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Magnetic Field MEMS-Sensor: Functional Characteristics Control during the Formation of Magnetosensitive Structures

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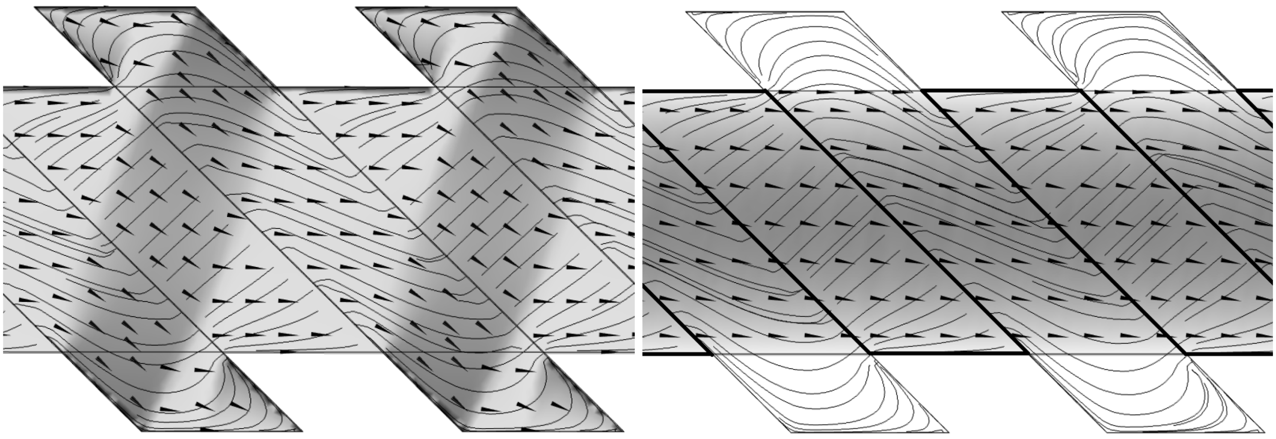
Abstract. In this work the results of substrate temperature effects on coercivity and magnetoresistance in ferromagnetic structures are shown. It was found that with an increase of the substrate temperature from 270 to 390 °C the magnetoresistance increases from 1.2 to 2.3% and the coercive force from 1.6 to 5.3 Oe. A new topology of anisotropic magnetoresistive structures is proposed. In these structures the shape of ferromagnetic elements repeats the shape of nonmagnetic conducting shunts. Sensitivity values obtained for both types of magnetic structures are compared.

Introduction

The development of contemporary microelectronic devices, magnetoresistors in particular, aims to improve their sensitivity, thermal stability and compactness. The range of use of magnetoresistive sensors in the technique is extremely wide therefore requirements to sensitivity value are extremely broad. The sensitivity to the magnetic field is determined by the ratio of the signal amplitude imbalance in magnetoresistive bridge, caused the by influence of the magnetic field, to the value of that field in the linear region of the transfer characteristics of the sensor. It is the most important parameter [1-2], because it determines the use of sensors to address various problems. The sensitivity value is influenced by a number of factors, among which first and foremost design and technology.



a) b)

Fig. 1. The magnetization distribution in magnetosensitive element a) the magnetization distribution in self-aligned structure, grey color distribution denotes the value of magnetization x-component; local magnetization vectors are denoted by black cones, black solid lines are representing the current lines. b) the magnetization distributions in traditional barber-pole structure.

To ensure a high level of output characteristics of AMR sensors it is needed to improve the magnetic properties of the magnetoresistive material (Fig.1). In particular, it is needed to maximize the AMR effect, which determines the output signal amplitude, and to prevent the strong growth of the coercive force and anisotropy field for maximum sensitivity and minimum hysteresis achievement. However, the magnetoresistive material parameters are determined not only by its internal characteristics, but by the composition and parameters of the film growth, particularly, average grain size [3-6]. The sensitivity improvement can be achieved, particularly, by alteration of the sensor shape.

