Optimization of spin valves with synthetic-ferrimagnetic layers for nanoscale sensing devices

Paulo Coelho[1,2], Diana C. Leitao[1,2], Susana Cardoso[1,2] and Paulo P. Freitas[1,2]

1 – INESC-MN and IN, Lisboa, Portugal
2 – Instituto Superior Técnico, Av. Rovisco Pais, 1000-029 Lisboa, Portugal

pcoelho@inesc-mn.pt

Magnetoresistive (MR) sensors, such as spin-valves (SV) or magnetic tunnel junctions, are nowadays used in a wide range of applications ranging from hard disk drives or homeland security systems to medical devices [1]. One of the main features of these sensors is the ability to tune their response and operation range as required, thus optimizing the sensitivity and functionality under distinct environments and conditions. Currently available MR sensors with detection levels below nanoTesla [2] allow the measurement of extremely low magnetic fields, and are therefore suitable candidates for magnetic imaging [3,4]. In particular, nanoscale MR sensors can provide the desired features for high spatial resolution. However, reduction in spin valve size increases strongly the effects arising from demagnetizing fields of the free layer, which in turn affects the device sensitivity. Thus, using a synthetic ferrimagnet (SF) free layer, composed by a ferromagnetic/metallic/ferromagnetic stack, lowers the effect of the magnetostatic field through the reduction of the effective magnetic thickness [5]. The sensitivity is thus largely improved.

The SV stack was deposited in a Nordiko 3000 Ion Beam Deposition (IBD) system, consisting of Glass/Ta(2)/NiFe(3)/IrMn(8)/CoFe(3.3)/Ru(0.8)/CoFe(3.3)/Cu(2.5)/CoFe(2)/NiFe(2)/Ru(1.2)/NiFe(2.5) /Ta(10) (thickness in nm), then annealed in vacuum for 15 min at 250ºC under 1T. The stack is composed by a synthetic antiferromagnetic (SAF) pinned layer [CoFe(3.3)/Ru(0.8)/CoFe(3.3)] and a SF free layer [CoFe(2)/NiFe(2)/Ru(0.8)/NiFe(2.5)]. This sample showed the following bulk magnetotransport properties: GMR~6.7 %, H_f~13.7 Oe and H_c<1 Oe. For comparison bottom-pinned SAF SV and top-pinned SV stacks were also deposited. Figure 2b summarizes all studied structures. The samples were patterned into stripes with a fixed length of 70 µm and height ranging from 2 to 6.5 µm, combining optical lithography and ion milling etching. Furthermore, another set of SAF-SF SVs were also prepared but patterned into stripes with a fixed length of 6 µm and height (h) ranging from 100 nm to 1000 nm, using electron beam lithography and ion milling etching.

The magnetic properties (Offset field,H_o; Saturation field,H_{sat}; Coercive field,H_c) of the samples from the micrometer down to nanometer sizes were studied (Fig.1). Both H_o and H_{sat} follow the same decreasing trend with increasing height. However, due to high H_c of larger size SV, only those with h<3.5 µm are eligible for sensing applications. For the nanometric SV, the SAF-SF structures present a more stable and lower H_o and most importantly lower values in H_{sat}. Notice that H_{sat} will define the ideal sensitivity of the device: $S_{ideal} = MR/(2H_{sat})$. The SAF-SF stack was chosen for nano SV process since the demonstrated properties would increase the device sensitivity. For the targeted sub-500nm structures the sensitivity values of SAF-SF SVs are higher than for SAF (only) SVs values. The SAF-SF SV exhibited gain factors in sensitivity between 2 (h=100 nm) to 5 (h=500 nm) times in comparison with SAF SV (Fig.3). Among the SAF-SF structures, the bottom pinned #2 shows a maximum gain factor of 2 compared to the top pinned #1, whereas there is not a considerable difference between the bottom pinned #2 and top pinned #2.

These structures are suitable to incorporate with magnetic flux concentrators for further increase in sensitivity, and thus use in high resolution and high sensitivity magnetic imaging.

References

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Figures:

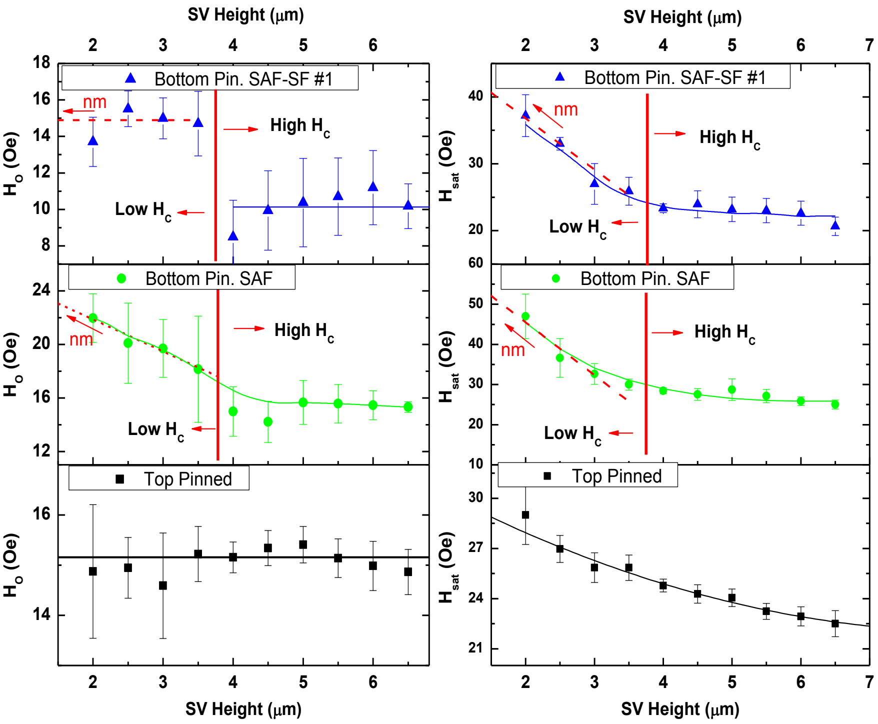

Figure 1: (Left) Offset field (H_o) variation with SV height (h) for the different SV structures. (Right) Saturation field (H_{sat}) variation with SV height for different SV structures. The lines are a guide to the eye.

