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An invariant magnetoimpedance element for stray fields detection

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Abstract

Magnetoimpedance sensitive element that consists of one FeNi[125 nm]/Cu[3 nm])3FeNi[125 nm]/Cu[500 nm]/(FeNi[125 nm]/Cu[3 nm])3/FeNi[125 nm] multilayered structure was designed for the magnetic field detection in the wide range angular interval and its magnetoimpedance was measured experimentally. Double rectangle sensitive element with improved performance was proposed on the basis of mathematical modelling. This simulation was used for optimizing the topology of a wide angle magnetic field sensor equipped with a sensitive element that consists of two crossed multilayered stripes. The creation of magnetoimpedance element, where the measuring response is independent or only slightly dependent on the angle of application of the external magnetic field-is an necessary requirement for the techniques of detection stray fields of complex configuration with unpredictable dynamics.

Keywords: Magnetoimpedance effect; Thin films; Flexible substrates; Magnetic anisotropy; Microdevises

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1. Introduction

Magnetodynamics of materials with high magnetic permeability is a hot multidisciplinary topic of physics of magnetic phenomena, polymer chemistry/colloidal systems, electronics and biomagnetism Llandro (2010) et al. and Antonov et al. (1997). One of the fast growing branches of this area-the giant magnetoimpedance (GMI) Makhotkin et al. (1991) and Kurlyandskaya et al. (2000). GMI phenomenon consists in the change of the total impedance of the ferromagnetic conductor under application of the external magntetic field Antonov et al. (1997) and Correa et al.

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(2010). Presently, in the thin film shaped samples, which are the most compatible with semiconductor electronics, the achieved sensitivity can be as high as 200%/Oe being sufficient for detection even magnetic fields of biogenic nature. It was already shown that GMI detectors can be used for evaluation the total stray field ensemble of superparamagnetic particles distributed on the surface of GMI element, including both "free" magnetic labels and immobilized magnetic labels configurations by Yuvchenko et al. (2014). This opens the possibilities of GMI application in the field of biosensing and as an instrument for characterization of polymer systems and biocomposites containing magnetic elements with different aggregation features. On the other hand, there is a need of thorough control of external magnetic fields of different configurations for environmental protection both living systems and medical equipment. Therefore, special efforts were made for the creation of particular kind of magnetic field sensors and one of them is wide-angle magnetic transducer. Up to now the main results were obtained for amorphous ribbon based sensitive elements Volchkov et al (2009) and Volchkov et al (2013). This option is very attractive for cheap sensitive elements working at reasonably low frequencies of the order of 5 MHz. At the same time the main disadvantage of the ribbon-based GMI sensitive elements is a big size (at least of the order of 50 mm).

In the present work, a giant magnetoimpedance sensitive element that consists of one FeNi-based multilayered structure was designed with the focus on the magnetic field detection in the wide range angular interval. Double sensitive element with improved performance was proposed on the basis of mathematical modeling based on the experimental data obtained for single rectangle type GMI sensitive element.

2. Experimental methods

The FeNi[125 nm]/Cu[3 nm])3/FeNi[125 nm]/Cu[500 nm]/(FeNi[125 nm]/Cu[3 nm])3/FeNi[125 nm] multilayered structures were deposited onto glass substrate by rf-sputtering in an Ar atmosphere using metallic masks. The thickness of the permalloy layers was selected on the basis of previous studies aiming to avoid the transition into a "transcritical" state Vas'kovskii et al (1997) and Coïsson et al.(2009) and Svalov et al. (2009). A constant magnetic field of 100 Oe was applied during sample deposition in order to create uniaxial induced magnetic anisotropy and high magnetic permeability to insure high GMI value.

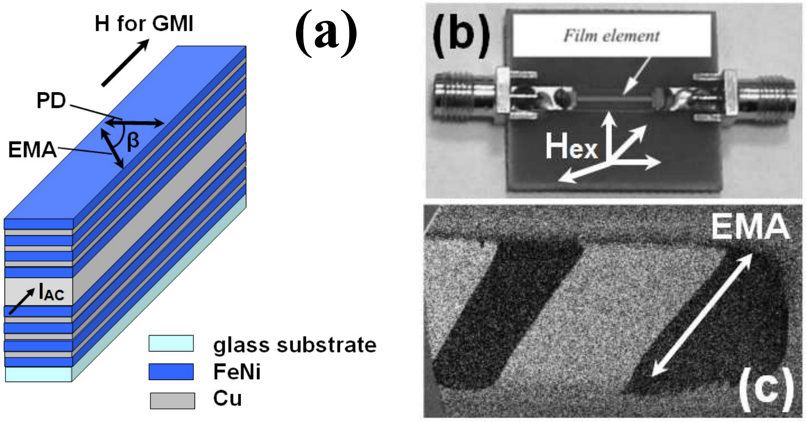

Fig. 1. (a) Schematic description of the structure of the GMI multilayers. [H for GMI] – applied external magnetic field, [PD] – perpendicular direction, [EMA] – Easy magnetization axis, [β] – angle between the direction, which perpendicular of long side of sample and EMA is equal to 45°. (b) GMI sensitive element in the "microstripe" line for magnetoimpedance measurements. The arrows indicate the direction of the external magnetic field Hex. (c) Image of magnetic domain structure obtained by Magneto-Optical Kerr Microscope for GMI rectangular element with 0.5 mm width.

In a majority of GMI studies the easy magnetization axis was usually created in the direction of the long side of rectangular sensitive element Makhotkin,et al. (1991) and Kurlyandskaya et al. (2000). At the same time, for wide angle sensors, that means a need to have reasonably high sensitivity with respect to an applied magnetic field with