Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp1408-1409

Spin-Transfer-Torque-Induced RF Oscillation for Fe/Cr/Fe Layers with an Antiferromagnetic Coupling Field

Takeshi Seki[1], Hiroyuki Tomita[1], Takekazu Yamane[1], Masashi Shiraishi[1], Teruya Shinjo[1] and Yoshishige Suzuki[1]

[1]Graduate School of Engineering Science, OsakaUniverity
1-3, Machikaneyama-cyo, Toyonaka, Osaka 560-8531, Japan
Phone: +81-6-6850-6223 E-mail: go-sai@spin.mp.es.osaka-u.ac.jp

1. Introduction

The spontaneous magnetization precession induced by spin-transfer-torque (STT) has recently attracted much attention since it leads to important potential applications such as a nanometer-sized microwave oscillator. [1,2] In order to apply STT-induced rf oscillators to a variety of electronic devices, the operation in a higher frequency region is important. One possible way to increase the rf oscillation frequency is to use an antiferromagnet or antiferromagnetically-coupled layers as a magnetic free layer for the rf oscillation. It is known that the ferromagnetic resonant (FMR) frequencies of antiferromagnetic materials are much higher than those of ferromagnetic materials. Ferromagnetic layers with an antiferromagnetic coupling field show two kinds of FMR modes: the acoustic mode and the optical mode. In addition, the appearance of the characteristic magnetization dynamic phase has been theoretically predicted in artificial magnetic structures due to the effect of spin current, [3] and several studies have focused on the spin transfer phenomena of antiferromagnetic materials. [4,5] Previously, we reported that the STT-induced FMR modes were observed for Fe/Cr/Fe layers with an antiferromagnetic coupling field by applying rf current, indicating the possibility of the dynamic phase induced by spin-polarized current in layers with an antiferromagnetic coupling field. [6]

In this study, the STT-induced rf oscillation was examined for Fe/Cr/Fe layers with an antiferromagnetic coupling field. The rf spectra for current-perpendicular-to-plane (CPP) giant magnetoresistance (GMR) pillars were measured by applying the dc bias current.

2. Experimental Procedure

A thin film was prepared on an MgO (001) single crystal substrate using a molecular beam epitaxy system. The stacking structure of the thin film is as follows: substrate / MgO (3) / Cr (5) / Au (20) / Cr (2) / Fe (10) / Cr (1.2) / Fe (3) / Au (3) (in nanometers). The base pressure was below 2×10^{-7} Pa. All the layers were epitaxially grown at room temperature. The deposition rate was 0.01 nm/sec. The 20 nm-thick Au buffer layer was annealed at 200ºC for 5 minutes. A magneto-optical Kerr loop indicates that both Fe layers were antiferromagnetically aligned in the low magnetic field region below the spin-flip field of 1.2 kOe and showed the parallel alignment above the saturation field of 1.8 kOe. Microfabrication for CPP-GMR pillars was carried out using electron beam lithography and Ar ion milling. The Fe/Cr/Fe layers were patterned with a rectangular shape of $0.1 \times 0.15\ \mu m^2$.

The rf spectra were measured using the lock-in modulation method. The dc bias current (I_{DC}) with small AC modulation current was applied to the CPP-GMR pillar through the bias-Tee. The rf voltage originating from the magnetization precession by STT was amplified by the RF preamplifier. After passing through the intermediate frequency output of the spectrum analyzer and the quadratic diode detector, the RF voltage was finally detected by the lock-in amplifier. All the measurements were performed at room temperature.

3. Results and Discussion

Figure 1 (a) shows a magnetoresistance (MR) curve for the CPP-GMR pillar measured using a dc two probe method. The external magnetic field (H) was applied along the easy magnetization direction. Owing to the antiferromagnetic coupling field, the two Fe layers show antiferromagnetic alignment in low H. A stair of the MR curve is also observed, indicating the spin-flip transition of the magnetization configuration. The differential resistance

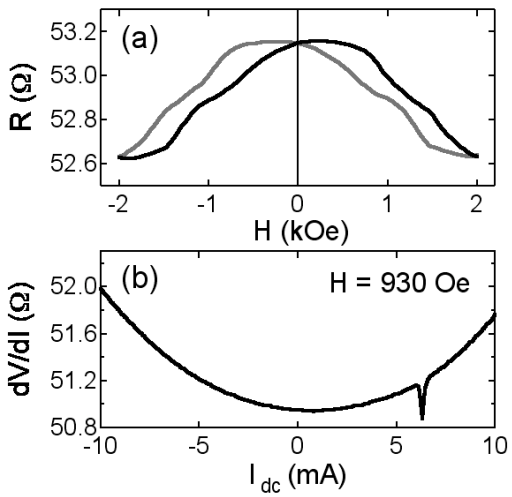

Fig .1 (a) A magnetoresistance curve for the CPP-GMR pillar of Fe/Cr/Fe layers with an antiferromagnetic coupling field. (d) The differential resistance as a function of the dc bias current (I_{dc}). The external magnetic field was set to 930 Oe.

