripe, respectively. The resistance variation at $H \approx \pm 100$ Oe is associated with the propagation of a DW from one end of CoFe wire to the other end. In General, when a low field applied, a DW is first nucleated in the diamond-shaped pad and pinned at a neck between the wire and pad. With an increased magnetic field, which is about ± 100 Oe in our case, the DW is injected and then

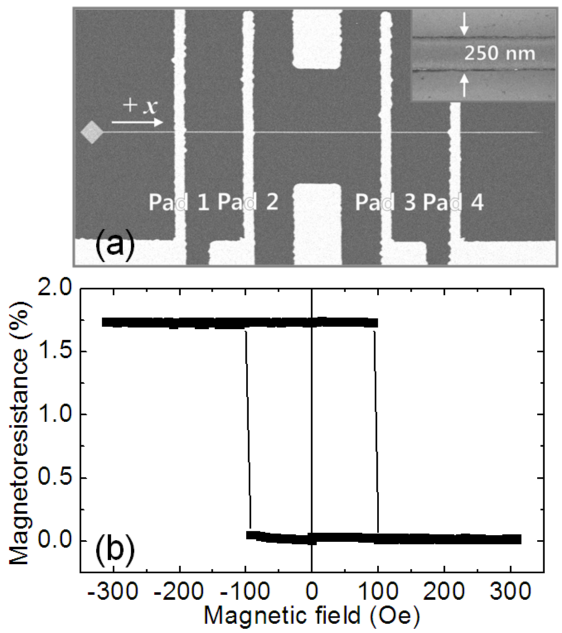

Fig. 1 (a) SEM image of spin-valve nanowire. (b) Normalized GMR curve of spin-valve nanow propagates through the wire.

Fig. 2 shows the resistance variation as a function of injection current I_{inject} for the spin-valve nanowires in the absence of a magnetic field at room temperature. The free layer of a spin-valve stripe was initially magnetized along the – *x*-axis, which caused an AP state in the spin-valve. Then, the resistance of the spin-valve stripe was measured after injection of pulsed I_{inject} for 10ms. As shown in Fig. 2(a), the resistance of the spin-valve stripe started to decrease at I_{inject} = 2.2 mA, corresponding to a current density of 1.76×10^{7} A/cm^{2}, and it dropped to the lowest value at I_{inject} = 2.7 mA. The resistance drop means that the magnetization at some part of CoFe free layer was changed from AP state to P state. After injection of I_{inject} = 2.8 mA into a spin-valve, which was initially in AP state, the GMR curve in terms of the applied magnetic field was measured and presented at the inset in Fig. 2(a). A switching field was found to be ~70 Oe, which is smaller than that of spin-valve stripe without current injection. This indicates that the resistance variation with the positive magnetic field is not associated with the nucleation of a DW in the diamond-shaped pad. It is likely that a DW in a free layer was nucleated by the injection current and remained somewhere in the free layer between the electrodes for current injection. Fig. 2(b) shows the resistance variation as a function of I_{inject} for a spin-valve, which was initially in P state. Similarly to the case in Fig. 2(a), the resistance of the spin-valve

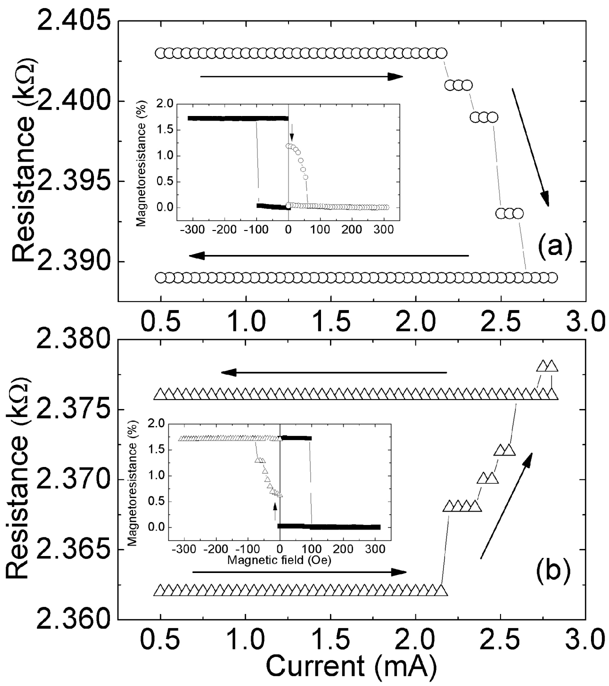

Fig. 2 Resistance at zero field in term of I_{inject} with an antiparallel (a) and a parallel configurations (b) a s initial states. Insets show the GMR curve in terms of the applied magnetic field from H = 0 after inje ction of a pulse current of 2.8 mA

stripe started to increase at I_{inject} = 2.2 mA by an amount of about 15 Ω.

It is widely known that the nucleation of DW in a uniformly magnetized wire is mainly related to Joule heating to a temperature, which is close to Curie temperature.[3] In our experiment, however, the temperature of spin-valve stripe was not likely to increase to Curie temperature, because we did not observed the change of exchange bias between the layers of CoFe and IrMn after the injection of high current. The blocking temperature of exchange bias between IrMn and CoFe was known to be 200 ~ 400 ^{o}C.[4] Therefore, the fact that there is no change of exchange bias after the current injection means that the temperature of spin-valve stripe did not exceed the blocking temperature. On the other hand, it was surmised that the current-induced domain nucleation at a relative low current might be caused by out-of-plane component of spin-polarized currents in the Cu layer.[5] We believe that the DW nucleation in this study is more likely due to the spin-polarized current itself rather than the Joule heating of the nano-wire.

Conclusion

We observed current-induced domain and DW nucleation in a submicron CoFe/Cu/CoFe spin-valve stripe. It was also found that the temperature of spin-valve stripe during current injection is lower than Curie temperature of CoFe layer. The domain nucleation at temperature, lower than Curie temperature, is likely to be caused by out-of-plane component of spin-polarized currents in spin-valve stripe.

References

1. Thomas, L., Hayashi, M., Jiang, X., Moriya, R., Rettner, C., Parkin, S. S. Oscillatory dependence of current-driven magnetic domain wall motion on current pulse length. *Nature*, **443** (2006) 197-200.
2. Allwood, D. A., Xiong, G., Cooke, M. D., Faulkner, C. C., Atkinson, D., Vernier, N., Cowburn, R. P. Submicrometer ferromagnetic NOT gate and shift register. *Science*, **296** (2002) 2003-2006.
3. Togawa, Y., Kimura, T., Harada, K., Matsuda, T., Tonomura, A., Otani, Y., Akashi, T. Current-excited magnetization reversal under in-plane magnetic field in a nanoscaled ferromagnetic wire. *Appl. Phys. Lett.*, **92** (2008) 012505-1 – 012505-3
4. Li, H., Freitas, P. P., Wang, Z., Sousa, J. B., Gogol, P., Chapman, J., Exchange enhancement and thermal anneal in $Mn_{76}Ir_{24}$ bottom-pinned spin valves. *J. Appl. Phys.*, **89** (2001) 6904 – 6906
5. Laribi, S., Cros, V., Muñoz, M., Grollier, J., Hamzić, A., Deranlot, C., Fert, A., Martínez, E., Reversible and irreversible current induced domain wall motion in CoFeB based spin valves stripes. *Appl. Phys. Lett.*, **90** (2007) 232505-1 – 232505-3