Giant magnetoimpedance in Vitrovac® amorphous ribbons over [0.3-400 MHz] frequency range

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Abstract

Giant magneto impedance (GMI) effect for as-cast Vitrovac® amorphous ribbons (Vacuum-schmelze, Germany) in two configurations (parallel and normal to the ribbon axis) is studied over the frequency range [0.3-400 MHz] and under static magnetic fields -160 Oe < $H_{dc}$ < +160 Oe. A variety of peak features and GMI ratio values, falling within a small field range, are observed and discussed.
The giant magneto-impedance effect (GMI) in amorphous ribbons and thin films has become a topic of growing interest for a wide variety of prospective applications in storage information technology and sensors possessing high sensitivity and fast response1,2.

Magneto impedance effect (MI) consists in change of impedance introduced by a low-amplitude alternating-current (ac) flowing through a magnetic conductor under application of a static magnetic field \( H_{dc} \) (usually applied in the plane along (LMI) or perpendicular (TMI) to the direction of the probe current). The origin of this behavior is related to the magnetic relative permeability \( \mu_r \) value of materials having the right value and direction of magnetic anisotropy field \( H_k \) that yields a given GMI ratio and profile versus \( H_{dc} \) field and frequency \( f \). For instance, in the LMI case, MI profile versus \( H_{dc} \) field exhibits either a single- or a double-peak, for easy magnetization axis (anisotropy axis) parallel or perpendicular to the current direction, respectively. The same behaviour is also observed when frequency \( f \) is varied.

For planar geometry (ribbon and thin films) and in-plane uniaxial magnetic anisotropy2,3, a large GMI ratio (dependent on \( \sqrt{\mu_r} \) is obtained with the easy magnetization direction transverse to the longitudinal axis of conductor possessing along this direction a “transverse” permeability \( \mu_{rT} \). Thus, it seems that a large transverse permeability \( \mu_{rT} \) resulting from the very small magnetic anisotropy (which is inherent to amorphous alloys) is necessary to give a strong GMI effect. But it is also shown2,3 that the maximum GMI value is not really dependent on the magnetic anisotropy but strongly on the magnetic softness, and, in the case of amorphous alloys, relies upon a small but well-defined anisotropy in the transverse direction7.

The distribution of magnetic anisotropy can also alter the GMI effect. It can be decomposed into longitudinal and transverse components along the long and short direction of the ribbon respectively and plays an important role in the GMI effect4,5,6.

The purpose of this work is to examine experimentally the GMI effect in LMI and TMI configurations with different magnetic anisotropy distributions in order to discriminate among all these components.

The GMI measurements were carried out on as-cast amorphous ribbons with nominal composition: \( \text{Co}_{66}\text{Fe}_{4}\text{Mo}_{2}\text{B}_{16}\text{Si}_{12} \) (Vitrovac® 6025). This Cobalt rich metallic glass alloy is interesting because of its relative permeability that can reach as high as 100,000.

Samples (2mm x 15mm x 30 \( \mu \text{m} \)) were cut parallel (CP) as well as transverse (CT) to
the ribbon long axis from an as-cast commercial band having the anisotropy axis along the ribbon axis. The samples obtained show the easy axis oriented only along the long geometrical axis of the samples (confirmed by hysteresis loop measurements) and different levels of anisotropy dispersion. For the transverse-cut sample (CT) the anisotropy axis is altered by strong demagnetizing field $H_{\text{dem}}$ present in this configuration and exhibits an in-plane rotation with respect to its original orientation.

Measurements of the GMI ratio were carried out by applying a field $H_{\text{dc}}$ parallel or perpendicular to the long sample axis using a novel broad band measurement method described elsewhere. All measurements were made at room temperature, in the frequency range [0.3 - 400 MHz], under $H_{\text{dc}}$ fields $-160 \text{ Oe} < H_{\text{dc}} < +160 \text{ Oe}$ and low-amplitude $ac$ current (0.1 mA). The MI ratio was determined by the expression:

$$\frac{\Delta Z}{Z} = \left| \frac{Z(H, f) - Z(H_{\text{max}}, f)}{Z(H_{\text{max}}, f)} \right|$$

where $H_{\text{max}}$ is the maximum value of $H_{\text{dc}}$ (that is 160 Oe).

Taking into account the easy axis orientations of the CT and CP samples measured in LMI and TMI configurations, a single-peak behavior is expected. However, the presence of a transverse anisotropy component and a very low $H_{\text{dem}}$ field in the LMI case results in a double-peak behavior. Thus, the GMI ratio versus $H_{\text{dc}}$ is the typical curve doubly peaking at $H = \pm (H_{kT} + H_{\text{dem}})$ close to the transverse component of the anisotropy field $H_{kT}$ with a separation of about 9 Oe between peaks (Fig.1) for the CP sample.

In the TMI geometry ($H_{\text{dc}}$ perpendicular to ribbon axis) with a larger $H_{\text{dem}}$ field ($H_{\text{dem}} >> H_{kT}$ for high $\mu_r$ magnetic material), the GMI ratio shows a split-peak Lorentzian-like profile with a separation of about 38 Oe between the peaks rounded by the distribution of anisotropy field $H_k$ (not shown here). Comparison of GMI ratio values for CP and CT samples measured at 10 MHz in LMI configuration (Fig. 2) shows a drop of the GMI ratio from 160% to 100%.

GMI strongly decreases as the frequency, $f$, increases. The imaginary part of impedance as a function of $H_{\text{dc}}$ and $f$ (not shown here) is very similar to that of total impedance, indicating that total impedance is made essentially of the imaginary part. The real component (not shown here), also displays a rounded split-peak shape (with field separation between peaks comparable to those of impedance), but is quite insensitive to $f$. This behavior can be ascribed to a more direct dependence on the skin effect that is expected at the frequencies.
FIG. 1: Three-dimensional plot of GMI ratio $\Delta Z/Z$ as a function of frequency $f$ and magnetic field $H_{dc}$ for Vitrovac® 6025 CP-cut sample for the LMI setup.

FIG. 2: GMI ratio profile $\Delta Z/Z$ as a function of magnetic field $H_{dc}$ in LMI configuration at a frequency of 10MHz for Vitrovac® 6025 CP (a) and CT (b) samples. Inset is a zoom-in on the split-peak structure.

used.
In conclusion, our work shows the complexity of GMI spectra modulated by the dispersion of magnetic anisotropy and influence of the demagnetizing field inherent to the geometrical structure of the samples.

1  K. Mohri et al., D. IEEE Trans. Magn. 38 (2002) 3063
2  L.V. Panina et al., IEEE Trans. Mag. 31 (1995) 1249.
3  D. Atkinson et al., IEEE Trans. Magn. 33 (1997) 3364
4  L. Krauss, J. Magn. Magn. Mater. 195, (1999) 764.
5  K.R. Pirotta et al., Phys. Rev. B 50 (1999) 6685.
6  R.L. Sommer et al., Appl. Phys.Lett. 67 (1995) 857.
7  A. Fessant et al., ICM 2003, Rome, Italy, Ref. N° 1386.
8  R. Valenzuela, J. Magn. Magn. Mater. 294, (2002) 300.