Substantial increase of the critical current on a Spin Transfer Nanopillar by adding an Fe/Gd/Fe trilayer

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Abstract

Spin Transfer Torque (STT) excitations have created an increasing interest on the last few years due to the technological possibilities of current induced domain wall movement [1], switching nanomagnets [2] or generating radiofrequency signals [3]. However, they can also be detrimental in other applications like magnetic read heads, where stability and signal-to-noise ratio are very important issues in which STT has a negative effect [4]. In consequence, while for many applications the goal is to reduce the critical current density (j_C) at which STT is induced, others require just the opposite.

The inclusion of Rare Earths (RE) contaminants on a magnetic layer has been one of the main approaches used to affect important magnetic properties like polarization, precessional frequency or damping [5,6,7]. Within RE, Gadolinium (Gd) is of special interest because it is ferromagnetic up to Room Temperature (T_C(Gd)=293 K) and it has a very large magnetic moment at low temperatures. As a dopant it has already shown great potential for tuning the resonance frequency of a magnetic domain wall [8] or its velocity in magnetic nanostripes [9], or even controlling the spin polarization of the material [5,9].

In this work we have studied the influence of Gadolinium on the STT in Permalloy based nanopillars. We report a remarkable increase of the j_C required to destabilize the Permalloy layer when a Fe/Gd/Fe ferrimagnetic trilayer is added onto the structure. Indeed, other ferrimagnetic structures have been already successfully applied in spin valves in order to increase the critical current for STT [10]. The use of a thin layer of Gd could potentially add stability to this kind of structures without detriment of performance.

The basic structure used in this study is SiO_2// Cu(60)/ CoFe(12)/ Cu(10)/ Py(4)/ <u>AFL</u>/ Cu(8) where Py stands for Permalloy ($Ni_{80}Fe_{20}$) and AFL is an Artificial Ferrimagnetic Layer of Fe(1)/ Gd(1)/ Fe(1). Numbers between brackets represent thickness in nanometers. In order to understand the effect of the AFL, we have measured also a reference sample with only Py in the free layer (i.e. SiO_2// Cu(60)/ CoFe(12)/ Cu(10)/ Py(4)/ Cu(8)). Figure 1 shows the phase diagram and some selected R-I loops measured at 10 K on elliptical pillars (with axis of 50 and 150 nm) patterned on the reference sample (Fig. 1a and 1b) and on the sample with AFL (Fig. 1c and 1d) respectively.

In the hysteretic region of the diagrams (at low fields) the j_C is observed to increase almost an order of magnitude with the insertion of the AFL (from $2.3\cdot10^7$ A/cm^2 to $1.6\cdot10^8$ A/cm^2). In the reference device, reversible transitions (usually associated to unstable precession-like motion of the free layer) are predominant out of the hysteretic region and can be observed even for very high fields (~500 Oe). On the other hand, in the device with AFL these reversible transitions are almost no existent in all the range of field applied. In fact, in this device there are not transitions at all for applied fields higher than ~200 Oe.

The effect of the Fe/Gd/Fe trilayer on the magnetic properties of the Py layer has been studied through Ferromagnetic Resonance, SQUID and P-Moke measurements (Fig. 2). We observed that the AFL modify the damping, saturation magnetization and thickness on the free layer, but these variations only explain an increase of the critical current by a factor 1.6. On the other hand, Gd has small polarization (~13% [5]), and most of the magnetic moment in the Gd layer comes from strongly localized 4f electrons. Therefore, all the angular momentum carried by the spin polarized current in the Py/Fe free layer must be transferred to the antiparallel Gd layer at the interface between the 3d Py/Fe and the 4f Gd. The effect of this sudden transfer of angular momentum can be observed experimentally in any standard Spin Valve just by inserting a very thin Gd layer between the non-magnetic layer and the free layer. By doing this the magnetoresistance value drops to zero [11]. The large j_C enhancement observed in our nanopillars seems to be caused by a reduction of the effective torque on the free layer associated to the sudden transfer of angular momentum at the interface of the antiparallel Gd layer.