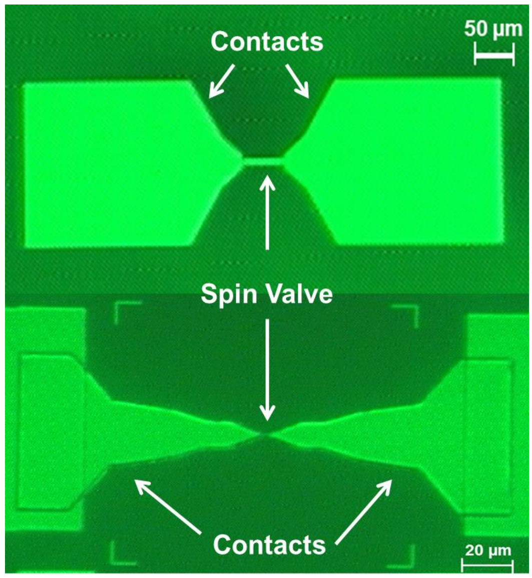

Figure 2: Microscope image of SV and contacts in the micrometric (Top) and nanometric (Bottom) processes.

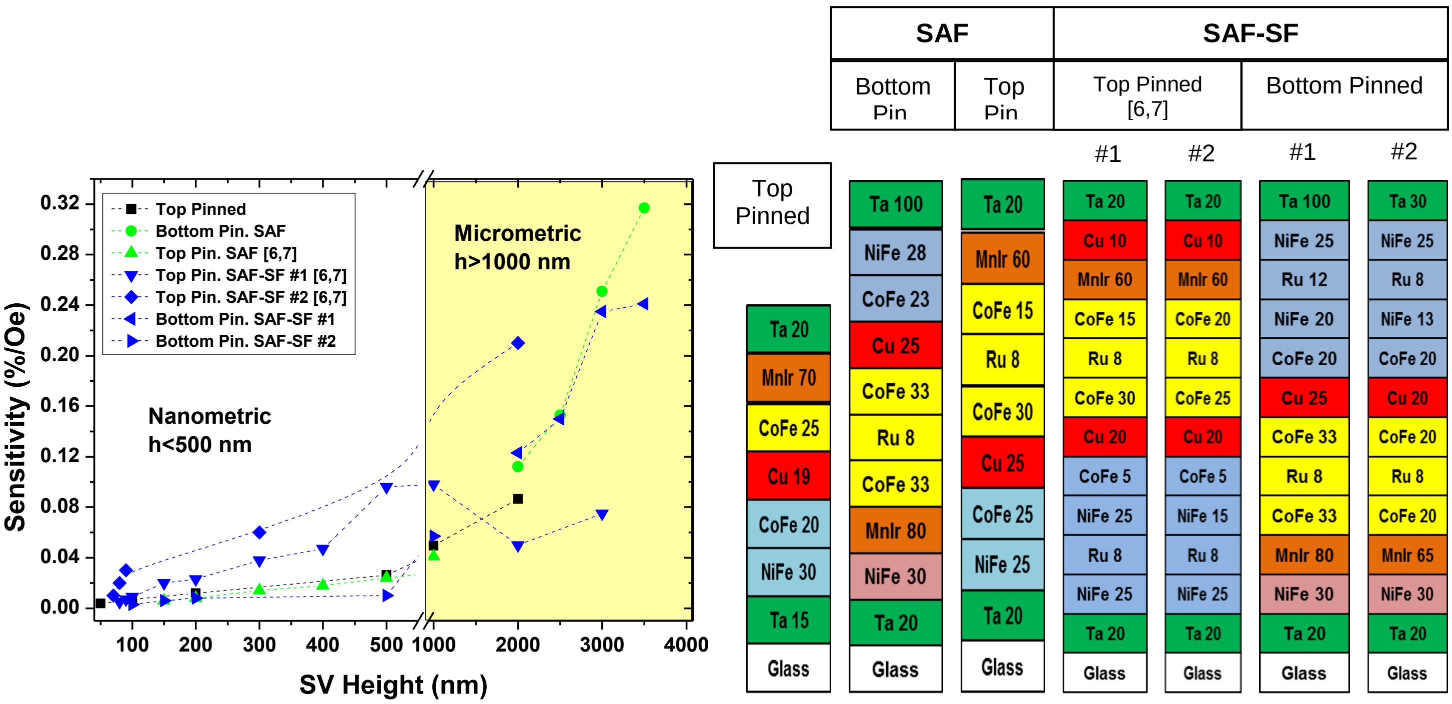

Figure 3: (Left) Sensitivity dependence on h for different SV. Nanometer and micrometer sizes are compared. (Right) Detailed SV stacks (thickness in Å) used for these studies from top pinned, bottom/top pinned SAF and bottom/top SAF-SF structures.