Experiment and Discussions

In this article the experiment to determine the impact of process parameters on the magnetron deposition rate and the grain size in films of FeNi 20:80 was conducted. Permalloy films were obtained by magnetron deposition on a Phase II AJA unit. The target diameter is 50 mm, the distance to the substrate is 112 mm, the thickness of the working and dielectric layers: FeNi (30 nm) / Si3N4 (120 nm) / SiO2 (600 nm) / Si (substrate).

It is shown the substrate temperature significantly influent on the average grain size in the film of permalloy at a constant magnetron power of 150 W and a working gas pressure of 0.5 Pa. To create the anisotropy and the AMR in the magnetron deposition chamber the magnetic field at least 40 Oe was generated. The AMR-effect increasing for high sensitivity achievement and a coercivity decreasing to increase the precision of conversion leads to the necessity of the optimum deposition temperature search. For this purpose, the dependence of the AMR effect and the coercive force on the substrate temperature during the deposition was obtained. This dependence shows the substrate temperature increasing above 320 °C leads to coercivity increasing and does not lead to a substantial AMR-effect increasing. In this regard, the temperature 320 °C was determined as optimal (Fig.2). Other magnetron deposition parameters affect the average grain size and output signal of AMR sensors much weaker.

Experimental samples of permalloy films (80%Ni20%Fe) on the silicon wafer with an insulating layer of Si3N4 were manufactured (Fig.3).

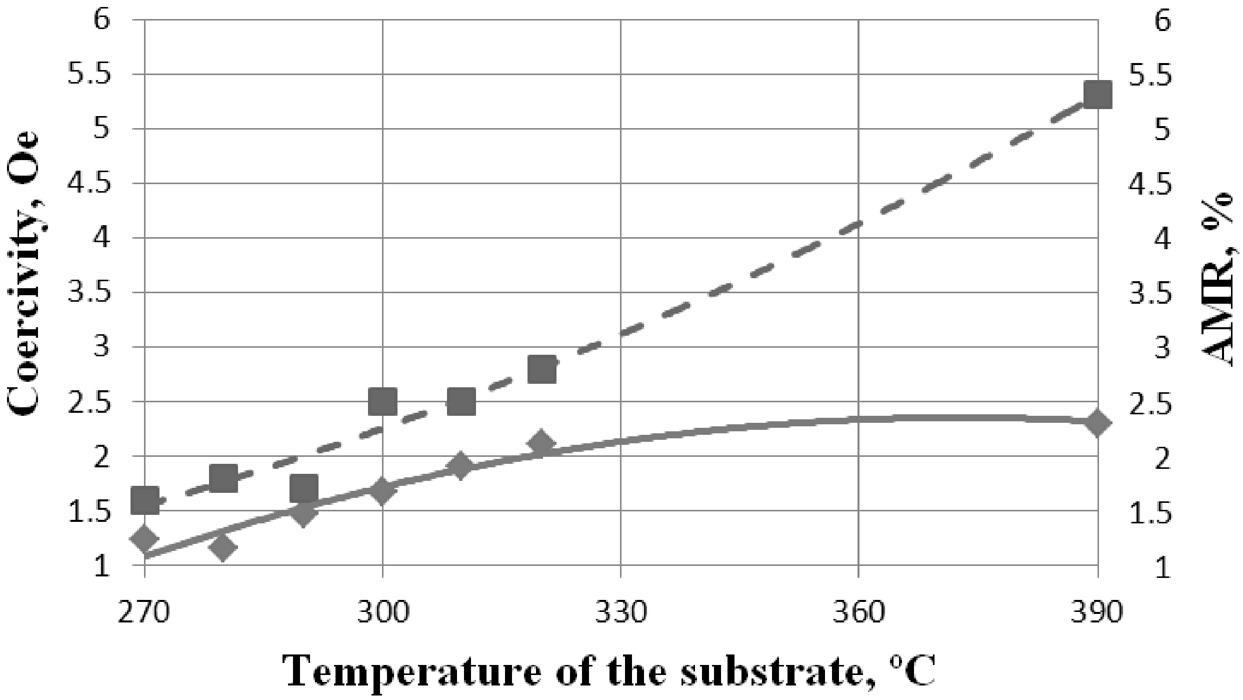
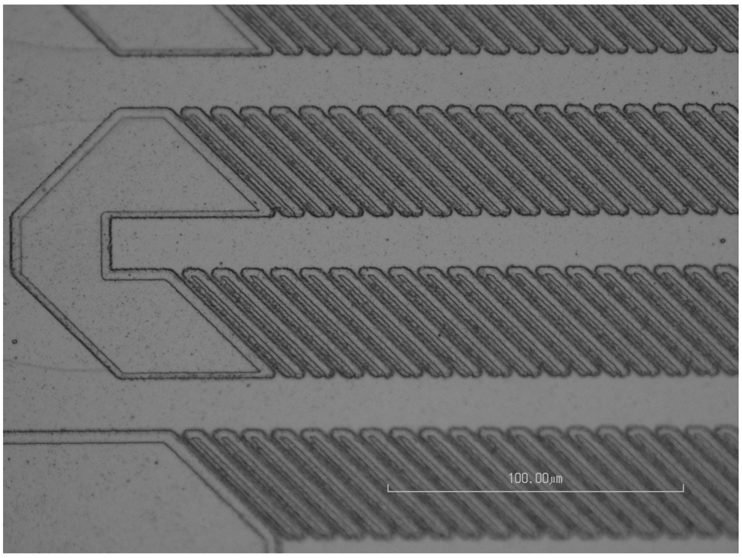
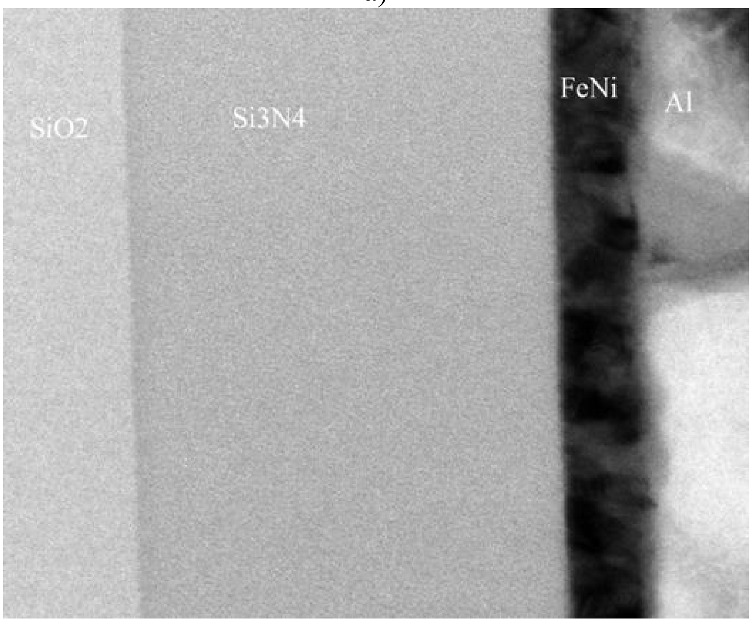


