Nanoscale MgO magnetic tunnel junctions sensors with incorporated biasing and enhanced sensitivity

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Abstract

Highly sensitive nanosensors with high spatial resolution provide the necessary features for high accuracy imaging of isolated magnetic nanoparticles or mapping of magnetic fields [1]. MgO based magnetic tunnel junctions (MTJ) showing large tunneling magnetoresistance (TMR) and low a resistance - area product (RxA) stand out as a good starting point for nanosensing devices. The most common methods to linearize transfer curves resort to the use of shape anisotropy [2,3] or biasing by permanent magnets [2]. The former, in particular for nanometric dimensions, provides very large saturation fields reducing significantly the linear operation range of the sensors, while the latter has the disadvantage of increasing the device's footprint. Recently, Zeng *et al.* reported a sensitivity up to 0.036 %/Oe [4] for nanosensors using an out of plane CoFeB layer with a thickness of 1.64 nm. Another alternative to linearize micrometric sensors has been reported resorting to MTJs with both pinned electrodes [5]. In this case, the linear range can be controlled by the exchange coupling strength in the sensing layer allowing the use of low aspect-ratio geometries and thus reducing the device footprint.

In this work we report the fabrication of nanosensor devices based on MgO-MTJs with pinned sensing layer. The MTJ stacks were deposited by a TIMARIS RF magnetron sputtering tool and consist of Ta5/CuN 50/Ta 5/CuN 50/Ta 5/ Ru 5/MnIr 20/ CoFe 2/Ru 0.85/ CoFeB 2.6/MgO < 1/CoFeB 3/ Ta 0.21/ NiFe 5/ CoFe 2/ MnIr (t) / Ta 10/Ru 7 (thickness in nm), where top MnIr layer has thicknesses *t* of 6 and 8 nm. The films were later patterned into circular (measure diameter D=120 to 500 nm) and elliptical pillars with low aspect ratio(120x140 to 120x200 nm) using combination of electron beam lithography, ion milling and lift-off [6]. As deposited MTJs show TMR~110%-150% and RxA~1-10 $\Omega\mu m^2$. Using consecutive annealing steps one is able to achieve the desired orthogonal magnetic configuration between sensing and reference layer [1]. The second annealing temperature was optimized in order to yield patterned sensors responses with improved linearity [7]. In these structures the sensor's linear range can be controlled by the exchange coupling strength, which in turn depends on the MnIr thickness. VSM characterizations indicated an exchange coupling field of -205 Oe for MnIr 8 nm and -65 Oe for MnIr 6 nm. However, if the exchange field is too small the effect of stray fields may dominate, leading to discontinuities in the transfer curve. Figure 1 shows the transport curves for selected devices with circular (a) and elliptic (b) shape. Overall, a linear non-hysteretic behavior was obtained for both stacks. However, an increase in sensitivity (S_0) was observed when thinner MnIr was used (Figure 2). Here we define sensitivity as $S_0 = 1/R_0\, dR/dH$ being directly comparable to other nanosensors reported in literature [4]. These results are in accordance with a linear operation range dominated by the exchange field strength. In fact, a noticeable improvement in the sensitivity for circular structures from an average value of ~0.1%/Oe for MnIr 8nm up to ~0.2%/Oe for MnIr 6 nm is observed. A significant increase in the sensitivity of elliptical devices is also observed, although displaying a dependence of S_0 on the size of the sensor. In this case a competition between the exchange field and the demagnetizing fields is clear leading to overall smaller S_0 values for ellipses when compared to dots. Nevertheless, such high S_0 values are a major improvement in comparison to that reported previously for nanometric sensors [4], and extremely competitive with values reported for micrometric spin-valve sensors [2,3].

