Journal of Magnetics 10(2), 48-51 (2005)

Improvement of the Spin Transfer Induced Switching Effect by Copper and Ruthenium Buffer Layer

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(Received 30 May 2005)

The spin transfer induced magnetization switching has been reported to occur in magnetic multilayer structures whose scope usually consists of one stack of ferromagnetic / non-ferromagnetic / ferromagnetic (F / N / F) materials. In this work, it is shown that: 1) Copper used as a buffer layer between the free Co and the Au cap-layer can clearly increase the probability to get the spin transfer induced magnetization switching in a simple spin valve Co 11 / Cu 6 / Co 2 (nm); 2) Furthermore, when Ruthenium is simultaneously applied as a buffer layer on the Si-substrate, the critical switching currents can be reduced by 30%, and the absolute resistance change delta R [ΔR] of that stack can be enlarged by 35%. The enhancement of the spin transfer induced magnetization switching can be ascribed to a lower local stress in the thin Co layer caused by a better lattice match between Co and Cu and the smoothening effect of Ru on the thick Co layer.

Key words : Spin transfer, Magnetoresistance-based spintronic devices, nano-scaled magnetic multilayers, Cu and/or Ru buffer layer

1. Introduction

It was predicted [1, 2] that a spin polarized current perpendicular to the layer plane of a magnetic multilayer can reverse its magnetic alignment. This reversal phenomenon, referred to as the spin transfer induced magnetization switching (SIMS), makes current-driven devices possible. Such devices posses the advantage over the conventional field-driven ones in that their dimension can be drastically reduced. Intensive works have been done to study this effect in trilayer spin valves, in synthetic antiferromagnetic (SAF) coupled or in antiferromagnetic (AFM) exchange biased ones, and also in magnetic tunneling junctions (MTJ).

In order to detect the SIMS effect, the multilayers have to be patterned into nanoscaled sizes so that the spin transfer torque could dominate over self-Oersted-field effects. The top electrical contact is then formed on the top of such junctions. A noble metal layer, such as Au [3, 4] or Pt [5], is usually used as a cap layer to protect the nano-junctions in further process following the patterning step. These cap layers do not have a good lattice match with Co and, therefore, can induce defects and local deformations in Co lattice. Although the lattice match between Co and the neighboring layers plays an important role in obtaining the SIMS effect, still almost no work on this has been published. In this article, the effect of Cu as a buffer layer between the top thin Co and the Au cap layer, and the effect of Ru as a buffer layer between Si/SiO_2 substrate and the thick Co layer in a simple trilayer spin valve Co 11 / Cu 6 / Co 2 (nm) are reported.

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2. Experiment

To extract the effect of Cu and Ru, the spin valves were divided into 3 groups: group I has the layer structure of Cu 50 / Co 11 / Cu 6 / Co 2 / Au 5 (nm); in group II, 2 nm Cu buffer layer was added on the top of the thin Co layer, resulting in Cu 50 / Co 11 / Cu 6 / Co 2 / Cu 2 / Au 5 (nm); in group III, both Cu and Ru buffer layers were applied, resulting in Ru 10 / Cu 50 / Co 11 / Cu 6 / Co 2 / Cu 2 / Au 5 (nm).

A combination of DC magnetron sputtering, ion milling, photo- and electron beam lithography was applied to prepare the spin valves of these 3 groups with a nanoscaled size of 96 nm × 150 nm. Details of our fabrication process were described elsewhere [6]. The magnetic properties of these multilayers were characterized by *M* (*H*) curves measured by VSM. Resistance changes upon applied field CPP-*R* (*H*), and SIMS signals, in the form of resistance changes versus injected direct current *R* (*I*), were detected by using a 4-point probe measurement system. In both measurements, the DC currents were sent perpendicular to the layer plane. In CPP-*R* measurement, a current of only few tens mA was applied, while for detecting the SIMS effect, currents of ± 8 mA or larger with a scan speed of 75 μA/sec were injected into the nano-junctions. The sign of injected currents is defined as positive when current flows from the thin Co layer to the thick Co layer, i.e. from the top to the bottom electrode, and as negative when it flows in the opposite direction (see Fig. 1).

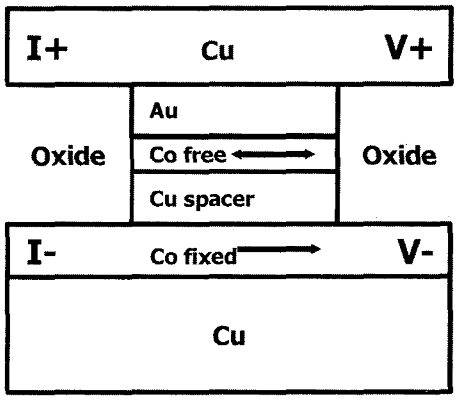

Fig. 1. A schematic cross sectional view of a trilayer spin valve.

