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Very large magnetoimpedance (MI) in FeNi/Au multilayer film systems

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Abstract

This paper investigates the magnetoimpedance (MI) effect in miniature NiFe/Au/NiFe multilayer film systems with layer thickness of 0.5 μm produced by RF sputtering. The magnetic films have a well-established transverse anisotropy, which was achieved by imposing a large magnetic field during the deposition and further annealing. The influence of insulating Al_2O_3 layers between the inner conductor and the magnetic layers on MI was also considered. The use of insulation is proving not to improve the MI behavior in thin film systems. The basic three layer film with in-plane size of 50 μm × 5000 μm shows the impedance change of more than 150% with the maximal sensitivity of 30%/Oe in the frequency range of 200–500 MHz. We believe this is the highest sensitivity reported for such miniature film systems.

Keywords: Magnetoimpedance; Multilayers; Magnetic anisotropy; Magnetic sensors

1. Introduction

Magnetoimpedance (MI) in sandwiched (magnetic/conductive/magnetic) thin films is being actively investigated in an attempt to miniaturise MI elements and maintain its high sensitivity for micro sensing applications [1–5]. These multilayer structures subjected to a high frequency current demonstrate a larger change in impedance in response to an external magnetic field than that of a single layer film. The efficiency of this enhancement depends on the conductivity ratio between the inner and outer layers [2]. For the inner lead made of a good conductor (Cu, Ag, Au) the dc resistance is low and can be overtaken at relatively low frequencies by the inductance produced by the magnetic layers. Further, the inner non-magnetic conductor plays a role of a laminating layer that may help to establish a well-defined anisotropy which increases the field sensitivity. Very large MI of more than 300% [1] was reported for film systems of 7 μm thick with amorphous magnetic layers (CoSiB) and Cu inner conductor. Inserting an insulator SiO_2 separation between the conductive lead and the magnetic films further improves the MI ratio up to 620% for this film structure [3].

For thinner multilayers (<1 μm), the maximum MI ratio is considerably smaller and seen at higher frequencies [2,6]. NiFe/Au multilayers of 1.5 μm show 20–30% of the impedance change at frequencies of 50–100 MHz, which is considerably smaller than that theoretically predicted. This can be related to existing deviations from a transverse anisotropy, diffusion during the sputtering process of magnetic/conductive layers on top of each other, which evens the resistivity across the system, and finally, with some measurement implications arising at higher frequencies.

In the present paper we study the magnetoimpedance effect in NiFe/Au film systems with and without insulation layer. The latter was reported to improve the properties of the samples because it enhances the quality of the interfaces by preventing inter-diffusion during annealing [3]. Although our results does not confirm this conclusion (probably because in our miniature systems the insulation worsen the film quality), we report very large MI values in the studied samples, more than 140% in NiFe/Au film systems with layer thickness of 0.5 μm, which are the best results in terms of sensitivity and miniaturisation.

2. Sample preparation

The NiFe/Au multilayer system was sputtered onto a glass substrate placed inside a static magnetic field to induce a transverse anisotropy during the deposition. The sputtered thicknesses were 500 nm for both NiFe and Au layers, and 80 nm for $A1_2O_3$ layers in the case of the insulated samples. The magnetic-

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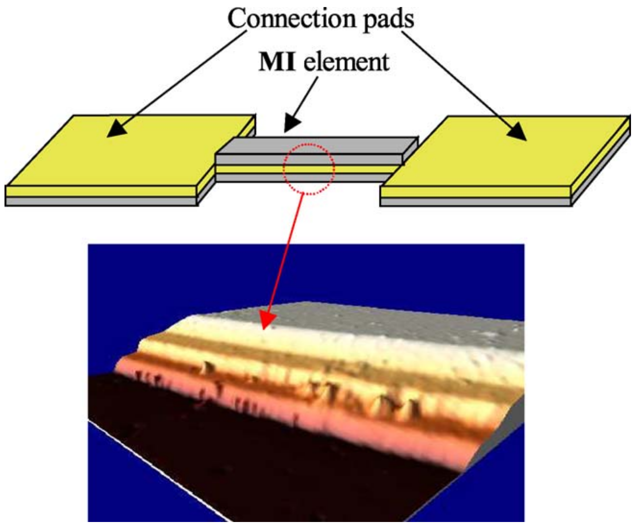

Fig. 1. Film structure (top) and topographic image of the border of the MI stripe of the 100 μm wide sample. The scan was performed by Atomic Force Microscopy.

alloy layers were sputtered from 81 to 19 wt.% NiFe target, and an RF bias of 80 V was applied to the substrate to improve film purity. Besides, magnetron sputtering was used for the deposition of non-magnetic Au and $A1_2O_3$ layers, thus improving the deposition rate. The vacuum before sputtering was taken down to a base pressure of 3×10^{-7} mbar, and the Ar gas pressure during the deposition process was kept at 5×10^{-3} mbar.

