Giant Magneto-Impedance and Applications

Manuel Vazquez
Institute for Materials Science, CSIC
28049 Madrid. Spain
mvazquez@icmm.csic.es

The Giant Magnetoimpedance, GMI, effect consists of a large variation of the impedance of a metallic magnetic conductor when submmitted to the action of a dc magnetic field. Typically, impedance is experimentally determined by the four point technique by which an ac current flows along the sample and a voltage is picked up to determine the impedance. Both components, real and imaginary, of impedance contribute to the GMI.

Its origin is related to the classical electromagnetic skin effect. When a high-frequency current flows along the sample, typically elongated, it is restricted to a small thickness at its surface. This penetration depth, according to the classical theory, is inversely proportional to the conductivity and to the permeability of the sample as well as to the frequency of the ac current. Consequently, large conductivity and permeability values lead to a reduced skin depth penetration depth. The skin effect has been conventionally studied in metallic conductors with high electrical conductivity so, elements like Cu, Au or Ag exhibit noticeable skin effect.

Although previously discovered, it has not been until the decade of the 90's when GMI has been actually observed and studied in a wide spetrum of magnetic materials with relatively high electrical conductivity. The magnetic permeability of such materials can be modified by the action of a dc magnetic field in such a way that it changes the penetration depth of the skin effect. Consequently, the impedance of these materials depends on the applied dc field. To observe the GMI effect is thus neccesary to deal with a material of large permeability which in addition can be suitably modified by a dc field. In short. GMI is expected to be observed in ultrasoft magnetic materials with as large as possible electrical conductivity. Also, their thickness should be comparable to the changes of skin depth induced by the applied dc field.

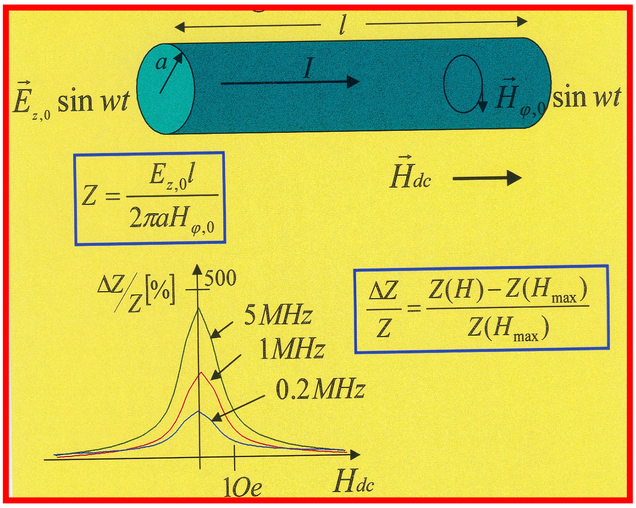

Figure 1.- Schematic view of the GMI effect is summarized in the figure, where a current *I* flows a long a wire submitted to a magnetic field H_{dc}. The definition of GMI as the relative change of impedance, $\Delta Z/Z$, is given together with a typical result for a magnetic microwire as a function of the applied field for a range of frequencies of the current *I*.

GMI is particularly large in materials as soft amorphous materials (ribbons and wires) where besides their soft character, they exhibit relatively high conductivity. Typical range of frequency at which GMI is observed goes from 100 kHz to 10 MHz for amorphous wires and ribbons, and typically increases with working frequency. Even though they are not so soft materials, GMI has been also observed in thin films and multilayers, and multilayer microwires (see figure 2).

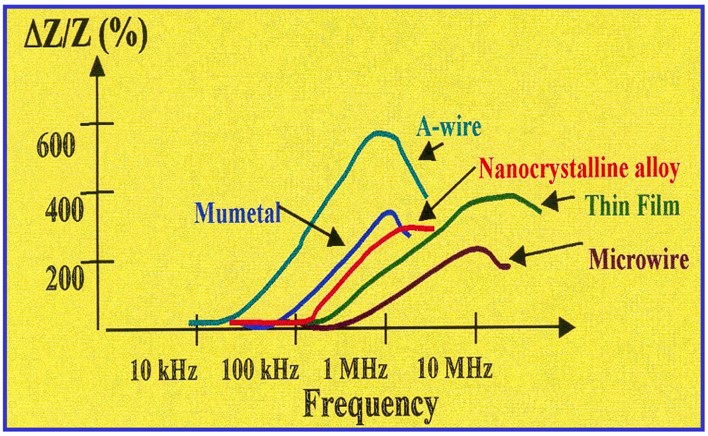

Figure 2.- Typical values of GMI for several families of soft magnetic materials

As a consequence of the stress dependence of magnetic permeability, changes in impedance can be observed in those materials when submitted to changing mechanical stress as tensile or torsional stresses. In such a case we will be talking about stress impedance, SI.

The connection between GMI effect and ferromagnetic resonance, FMR, has been discussed in a number of works. In this case, resonance phenomena are typically observed in the GHz range, and particularly the natural ferromagnetic resonance, NFMR, is detected between 2 and 12 GHz for example for amorphous microwires depending on the magnetostriction constant.

Applications of GMI effect have been proposed in a number of sensor devices where sensing element exhibits the mentioned characteristics. A number of sensor devices make use of GMI effect. The first and main application is as magnetic field sensor, where the GMI element is placed in a region of changing dc field which amplitude is to be quantified. A direct consequence of it is for example a dc current sensor where the magnetic field created by such a current is measured.

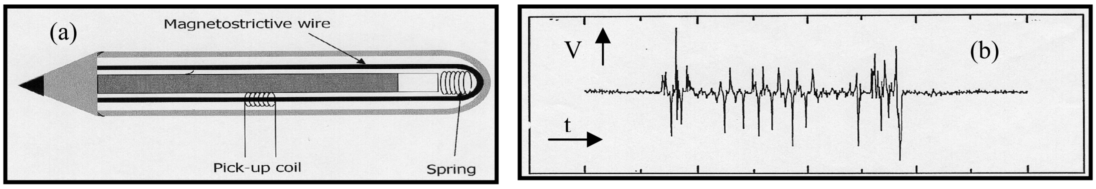

Figure 3.- Schematic view of a magnetoelastic pen (a) based on the stress dependence of GMI and a typical magnetoelastic signature (b).

Other family of sensor devices make use of the stress impedance. In these cases stress sensors are developed, as tensile, bending or torsion sensors. This family of sensors include also a magnetoelastic pen for authentication of signatures (figure 3), or curvature sensor in household electrical appliances.

In the lecture, different aspects about the giant magnetoimpedance effect will be considered from the definition and origin of GMI effect, the materials that suit better to design the GMI effect, their characteristics and phenomenology, and finally their applications in various sensor families.

References.-

1.- Giant Magnetoimpedance, Handbook of magnetic materiasl, M. Knobel, M. Vazquez and L. Kraus, ed. K.H.J. Buschow, Vol 15, Chapter 5, 2003, pp. 497-563. Elsevier, 2003

2.- Magnetic Sensors and Magnetometers, P. Ripka and L. Kraus ed. Artech House, 2001, pp 349-367

3.- See special issue of J. Magn. Magn. Mat. 249 (2002) devoted to the International Workshop on Magnetic Wires and Applications, San Sebastián (Spain) 2001.

4.- Kamruzzaman Md., I.Z. Rahman, J. Mater Proc Techn. 119 (2001) 312

5.- M. Knobel and K. Pirota, J. Magn. Magn. Mater 242-245 (2002) 33