3. Results and Discussion

In the spin valves of group I, where neither Cu nor Ru buffer layer was applied, the SIMS effect hardly occurs, even when good magnetoresistance signals, CPP-R (H) curves, were obtained in such junctions. A typical case of this group is presented in Fig. 2-a). While the *R* (*H*) curve, on the left side, has a nice shape, and shows the abrupt changes of ~50 mΩ in resistance of that junction at certain values of the applied magnetic field, the *R* (*I*) curve, on the right side, shows no sudden change in resistance. That means the magnetic moment of the thin Co layer in that sample, numbered I for convenience, can be clearly reversed by an applied magnetic field, but not by an injected current. The absence of a SIMS in that junction may be explained by a spatially varying anisotropy in the thin Co layer which should result from a high local strain due to the lattice mismatch between the

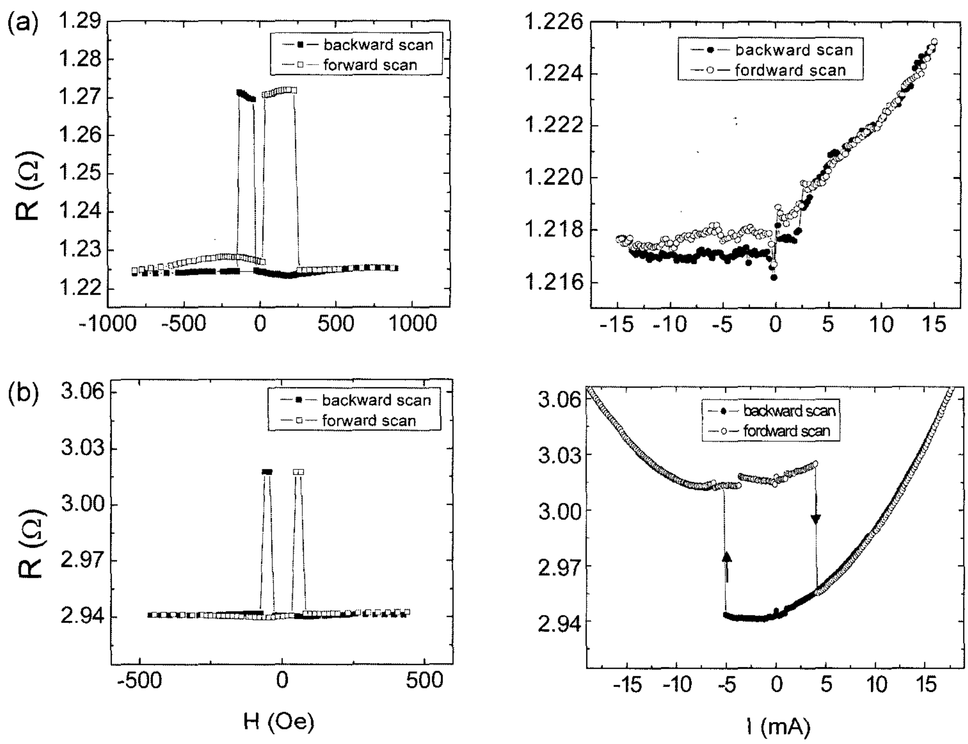

Fig. 2. Effect of Cu buffer layer on SIMS signals of trilayer spin valves. (a) CPP- *R* (*H*): open and solid squares and *R* (*I*): open and solid circles, curves of spin valves without Cu and Ru buffer layers; (b) Those curves of spin valves with Cu buffer layer between the thin Co and the Au cap layer.

thin Co and the Au cap layer [7].

To solve this problem, in group II, we inserted a 2 nm-thick Cu as a buffer layer between the thin Co and the Au cap layer. For this group, in the samples, which possessed good CPP-magnetoresistance signals, the SIMS effect usually took place. Fig. 2-b) gives *R* (*H*), on the left side, and *R* (*I*), on the right side, of one sample, numbered II. On the *R* (*I*) curve, the total resistance increases abruptly from low level of the parallel magnetic alignment (P) to the high level of the antiparallel one (AP), when the injected current sweeps from a large positive value to –5.05 mA, called the P-AP critical current I_c^-, and decreases back to the low level when the injected current sweeps back to +4.00 mA, called the AP-P critical current I_c^+. The magnitude of resistance change of 70 mΩ in this current scan is the same with that in the field scan shown by *R* (*H*) curve. This agreement indicates that the abrupt resistance changes by injected current result from the complete reversals of the magnetic alignment of that junction.

For group III, a 10 nm thick Ru layer was deposited first on the Si/SiO_2 substrate, and then the multilayer with Cu buffer layer as that of group II. As seen in Fig. 3, the *M* (*H*) curve, open squares, of the multilayer with Ru buffer layer does not show a "tail", while the *M* (*H*) curve, solid squares of the one without buffer layer does.

