# Nanostructured GMI multilayers deposited onto flexible substrates for low pressure sensing

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GMI (Giant Magneto-Impedance) is the great change of the electrical impedance that soft ferromagnetic materials exhibit when a magnetic field is applied. It is a classic electrodynamic effect: in the quasiestatic regime (when the wavelength of the electromagnetic field is much greater than the circuit dimensions) the impedance change can be described using Maxwell equations for specific boundary conditions [1-2]. This effect is basically a consequence of the reduction of the effective section of the material for AC current flow due to the skin effect, and is controlled by the changes of the permeability of the material caused by the application of an external magnetic field [3]. GMI applications require a soft magnetic material with low coercivity, very high magnetic permeability and high saturation magnetization. In case of amorphous materials Co-based wires and ribbons can be considered as most studied GMI materials [4]. For thin films and multilayers one of the most suitable materials displaying this effect is the $Fe_{19}Ni_{81}$ permalloy.

Many sensor applications require thin film based sensitive elements that for good GMI response have to be about one micron thick. The GMI material used in this investigation is based on permalloy ($Fe_{20}Ni_{80}$) obtained by sputtering at an argon pressure of $3.8 \times 10^{-3}$ mbar under a magnetic field of 250 Oe applied in the plane of the film to induce a well defined magnetic anisotropy. Previous studies [1] have demonstrated that, once the thickness of the film reaches 200 nm, a columnar structure develops that ruins the in-plane anisotropy and the magnetic softness required for high GMI values. To avoid this problem, we have developed nanostructured magnetoimpedance multilayers. The insertion of 6 nm thick titanium layer between 170 nm thick permalloy layers, result in the breaking of the columnar structure of the permalloy film without deteriorating the magnetic softness. It is also possible to increase the MI performance, even at lower frequencies, using a sandwich structure by inserting a nonmagnetic conductor between two magnetic layers. This configuration enhances the magneto-inductive effect and allows obtaining higher GMI ratios when the conductivities of both types of layers are different enough. Thus, the material for our work is an F/C/F sandwich, where F is the magnetic structure made of permalloy and Ti layers described above and C is a conductive, non-magnetic copper layer. The structure of the MI element is, therefore, $(FeNi(170\ nm)/Ti(6\ nm))_3/Cu(250nm)/(Ti(6\ nm)/FeNi(170\ nm)_3$.

For comparison, samples were deposited directly onto glass and over flexible and transparent Cyclo Olefin Copolymer (COC) in the form of elongated strips of 0.5 mm width and 10 mm length using metallic masks (Figure 1). The MI measurements were performed by RF techniques using the method described in Ref. [7]. The sample was glued with conductive silver paint between two microstrip lines (with 50 Ω of characteristic impedance) and placed inside a pair of Helmholtz coils. The impedance was obtained from S11 parameter measurements made by a network analyzer, after proper calibration and mathematical subtraction of the test fixture contributions. In this way, the complex impedance Z of the sample was measured at different pressure values as a function of the external magnetic field in a frequency range of 300 kHz to 300 MHz where the quasi-static processes dominate the MI behavior and the resonance effects are still unimportant. The GMI ratio was defined with respect to the magnetically saturated sample in the maximum applied field of $H_{Sat}$= 150 Oe. To study the performance of the samples deposited onto the COC_substrates as pressure detectors, different weights were placed over a rectangular glass (14 mm x 18 mm) to reach a maximum pressure of 4 Pa.

There is a considerable decrease in the GMI ratio (Figure 2) when the multilayer is deposited onto the flexible substrate compared with the one deposited on the rigid glass substrate. Even so, the sensitivity is still high thanks to the excellent performance of the multilayer nanostructure. In zero applied field (Figure 3) the real part of the impedance displays a relative change of 25% with the impedance monotonically increasing when increasing the pressure. The maximum sensibility to the applied magnetic field is reached at 6 Oe. The sensitivity to pressure at this field is shown in Figure 4. It displays a maximum change of 13 % with higher sensitivities at low pressures (10 % of change between 0 and 1 Pa). Both graphs (Figures 3 and 4) display_also the data taken at nearby values of the applied field to show the influence of small changes in the applied magnetic field during the pressure experiments.

In conclusion, we demonstrate first that excellent GMI response can be obtained from nanostructured multilayers deposited onto a flexible and transparent polymeric substrate. These magnetic nanostructures can be useful for a number of applications as detection of magnetic micro and nano particles in microfluidic chambers that are fabricated using such materials [8]. On the other hand, we have centered in studying the pressure response of the materials deposited. Good pressure sensitivities are obtained at zero magnetic field applied and at MI maximum sensibility magnetic field when the nanostructure element is deposited onto a polymeric substrates. Focusing on possible pressure sensor applications, we have checked that our sensor impedance change due to pressure, is stable when small magnetic field variations are applied.

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## Figures:

**Figure 1**

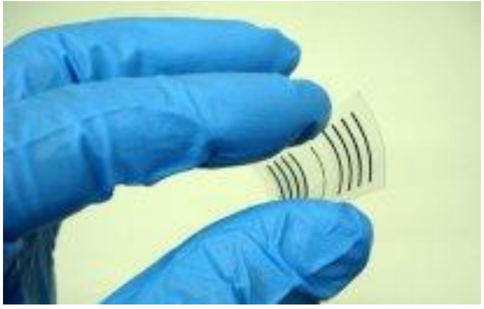

**Figure 2**

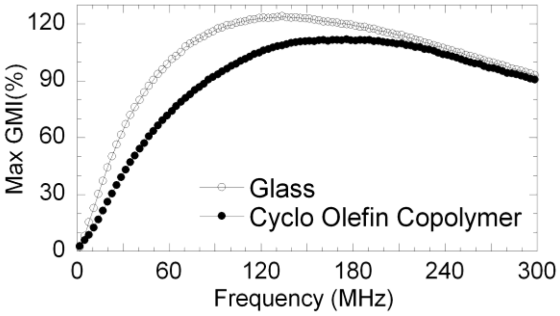

**Figure 4**

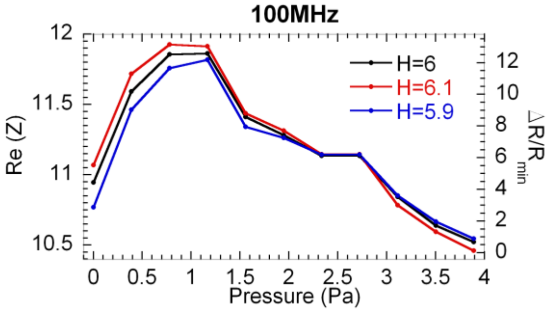

**Figure 3**