Great improvement of Magneto-Impedance in FeNi-based multilayers by adding Ti spacers of nanometric thickness

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Soft magnetic thin films with high permeability are being actively studied in several fields such as magnetoelectronics (based on domain wall dynamics, for instance), spin polarized transport, flux concentrators for microdevices and materials for high sensitivity magnetic field sensors, among others. In some of these fields, basic research is exploring amazing possibilities, but still far from real applications. In some others, oriented investigations are trying to enhance the properties of the materials to improve the performance of the devices.

Soft ferromagnetic materials exhibit the Magneto-Impedance (MI) effect manifested by a great change of their electrical impedance under the influence of a magnetic field. If is basically a consequence of the reduction of the effective section for current flow due to the skin effect, and is controlled by the changes of the material permeability due to the applied magnetic field. The relative change in impedance can reach 800% with huge sensitivities to small fields, up to changes of about 500% per Oesterd [1,2]. These extraordinary figures are not approximated at low fields by any other room-temperature magnetic field sensor. Cobalt-based amorphous wires are used in commercial magnetic field sensors that are utilized, for instance, in electronic compasses to detect the Earth magnetic field [3].

In fact, magnetic field sensors are earning an exceptional prominence for multiple applications such as personal electronics (entertainment gadgets, smart phones and related devices, sports, etc.), automotive and transportation (driving aids and autonomous vehicles, high speed trains, aerospace, etc) and bio-medicine (quick and self-diagnosis, targeted drug dosing, localized cancer treatment, etc.). New, competitive sensors must combine high performance with small size (microsensors) and smooth interfacing with conditioning electronic circuitry. Thin film-based MI sensors are well-adapted candidates to fulfill those requirements.

Permalloy ($Fe_{20}Ni_{80}$) thin films can be easily fabricated by evaporation or sputtering (which is preferred for mass production). For MI, a small, well-defined transverse anisotropy (anisotropy field of 1 to 5 Oe) is desired. This can be accomplished by applying a magnetic field during deposition and can be improved by an after-deposition magnetic field annealing. On the other hand, MI is dominated by the skin effect, which is noticeable when the penetration depth is comparable to the thickness of the film. For good results at 1 GHz, 1μm thick films are needed. However, thick sputtered FeNi films develop a columnar structure that takes the anisotropy out of the plane and ruins the magnetic softness. The Argon pressure during the sputtering process determines the energy of the atoms arriving at the surface and the structure of the deposit. After a systematic study of these dependences we succeeded in obtaining 170 nm thick films with optimum magnetic properties deposited at room temperature with an Ar pressure of 4×10^{-3} mbar [4].

In order to further increase the overall thickness of the MI material we have explored a multilayered approach using thin Ti layers to frustrate the tendency of FeNi layers to develop the columnar structure. We have determined that a 6 nm thick Ti layer is sufficient to accomplish that, and have produced multilayered samples of the type $[FeNi(170nm)/Ti(6nm)]_n/FeNi(170nm)$ up to n=5, which sums up about 1 μm thin sample [5].

Best MI results are obtained when the Magneto-Inductive effect (reactive part of the impedance) is enhanced. This can be done using a trilayer structure with the magnetic layers enclosing a non-magnetic conducting layer (gold, silver or copper, for instance). We have prepared and tested a series of $[FeNi/Ti]_n/Cu(t)/[FeNi/Ti]_n$ multilayered structures with n from 1 to 6 and central Cu layer thicknesses (t) from 10 to 500 nm (figure 1). The samples were deposited onto either rigid glass or flexible polymeric substrates by rf-sputtering, using metallic masks for patterning the samples in the form of 10 mm long and 1 mm wide stripes. Figures 2 shows the MI at 35 MHz (at which the maximum sensitivity is achieved). Figure 3 displays the frequency dependence of the MI ratio and the MI sensitivity of a sample with $n = 3$ and $t = 500$ nm deposited onto a glass substrate. The measurements were performed in a network analyzer using a microstrip line test fixture. The MI ratio $\Delta Z/Z$ for the absolute value of the impedance is defined with respect to the value at the maximum applied field (150 Oe). The MI sensitivity is defined by S (%/Oe) = $(\Delta Z/Z)/\Delta H$, with $\Delta H = 0.1$ Oe. The values of MI (210 %) and S (110 %/Oe) are extremely competitive and promising for applications.

