

### Analysis of the intrinsic field sensitivity and noise of magnetoimpedance sensors.

L. Melo<sup>1</sup>, D. Menard<sup>2</sup>, A. Yelon<sup>2</sup>, B. Dufay<sup>3</sup>, O. Mareschal<sup>3</sup>, S. Saez<sup>3</sup>, C. Dolabdjian<sup>3</sup>  
 1. Electrical Engineering, Ecole Polytechnique de Montreal, Montreal, QC, Canada; 2. Engineering Physics, Ecole Polytechnique de Montreal, Montreal, QC, Canada; 3. GREYC, ENSICAEN and University of Caen, Caen, France

The giant magnetoimpedance (GMI) effect is observed when the impedance of a magnetically soft conductor is measured as a function of frequency of the drive current and the applied external dc field.<sup>1</sup> Technological applications of the GMI effect such as magnetic, current and stress sensors<sup>1</sup> primarily require high impedance variation, high intrinsic sensitivity to dc and ac fields and low intrinsic magnetic noise. The magnitude of the effect,  $\Delta Z$ , is commonly given by the change of impedance relative to the impedance at saturation. The sensitivity,  $S$  (in units of %/Oe or %/T), is proportional to the derivative of  $\Delta Z$  with respect to the applied dc field. The magnetic noise,  $MN$  (in units of T/ $\sqrt{\text{Hz}}$ ), which is a quantity proportional to the voltage-noise-to-sensitivity ratio, defines the minimum measurable field in 1Hz bandwidth and dictates sensor performance. In this work, the experimental and theoretical behaviour of  $S$  and  $MN$  are analyzed as a function of frequency and applied fields, including the effect of a dc bias current, for a Co-based magnetic conductor. A procedure to obtain the external parameters yielding the highest  $S$  and minimum  $MN$  is outlined.

We have recently proposed a simple model to evaluate the GMI  $MN$  and  $S$  in the MHz regime of anisotropic magnetic wires.<sup>2</sup> The model accounts for a biasing dc circumferential field,  $H_{bias}$ , which is included in the internal field of a single domain cylindrical magnetic conductor. For given frequency,  $H_{bias}$  and easy axis direction,  $S$  is evaluated as a function of the external axial dc field,  $H_{ext}$ . The field yielding the maximum sensitivity ( $S^{max}$ ),  $H_{ext}^{max}$ , is determined, defining the sensor working point. The  $MN$  is then evaluated at  $H_{ext}^{max}$ . For helical magnetic structures having the easy magnetization axis close to circumferential, calculations show that both  $S^{max}$  and  $MN$  (at  $H_{ext}^{max}$ ) decrease for increasing  $H_{bias}$ .<sup>2</sup> The field  $H_{bias}$  essentially increases the internal field, which effectively makes the wire magnetically harder and hence, less sensitive to the driving signal when  $H_{ext}$  is applied.

Calculated normalized sensitivity,  $\Lambda$ , as a function of  $H_{ext}$  and  $H_{bias}$  at 10MHz for a 35 $\mu\text{m}$  diameter is presented in Fig. 1. The quantity  $\Lambda$  is given by  $\Lambda = H_k S$ , where  $H_k$  is the anisotropy field of the wire and  $S = d\eta/dH_{ext}$ ,  $\eta = (\xi\mu_t^{1/2} - 1)\cos^2\theta$ ,  $\xi$  is a function of the wave vectors and material parameters,<sup>2</sup>  $\mu_t$  is the transverse permeability and  $\theta$  is the angle between the static magnetization direction and the direction of  $H_{ext}$ . The permeability depends on frequency, internal field and magnetic damping. The parameter values used in the calculations are typical for Co-rich amorphous wires. Also, we have used  $H_k = 1.4\text{Oe}$  and an easy axis angle of  $72^\circ$  (relative to the axial direction) in the calculations. We observe in Fig. 1 that for this frequency and easy axis angle,  $S$  broadens with  $S^{max}$  (black points) decreasing when  $H_{bias}$  is applied (see also broken lines A and B), as a consequence of the increase of the internal field.

This may not be the case for a wire with an axial easy axis. Figure 2 shows experimental results of  $\Delta Z/R_{dc}$  and  $S$  from the measurement of the impedance of an as-cast Co-based wire as a function of  $H_{ext}$ , when the wire was submitted to a dc bias current,  $i_{bias}$ . The impedance was measured in a HP 8753B Network Analyzer (NA). For the  $i_{bias}$ , injected into the device, we used the bias input of the NA. The experimental sensitivity shown in Fig. 2 was then obtained from the numerical derivative of the impedance versus field curve. In Fig. 2a,  $\Delta Z/R_{dc}$  and  $S$  vs.  $H_{ext}$  at  $f=10\text{MHz}$  and  $100\text{MHz}$  for  $i_{bias}=20\text{mA}$  are shown. This value of  $i_{bias}$  is equivalent to a  $H_{bias} \sim 2\text{Oe}$  at the surface of the wire,

which is close to the  $H_k$  of this sample. Figure 2b shows  $S$  vs.  $H_{ext}$  at  $f=100\text{MHz}$  for  $i_{bias}=40\text{mA}$ ,  $20\text{mA}$  and  $4\text{mA}$ . These results show that there are optimal frequency and dc bias conditions to maximize the sensitivity. The high  $S^{max}$  for a non-zero  $H_{bias}$  opens the possibility for the observation of very low values of  $MN$  predicted by the theory.<sup>2</sup>

In this work, the behavior of  $S$  and  $MN$  are analysed and compared with experiment at frequencies up to  $500\text{MHz}$  on Co-based amorphous wires.

[1] M. Knobel, M. Vazquez and L. Kraus, in Handbook of Magnetic Materials 15, K.H.J. Buschow, ed., Elsevier (2003).

[2] L.G.C. Melo et al., IEEE Trans. Magn., 43, 2992 (2007), and L.G.C. Melo et al., J. Appl. Phys., accepted, Nov. 2007.

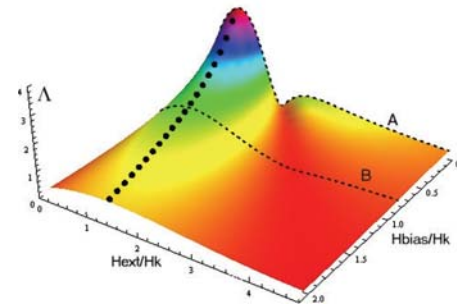


Figure 1. Normalized sensitivity as a function of applied fields at 10MHz for a wire with (almost) circumferential easy axis angle.

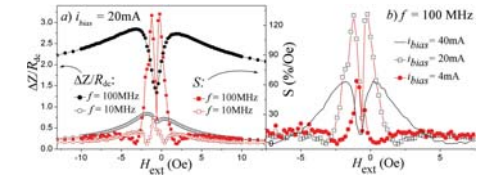


Figure 2. Experimental results for an as-cast amorphous microwire ( $R_{dc}=20\Omega$ ). a)  $\Delta Z/R_{dc}$  and  $S$  for  $i_{bias}=20\text{mA}$  and  $f=10\text{MHz}$  and  $100\text{MHz}$ . b)  $S$  for  $f=100\text{MHz}$  and  $i_{bias}=40\text{mA}$ ,  $20\text{mA}$  and  $4\text{mA}$ .