After deposition the wafer was patterned out by conventional photolithography methods, using an in-contact mask aligner with an ultra-violet exposure source, and later developed and dry-etched to obtain films with widths in the range from 5 to 200 μm, and lengths of 2 and 5 mm, with rectangular 2 mm × 1.5 mm contact pads at each end (Fig. 1, top insert).

The described patterning process must be performed in two stages in order to etch through the layers above the Au in the contact pads region (upper FeNi in the non-insulated samples and both upper Al_2O_3 and FeNi in the insulated ones). Each etching stage produces a certain amount of undercutting (overetching) on the MI stripe border, as seen in Fig. 1 (bottom). The 3D image has been taken by Atomic Force Microscopy.

The preparation was completed with a thermal treatment at 450 °C and a pressure of 50 m Torr for 1 h to relax internal stresses. As mentioned above, the placement of insulation layers should prevent the diffusion between Au and FeNi that takes place at high temperatures due to the concentration gradients.

During the whole annealing process (including heating and cooling stages) a strong transverse static field (100 Oe) was applied to enhance the transverse anisotropy induced during deposition.

3. Experimental and discussion

In order to make a basic magnetic characterization of the samples we have performed Kerr effect measurements on the NiFe upper layers (sensitive up to about 100 nm from the surface). The experiments have been made at room temperature, using a

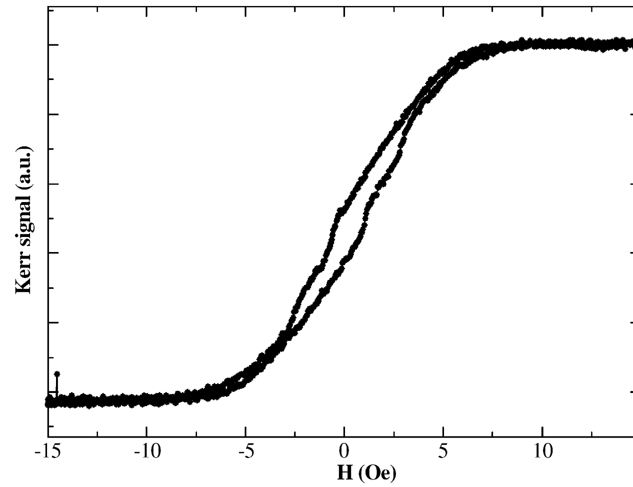

Fig. 2. Hysteresis loop of the upper magnetic layer of the 100 μm wide sample, measured by Kerr effect.

10 Hz excitation field applied along the sample axial direction. The hysteresis loop is close to linear, which is typical of a transverse anisotropy, with an effective anisotropy field H_K at about 8 Oe, as depicted in Fig. 2.

The technique used to perform the GMI measurements is extensively explained in [7]. In short, the sample is glued onto a microstrip line designed for 50 Ω characteristic impedance. Both ends of the microstrip line are soldered to SMA connectors, one of which is loaded with a precision 50 Ω termination and the other is connected to a Network Analyzer through a SMA to N transition and a RF N-type coaxial cable (a schematic view of the test fixture and its high frequency model is presented in Fig. 3). The impedance is obtained from S_{11} parameter measurements after proper calibration and mathematical subtraction of the non-desired high frequency impedance contributions of the test fixture.

To measure the impedance as a function of the applied magnetic field, the test fixture is placed in the central region of a pair of Helmholtz coils. The static magnetic field is applied longitudinally to the sample, up to a maximum value of $H = 100$ Oe, which is sufficient to produce a complete magnetization cycle: from

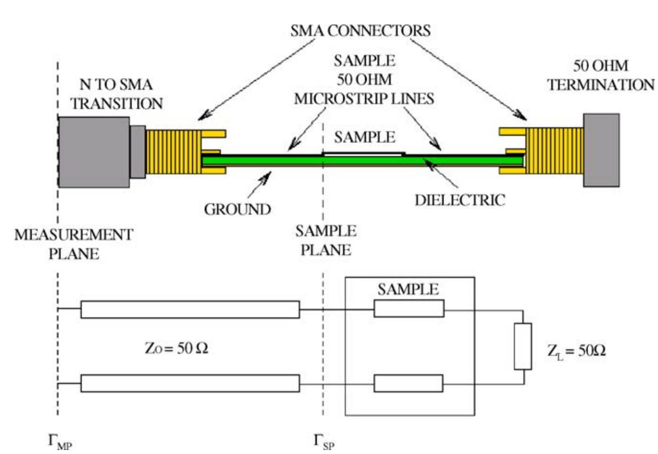

Fig. 3. Schematic view of the measuring fixture (top) and its equivalent circuit (bottom).