Journal of Magnetism and Magnetic Materials 324 (2012) 3002–3005

Contents lists available at SciVerse ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Reference layer exchange in spin transfer torque experiment using magnetic-coated nanometric point contacts

R.O. Cunha*, D.L. Baptista, M. Heinemann, M.F. Kuhn, J.E. Schmidt, L.G. Pereira

Instituto de Física, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS 91501-970, Brazil

ARTICLE INFO

Article history:
Received 7 March 2012
Received in revised form
19 April 2012
Available online 11 May 2012

Keywords:
Spin transfer torque
Nanotips
Magnetic nanotips
Magnetic multilayers
Polarizer layer
Magneto transport in nanotips

ABSTRACT

We investigate the importance of using nanotips on a point contact spin-transfer torque (STT) experiment. A systematic analysis comparing the STT in a magnetic thin film in current-perpendicular-to-plane (CPP) geometry sample for magnetic coated and uncoated tungsten nanotips is shown. The STT effect presents a reverse resistance to current behavior when using a magnetic coating layer on the nanotips. We demonstrate that the magnetic layer on the tip may assume the role of a polarizer layer. This effect opens up the possibility of exploiting simpler architectures in STT-based devices, such as STT-random access memory (STT-RAM).

1. Introduction

The spin-transfer torque (STT) effect was predicted in 1996 by Slonczewski [1] and Berger [2]. Few years later, the STT was experimentally observed in a variety of current-perpendicular-to-plane (CPP) geometries [3–6]. The effect can be specially used to flip the active elements in magnetic random access memory (MRAM). However, the great difficulty in these experiments is to obtain an electric current density (J) necessary to active the STT effect ($J \sim 10^6 - 10^9$ A/cm^2) [7–9]. Although the use of nanopillar and nanocontact structures leads to the required current densities, its development usually involves sophisticated nanofabrication devices. In contrast, nanotips may be an efficient alternative structure. Special advantage is its relatively simple manufacturing. In 1998, Tsoi et al. [3] investigated the STT effect for the first time including a mechanical point contact. Nevertheless, a detailed study concern the influence of the tip characteristics on the STT effect is still missing, especially when magnetic materials are used as point probes.

In this work we investigate the importance of thin magnetic coatings in a nanotip point contact STT experiment. A systematic analysis of the role of the tip cover layer on the spin transfer effect in a trilayer CPP geometry sample is presented.

2. Experimental

Tungsten nanotips were prepared using a electrochemical process of corrosion similar to that used for fabricating scanning tunneling microscopy (STM) tips [10]. In the case of STM, nanometer scale metallic tips are required for achieving high sensitivity of tunneling current. When using these tips as electrical point contacts high current density is reached. Although different metals can be used, tungsten, in particular, is a common choice since it is very stiff and presents low oxidation rate [11]. The tips were prepared using a tungsten wire of 0.25 mm in diameter. The wire is introduced through a thin membrane of an aqueous solution of NaOH 2 M supported by a platinum ring at room temperature. Electric potential difference between the tungsten wire and the platinum ring causes the corrosion process [12], which is carefully monitored in order to get extremely thin structures at the tip. Finally, some tips were coated by a thin NiFe (15 nm) and Co (30 nm) film via magnetron sputtering. Scanning electron microscopy (SEM) analyses were carried out to estimate the tip diameter. Typical values of 100 nm were obtained as shown in Fig. 1.

The trilayer samples used in the STT experiments were prepared by magnetron sputtering using Ar plasma at deposition pressure of 0.36 Pa. The base pressure was better than 4×10^{-5} Pa. A nominal film composition of Cu(50 nm)/NiFe(15 nm)/Cu(8 nm)/NiFe (3 nm)/Cu(5 nm) was deposited onto polished Si (1 0 0) substrate. The first layer of Cu acts as a bottom electrode, which was first deposited using a 150 μm width line mask. The essential part of the multilayer, NiFe/Cu/NiFe, was deposited in part of Cu trail, as shown schematically in Fig. 2. The bottom Cu layer is thick

* Corresponding author. Tel.: +55 51 3308 6506; fax: +55 51 3308 7286.
E-mail address: rafaelotoniel@gmail.com (R.O. Cunha).

