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A novel broadband measurement method for the magnetoimpedance of ribbons and thin films

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Abstract

A novel broad-band measurement method of the magneto-impedance in thin films and ribbons is presented. It is based on the automated measurement of the reflection coefficient of a cell loaded with the sample. Illustrative results obtained with a permalloy multilayer thin film are presented and discussed.
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1. Introduction

The magneto-impedance (MI) effect consists of a change in the complex impedance of a ferromagnetic conductor under application of a static magnetic field H_{DC}. This effect has been observed over a wide frequency range from few kHz up to several GHz. MI is related to the effective permeability of the sample, and hence, all mechanisms affecting magnetization processes of the material ought to be considered. Albeit this effect is usually weak, a giant magnetoimpedance effect (GMI) in amorphous ferromagnetic FeCoSiB wires with small magnetic fields (a few Oersteds) and at low frequencies (kHz to MHz) was discovered [1]. A smaller MI effect has also been observed, later on, in ribbons and thin magnetic films [2].

Several reasons explain that interest. Firstly, potential applications of GMI in magnetic fields sensors and magnetic recording heads have been studied and tested in different systems (thin films, sandwich structures, amorphous ribbons and microwires, etc.). Secondly, from the theoretical viewpoint, a better understanding of the mechanisms that drive MI and GMI effects provides an additional tool to investigate intrinsic and extrinsic magnetic properties of soft ferromagnetic materials.

In both cases thin films and ribbons possess several advantages with respect to wires because they allow several orientations of H_{DC} versus AC current direction. Moreover, sputtered or otherwise produced films allow multilayering and size reduction required for integrated devices.

At frequencies above a few 10s of MHz, sample length is no longer negligible with respect to the AC signal wavelength and consequently, transmission line theory must be used [3].

In this paper, an appropriate broadband frequency method for the determination of the MI effect, in thin films and ribbons, is presented. The method is based on the automated measurement, by a network analyser, of the reflection coefficient of a cell loaded by the film under test. The field H_{DC} can be applied either in the plane of the sample or out of it with sets of Helmholtz coils. Some illustrative results obtained using this measurement method with a permalloy multilayer thin film are presented and discussed.

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2. Experiment

The samples used in the present work are single NiFe magnetic thin films of different thicknesses (from a few hundred to a few thousand Å), NiFe multilayer and sandwich structures deposited by RF diode sputtering on 20×2 mm glass substrates. These samples present an in-plane magnetization perpendicular or parallel to the sample axis.

The measuring device is a matched clip fixture, connected to a HP8753 network analyser yielding the complex reflection scattering coefficient S_{11} of the clip fixture loaded by the sample.

The complex impedance $Z(H,f)$ of the sample, is given by

$$Z(H,f) = Z_0 \frac{S_{11}(H,f) + 1}{S_{11}(H,f) - 1}$$

with $Z_0 = 50\ \Omega$ the device characteristic impedance.

The input RF power is 0 dBm and the DC external magnetic field H, applied by two pairs of Helmholtz coils, can be swept from -200 to 200 Oe along or perpendicular to the sample axis.

The apparatus, briefly described here, allows the exploration of the MI effect over a broad frequency band from 0.3 to 500 MHz. The lower bound is imposed by the analyser capabilities and the upper one by our cell design, nevertheless, the method may be easily extended, to lower or to higher frequencies.

The MI ratio used is given by the expression:

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

where H is the DC applied magnetic field, $H_{\max}$ the maximum value of H and f the frequency of the driving AC current.

Numerous samples have been tested using this apparatus. As an example, the results obtained in the longitudinal configuration for a multilayer thin film is shown in the figure below (Fig. 1). The sample is a trilayer thin film ($Ni_{80}Fe_{20}/SiO_2/Ni_{80}Fe_{20}$). The thicknesses are 960 Å for the $Ni_{80}Fe_{20}$ layers and 14 Å for the SiO_2 layer. This sample exhibits an in-plane magnetization perpendicular to the sample longitudinal geometrical axis. The measurements are done in the 0.3–400 MHz frequency range and for a DC magnetic field varying from -40 to 40 Oe. This sandwich structure is peculiar due to the presence of a very thin insulating layer of SiO_2 that provides a significant lowering of the coercive field of the structure as we have previously shown [4]. A weak coercive field is required in some MI based sensors and might be designed along the lines previously described in [4].

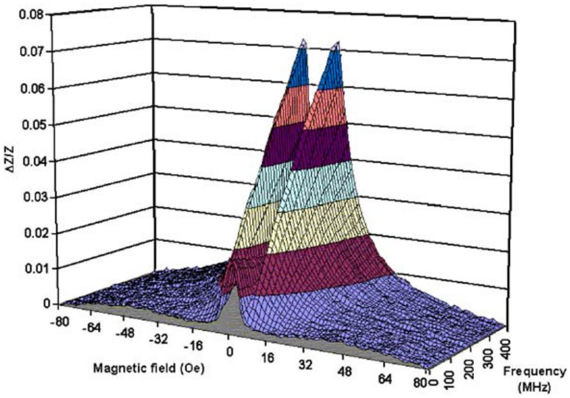

Fig. 1. Three-dimensional plot of the normalised MI ratio $\Delta Z/Z$ for a $Ni_{80}Fe_{20}/SiO_2/Ni_{80}Fe_{20}$ sandwich structure versus frequency and field.

For relatively low frequencies, the $\Delta Z/Z$ ratio decreases first quickly with increase of the DC field H. When the frequency increases, the field dependence of $\Delta Z/Z$ gradually changes. The magnitude of the MI ratio increases with the increase of DC magnetic field H, reaching a sharp peak for H nearly equal to H_k, the effective anisotropy field of the sample ($H_k \approx 4.8$ Oe), and then gradually decreases to zero with further increase of the magnetic field.

3. Conclusion

A novel automated broadband frequency method for the determination of the MI effect in thin films and ribbons, based on the measurement of the reflection coefficient of a loaded cell, is presented. The measurement configuration, allows in-plane and out of plane measurements. The results obtained with this measurement method on permalloy thin films sandwich structures and CoFeSiB ribbons are in good agreement with those obtained by other conventional methods.

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