It is also important to highlight the fact that the total ΔR of the device does not change much by adding Fe/Gd/Fe, as the thickness of the Py layer underneath is of the order of its spin diffusion length. Therefore our results with this type of trilayers might constitute a potential solution to the problems of STT instability in some nanometer-size devices.

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Figures:

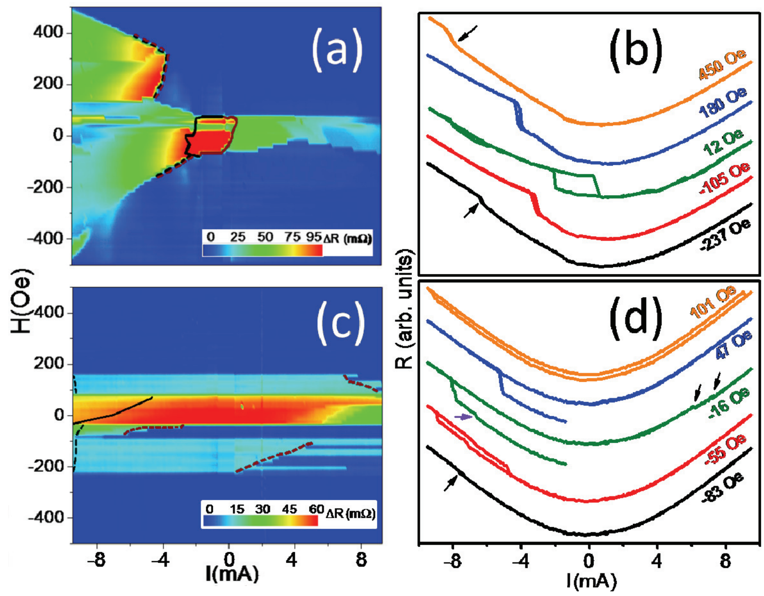

Figure 1: Stability phase diagram at 10 K corresponding to a reference Py device (a) and to a device with Fe/Gd/Fe (c). Color diagrams have been obtained from the positive branch (i.e. from $-I_{max}$ to $+I_{max}$) of the R-I loops for different fields, and normalized so ΔR=0 corresponds to P state (dark blue in the diagrams). The colored lines on top of the contour plots highlight hysteretic transitions. Brown lines indicate a transition from high to low resistance in the positive branch ($-I_{max}$ to $+I_{max}$), either from AP-state to lower resistance (solid brown line) or from some other intermediate resistance value (I-state) to a lower resistance (dashed brown line). Black lines represent transitions from the P state to a higher resistance state on the negative branch of the R-I loops, either from P to AP state (solid black line) or from P to a I-state (dashed black line). Selected R-I loops at 10 K and different fields for the reference device are represented in (b) and for the device with Fe/Gd/Fe in (d). The current sequence was I=0→ -Imax → +Imax → 0. Arrows in (c) and (d) emphasize minor transitions or instabilities.

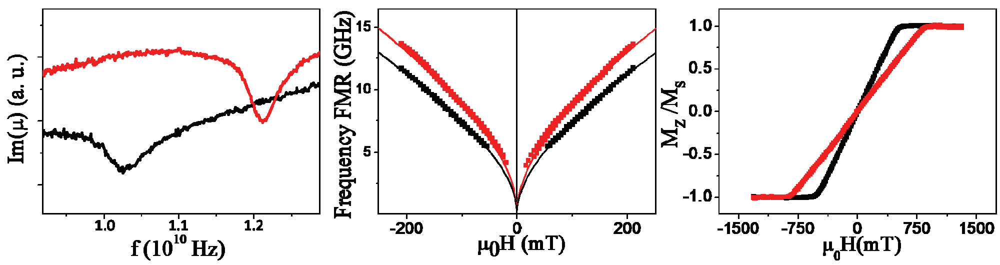

Figure 2: Measurements at RT in a Py(4nm)-film (black symbols) and a Py(4nm)/Fe(1nm)/Gd(1nm)/Fe(1nm)-film (red symbols). (a) Imaginary part of the permeability measured at high fields. (b) FMR data (symbols) adjusted to the Kittel equation (line). (c) P-Moke hysteresis loops with the field applied perpendicular to the sample plane.