0304-8853/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jmmm.2012.04.043

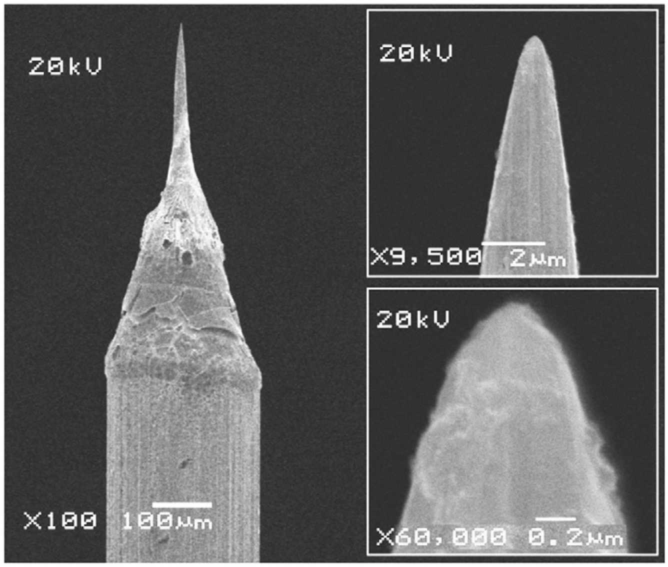

Fig. 1. SEM micrographs of a non-coated tungsten tip at different magnifications. The insets show the extremity of the tip which is about a few tens of nanometers in diameter.

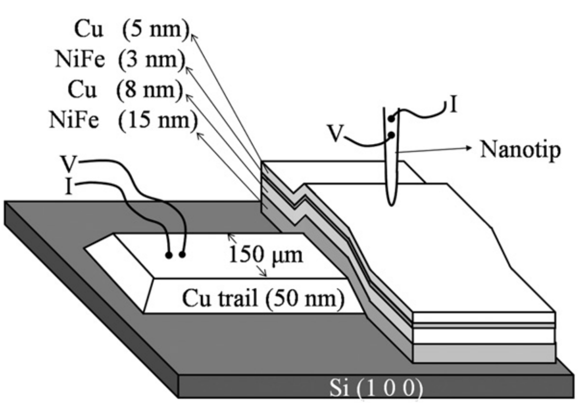

Fig. 2. Schematics of the experimental setup for the spin transfer measurements. The *W* nanotip is attached on the multilayer surface upon the Cu trail.

enough to improve the electric conduction and the top Cu layer acts as a protective layer.

The point contact between the nanotip and the trilayer sample is controlled through a piezo nanopositioner. The *W* tip is slowly approximated to the sample surface while the electrical current passing through the system is monitored. The schematic of the experimental setup is shown in Fig. 2. Measurements of voltage *V* as a function of *I* were carried out with a continuous variation of current through the samples at room temperature.

3. Results and discussions

Measurements of giant magnetoresistance (GMR) were also carried out, but the effect was not observed in the magnetization curve (not shown). The coercivities of both magnetic layers are close, which does not favor the antiparallel configuration necessary for the GMR effect. Prior to each STT measurement, a high magnetic field was applied in the plane of the sample, aiming to align the magnetizations of both NiFe layers. During the measurements, a low magnetic field at opposite direction of the saturation field is applied.

Initially, the STT effect was obtained using pure (uncoated) *W* nanotips. It is possible to observe two distinct current behaviors. When the current flows from the nanotip to the sample, i.e., the current flows through the thinner (free layer) to the thicker (reference) NiFe, a parallel configuration between momenta of the NiFe layers is favored. This current sense was labeled as positive. Differently, when the current is negative, i.e., when it flows from the sample to the *W* nanotip, an antiparallel magnetic layer configuration is established. Fig. 3 shows the resistance versus current for different values of external magnetic field for both positive and negative directions. The inset represents the current sense configuration, here adopted as positive.

In a second experiment, Co coated W nanotips were used as contacts for the same previously measured trilayer sample. Fig. 4 shows the dependence of the resistance as a function of the electrical current. The result is an inverse behavior towards the STT effect shown in Fig. 3 for uncoated *W* tips. It is possible to observe a leap up in the resistance for the positive current while it leapt down for the negative one. This reverse behavior could be explained through a relative spatial rearrangement of the free and reference layers.

In order to verify the conceivable exchange between the reference NiFe layer of the sample and the Co layer of the coated tip as the magnetic polarizer layer, a final experiment was performed. It consists of using a single magnetic layer with a nominal composition of Cu(50 nm)/NiFe(6 nm)/Cu(8 nm) and a NiFe coated tip for contacting. The STT effect observed in Fig. 5 for the single magnetic sample presents similar behavior to those shown in Fig. 4. This result confirms that, as suggested by the previous experiments, the coated *W* nanotips can polarize the current. In this