References

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Figures

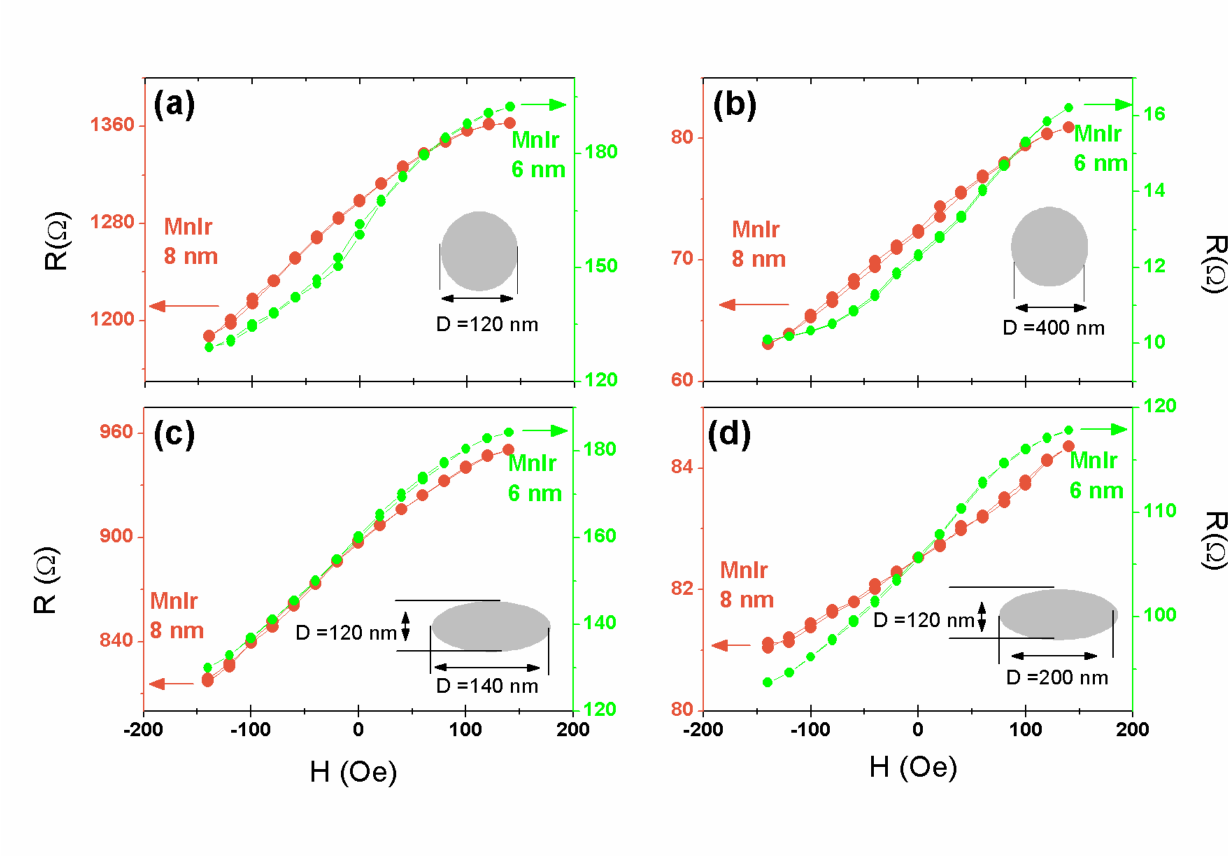

Figure 1 : Representative transfer curves for circular and elliptical nanosensors displaying the linear non-hysteretic behavior.

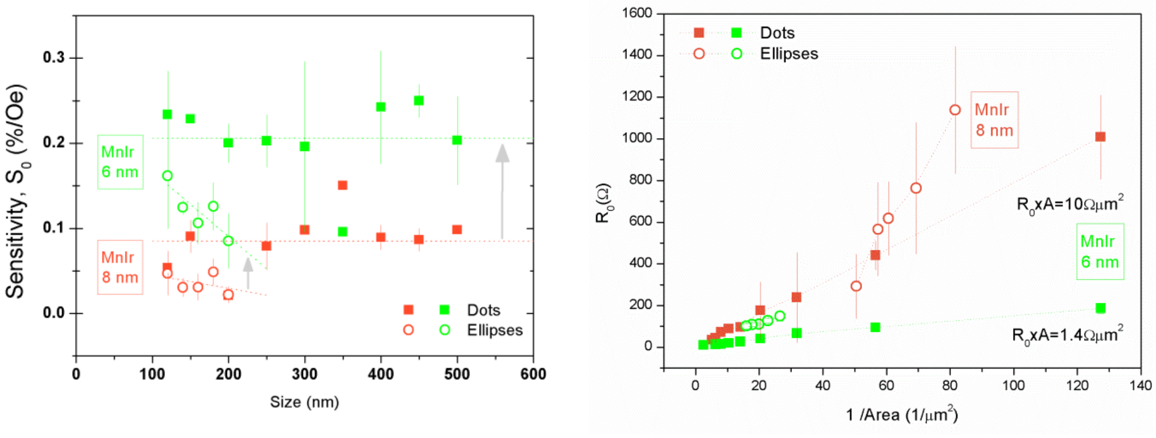

Figure 2: (left) $S_0 = 1/R_0\, dR/dH$ dependence on the size of the nanosensor (size corresponds to the diameter in dots and to the largest dimension in ellipses). A total of about 120 nanodevices were measured for sample with MnIr 8 nm, and about 100 devices for MnIr 6 nm (right) Dependence of the resistance value at zero field on the area of the sensor.