(dV/dI) as a function of I_{DC} at H = 930 Oe is shown in Fig. 1 (b). The magnetization configuration at H = 930 Oe is an intermediate state between the antiparallel and parallel alignments. The positive sign of I_{DC} corresponds to the electron flow from the 10 nm-thick Fe layer to the 3 nm-thick Fe layer. A clear dip of the differential resistance is observed at I_{DC} = +6.3 mA. This direction of I_{DC} provides the 3 nm-thick Fe layer with STT supporting the parallel alignment. The dip of differential resistance is attributable to the abrupt change of the magnetization configuration by STT.

Figure 2 (a) shows rf spectra for the CPP-GMR pillar measured at H = 910 Oe. The values of I_{DC} are (a) +5 mA and (b) +8 mA. No clear peak is observed for the rf spectrum with applying I_{DC} = +5 mA. As I_{DC} increases up to +7 mA, however, several peaks appear. Since those peaks appear above a threshold current and are not observed for the negative I_{DC}, the observed peaks originate from the magnetization dynamics induced by STT. With further increasing I_{DC}, the peak frequencies of the peaks at 9.5 GHz and 18.8 GHz gradually shift to the lower frequency side. This tendency is interpreted by the effect of STT and is consistent with previous results for uncoupled layers such as Co/Cu/Co [1]. On the other hand, the peak frequencies for the other peaks are almost constant or show the slight blueshift with I_{DC}.

At H = 910 Oe, the largest amplitude of the rf signal is obtained for the peak at 18.8 GHz. This peak frequency is almost twice as high as 9.5 GHz, and both peaks show the similar magnetic field and dc bias current dependences of the peak frequencies. Therefore, the peak at 9.5 GHz is the fundamental peak, and the peak at 18.8 GHz is the second harmonics. Those peak frequencies show the redshift with

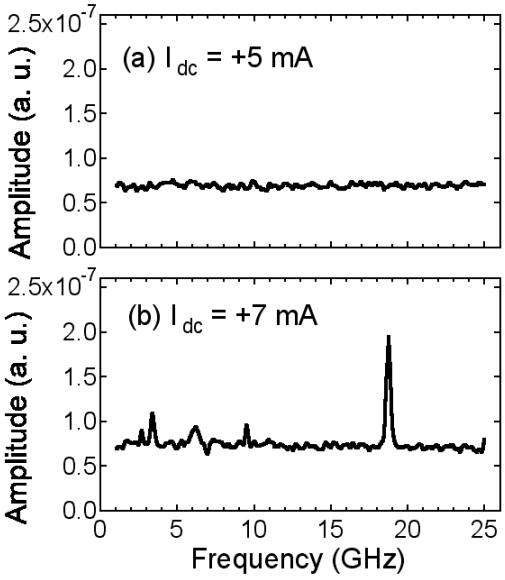

Fig .2 rf spectra for the CPP-GMR pillar of Fe/Cr/Fe layers with an antiferromagnetic coupling field. (a) I_{dc} = +5 mA and (b) +7 mA were applied. The external magnetic field was set to 910 Oe.

increasing H, which are opposite tendencies to the results for uncoupled layers following the Kittel's equation. [1,2] An important point is that the STT-induced rf oscillation for the present Fe/Cr/Fe layers with an antiferromagnetic coupling field is observed at the external magnetic field where the magnetization configuration of the two Fe layers is between the antiparallel and parallel alignments, which is also different from the case of uncoupled layers.

4. Summary

The STT-induced rf oscillation was investigated for the CPP-GMR pillars including the Fe/Cr/Fe layers with an antiferromagnetic coupling field. Above the threshold current, clear peaks were observed in the rf spectra, and the peak frequencies clearly shifted with I_{DC} and H. The STT-induced rf oscillation was observed at H where the magnetization configuration of the two Fe layers was an intermediate state between the antiparallel and parallel alignments. The magnetic field dependence of the peak frequencies showed the different tendency from the results for uncoupled layers.

Acknowledgements

This work was partly supported by a Grant-in-Aid for Scientific Research in Priority Area from MEXT and SCOPE from MIC. The first author was supported by Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists.

References

[1] S. I. Kiselev, J. C. Sankey, I. N. Krivorotov, N. C. Emley, R. J. Schoelkopf, R. A. Buhrman, and D. C. Ralph, *Nature* **425**, 380 (2003).

[2] W. H. Rippard, M. R. Pufall, S. Kaka, S. E. Russek, and T. J. Silva, *Phys. Rev. Lett.* **92**, 027201 (2004).

[3] M. Onoda, and N. Nagaosa, *Phys. Rev. Lett.* **96**, 066603 (2006).

[4] S. M. Rezende, F. M. de Aquiar, M. A. Lucena, and A. Azevedo, *Phys. Rev. Lett.* **84**, 4212 (2000).

[5] Z. Wei, A. Sharma, A. S. Nunez, P. M. Haney, R. A. Duine, J. Bass, A. H. MacDonald, and M. Tsoi, *Phys. Rev. Lett.* **98**, 116603 (2007).

[6] T. Seki, H. Tomita, A. A. Tulapurkar, M. Shiraishi, T. Shinjo, and Y. Suzuki, *Appl. Phys. Lett.* **94**, 212505 (2009).