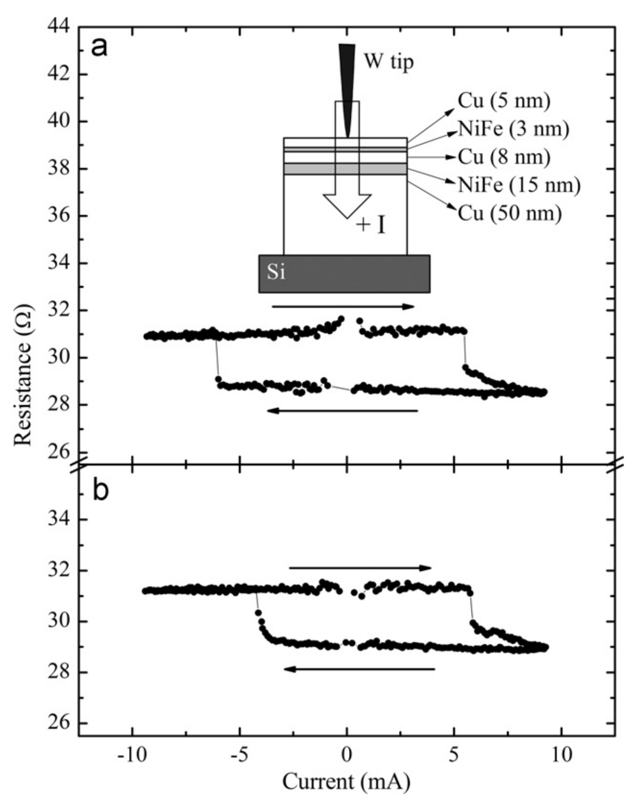

Fig. 3. Representative spin-transfer torque effect for (a) 62 Oe and (b) 242 Oe external magnetic field. The dots correspond to the normalized resistance as a function of current for a pointcontact on a NiFe/Cu/NiFe trilayer. The horizontal arrows represent the data acquisition orientations of the measurements. The positive polarity adopted to this configuration using a pure *W* tip is represented in the schematic inset.

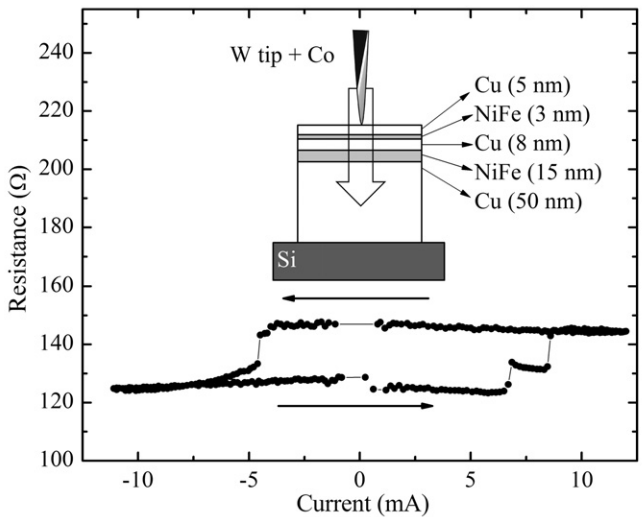

Fig. 4. Resistance as a function of the current for a point-contact on a NiFe/Cu/NiFe trilayer using a Co coated *W* tip. The polarity of this configuration is negative, represented in the schematic inset. The horizontal arrows represent the data acquisition orientations.

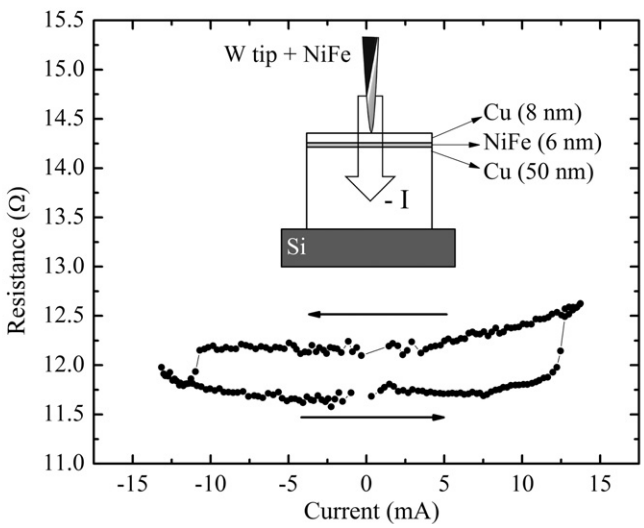

Fig. 5. Representative spin-transfer torque effect shown as resistance as a function of the current for a pointcontact on a monolayer of NiFe. The second magnetic layer, NiFe, is deposited on the *W* tip. For this configuration, the polarity of the current is negative, as represented in the schematic inset.

Table 1
Critical current density (J_{UP} and J_{DOWN}) estimation from the tip contact area. The radius of the tip (~ 50 nm) was estimated through SEM micrographs.