Such "tail" could result from a local fluctuation of the easy axis in the thick Co layer. This means Ru buffer layer can induce a better crystalline anisotropy in the thick Co layer. As a result, the magnetoresistance can increase, and the SIMS effect can be enhanced. Fig. 4 demonstrates *R* (*H*) and *R* (*I*) curves of one sample, numbered III, in group III. Clear jumps of resistance with the same magnitude in the both curves were obtained.

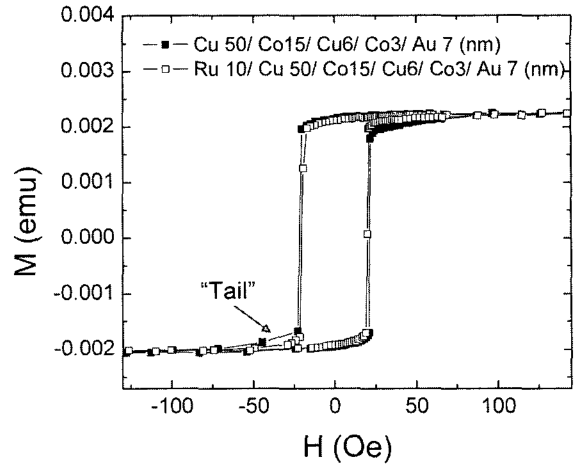

Fig. 3. *M* (*H*) curves of a trilayer spin valve with (open squares) and without (solid squares) Ru buffer layer.

Again, this is an evidence of the full reversals of the magnetic moment caused by injected currents. If the average critical switching current is defined as $J_C = (|I_C^+| + |I_C^-|/2 \times \text{junction area})$, J_c in the sample III is 2.4×10^7 A/cm^2, which is 30% lower than that of 3.5×10^7 A/cm^2 in the sample II. The absolute resistance change in sample III, which is of 95 mΩ, is increased by 35% compared to that in sample II. The above results show an appropriate combination of Cu and Ru buffer layer can give rise to an enhancement of SIMS effect in a Cobalt-based trilayer spin valve.

4. Conclusion

The effect of Cu buffer layer on the top of the thin Co and Ru buffer layer under the thick Co layer on the SIMS

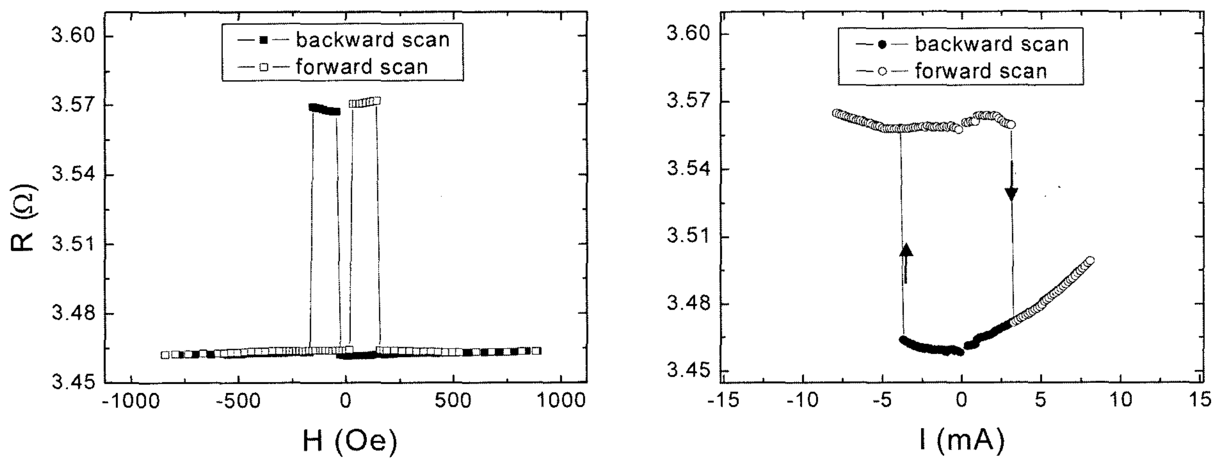

Fig. 4. Enlargement of SIMS signals in trilayer spin valves by Cu and Ru buffer layer. Open and solid squares represent the CPP- *R* (*H*) curve. The *R* (*I*) curve is presented by open and solid circles.

in cobalt-based trilayer spin valves was investigated. The experimental results showed that Cu buffer layer could significantly improve the SIMS effect, while Ru buffer layer in combination with Cu buffer layer could induce a decrease in the critical switching current by 30%, and an increase in the absolute resistance change of 35%. These enhancements can be attributed to the improvement in the crystalline microstructure, which could result in a better crystalline anisotropy in the two Co layers.

Acknowledgements

This work was supported by the TND Frontier Project funded by KISTEP, by the Korea Institute of Science and Technology Vision 21 Program, and by the Ministry of Science and Technology of Korea through the Cavendish-KAIST Cooperative Research Program.

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