References

[1] M. Vázquez, J. Magn. Magn. Matter., **226-230** (2001) 693.
[2] G. V. Kurlyandskaya, H. Yakabchuk, E. Kisker, N. G. Bebenin, H. García-Miquel, M. Vázquez, V. O. Vas´kovskiy, J. Appl. Phys., **90** (2001) 6280.
[3] Y. Nakamura, T. Uchiyama, C. M. Cai, and K. Mohri, IEEE Trans. Magn., **44**, (2008) 3981.
[4] A. V. Svalov, I. R. Aseguinolaza, A. García-Arribas, I. Orue, J. M. Barandiaran, J. Alonso, M. L. Fernández-Gubieda, and G. V. Kurlyandskaya, IEEE Trans. Magn. **46** (2010) 333.
[5] G. V. Kurlyandskaya, A. V. Svalov, E. Fernández, A. García-Arribas, and J. M. Barandiaran, J. Appl. Phys. **107** (2010) 09C502.

Figures

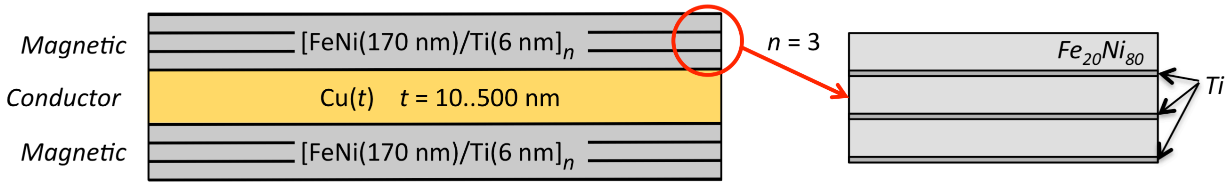

Figure 1. Scheme of the structure of the multilayered $[FeNi/Ti]_n/Cu(t)/[FeNi/Ti]_n$ samples.

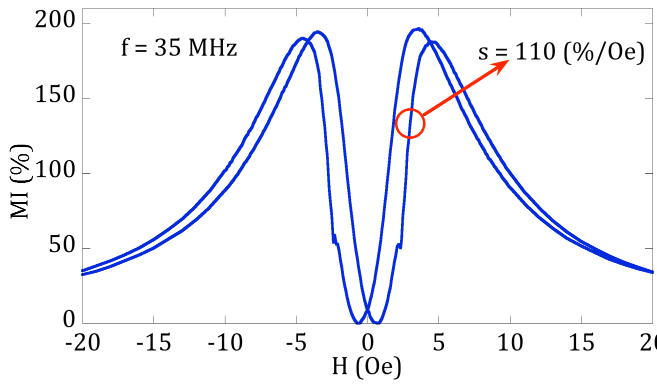

Figure 2. Low field detail of the Magneto-Impedance curve (ΔZ/Z) for a multilayered $[FeNi/Ti]_5/Cu/[FeNi/Ti]_5$ sample with a central Cu layer thickness of 500 nm, measured at the frequency at which the sensitivity is maximum.

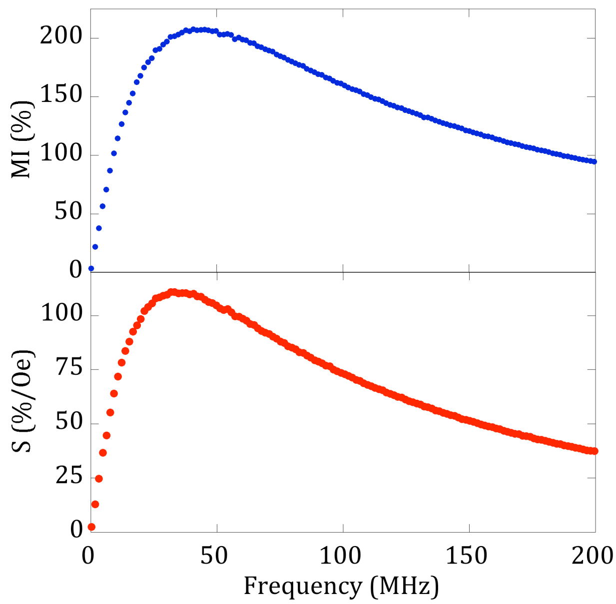

Figure 3. Frequency dependence of: (top) the maximum value of the Magneto-Impedance ratio and (bottom) of the maximum value of the sensitivity for a multilayered $[FeNi/Ti]_5/Cu/[FeNi/Ti]_5$ sample with a central Cu layer thickness of 500 nm.