Experiment	J_{UP} (A/cm^2)	J_{DOWN} (A/cm^2)
W_{PURE} (Fig. 3a)	-7.50×10^7	6.96×10^7
W_{PURE} (Fig. 3b)	-4.31×10^7	7.32×10^7
W_{Co} (Fig. 4)	8.28×10^7	-5.12×10^7
W_{NiFe} (Fig. 5)	15.58×10^7	-13.62×10^7

case, the magnetic coated layer on the tip assuredly assumes the role of the reference layer in STT experiments.

The critical current densities (J) involved in our STT switching experiments were estimated using the tip contact area as showed in Table 1, where J_{UP} and J_{DOWN} correspond to the current densities for the leap up and the leap down in resistance, respectively. The values are consistent with other experiments reported elsewhere [6,13].

4. Conclusions

The results obtained for the single magnetic layer may suggest that the polarization of the electronic current for the trilayer configuration (Fig. 4) could be also accomplished in the magnetic layer on the tip instead of being polarized at the reference NiFe layer. It means that the torque in the free NiFe layer would be generated by spin-polarized electrons at the Co coating on the tip. So the antiparallel state would be favored at positive bias in which the resistance increases. In contrast, the resistance of the system would decrease at negative bias. It is important to emphasize that the role of the former reference layer in Fig. 4 (the thicker NiFe layer) is not clear in this situation. The hypothesis that the polarization of the current in the coated tip is much more effective than the polarization in the 15 nm NiFe layer is being investigated. Further experiments where the thickness of the magnetic coated layer over the *W* tips is varied are currently in progress.

In summary, we have performed a STT experiment with coated and uncoated *W* nanotips as nanometric point contacts. We show that the STT presents a reverse behavior in the polarity in the free layer when using a magnetic coating layer on the *W* nanotips. The change of the current sense is clearly observed through the up and down leaps in the resistance for pure or coated *W* tips measurements. The results indicate that the magnetic coating layer on the tip assumes the role of a polarizer layer. The results also demonstrate the capability of observing STT using inexpensive apparatus which may lead to advances in both applied and fundamental research in the field.

Acknowledgments

This work was supported in part by the Brazilian agency CNPq. The authors thank Drs. Julian P. Geshev and Mario N. Baibich for their helpful revision of the manuscript.

References

[1] J. Slonczewski, Journal of Magnetism and Magnetic Materials 159 (1996) 1.
[2] L. Berger, Physical Review B 54 (1996) 9353.
[3] M. Tsoi, A.G.M. Jansen, J. Bass, W.-C. Chiang, M. Seck, V. Tsoi, P. Wyder, Physical Review Letters 80 (1998) 19.
[4] E.B. Myers, D.C. Ralph, J.A. Katine, R.N. Louie, R.A. Buhrman, Science 867 (1999) 285.
[5] J.A. Katine, F.J. Albert, R.A. Buhrman, E.B. Myers, D.C. Ralph., Physical Review Letters 84 (2000) 3149.
[6] J. Grollier, V. Cros, A. Hamzic, J.M. George, H. Jaffrès, A. Fert, G. Faini, J. Ben Youssef, H. Legall, Applied Physics Letters 78 (2001) 3663.
[7] X.J. Wang, H. Zou, Y. Jia, Applied Physics Letters 93 (2008) 162501.
[8] J.C. Slonczewski, Journal of Magnetism and Magnetic Materials 247 (2002) 324–338.
[9] W.H. Rippard, M.R. Pufall, T.J. Silva, Applied Physics Letters 82 (2003) 1260.
[10] J.P. Ibe, P.P. Bey Jr., S.L. Brandow, R.A. Brizzolara, N.A. Burnham, D.P. DiLella, K.P. Lee, C.R.K. Marrian, R.J. Colton, Journal of Vacuum Science and Technology A 8 (1990) 3570.
[11] M. Kein, G. Schwitzgebel, Review of Scientific Instruments 68 (1997) 8.
[12] M. Fotino, Review of Scientific Instruments 64 (1993) 159.
[13] J.A. Katine, Eric E. Fullerton, Journal of Magnetism and Magnetic Materials 320 (2008) 1217.

Web References

[1] 〈10.1016/0304-8853(96)00062-5〉.
[2] 〈10.1103/PhysRevB.54.9353〉.
[3] 〈10.1103/PhysRevLett.80.4281〉.
[4] 〈10.1126/science.285.5429.867〉.

[5] ⟨10.1103/PhysRevLett.84.3149⟩.
[6] ⟨10.1063/1.1374230⟩.
[7] ⟨10.1063/1.3005426⟩.
[8] ⟨10.1016/S0304-8853(02)00291-3⟩.
[9] ⟨10.1063/1.1556168⟩.
[10] ⟨10.1116/1.576509⟩.
[11] ⟨10.1063/1.1148249⟩.
[12] ⟨10.1063/1.1144419⟩.
[13] ⟨10.1016/j.jmmm.2007.12.013⟩.