Fig. 2. The dependence of the coercivity (dashed line) and the AMR-effect (solid line) on the substrate temperature.



a)



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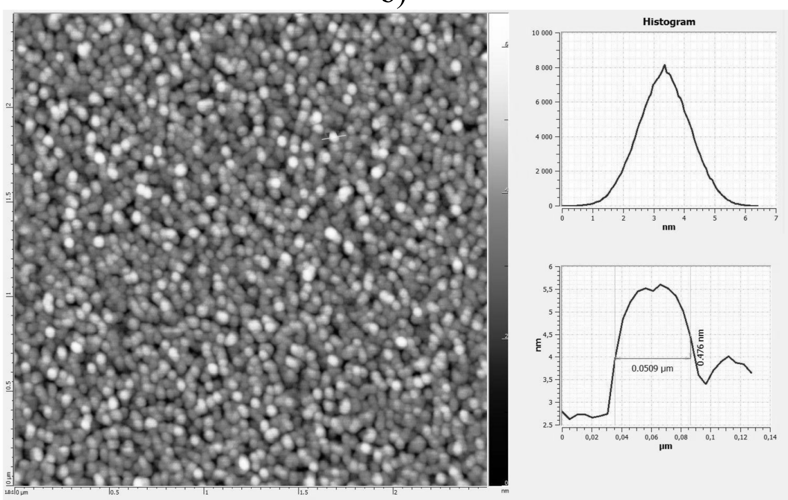
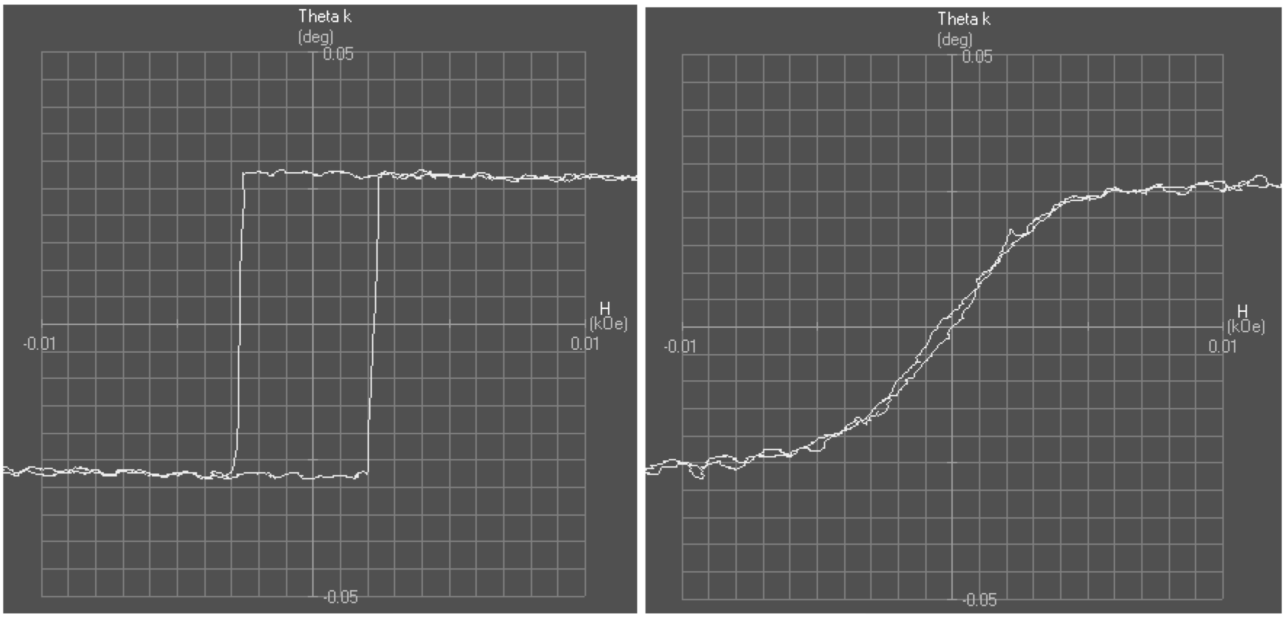


c)

Fig. 3. The experimental sample a) the image of ferromagnetic strips b) the image of a slice of a sample obtained on a transmission electron microscope c) the image of the sample surface obtained on a AFM AIST-NT Smart SPM-1000.

Magnetic hysteresis loops were obtained (Fig.4). The value of AMR effect was 2.2%. Then a layer of conductive material (Al) with a thickness of 0.6 µm was formed. Samples with magnetic and non-magnetic layers of a given shape were formed by using photolithography operations. The array of usual and self-aligned structures with the same topological dimensions was manufactured [7-9]: the width of the magnetic strip is 10 µm, the distance between shunt strips is 6 µm, the width of the shunt strips is 6 µm. The transfer functions were obtained and the sensitivity was calculated (Fig.5).



a) b)

Fig. 4. The hysteresis of magnetization a) along the easy magnetization axis b) along the hard magnetization axis.

It is known the AMR increases with the permalloy film thickness increasing. However, with the thickness increasing the conductivity of the layer grows, and the resistance of the diagonal of the bridge AMR sensor decreases. This leads to significant heating and temperature characteristics deterioration. Therefore, the magnetoresistive layer thickness is selected maximum with condition - the resistance of the bridge diagonal is 1.5 kOhm in the existing topology. The traditional sensor (with straight magnetic strip) has relatively uniform distribution of magnetization. This leads to the sensor sensitivity decreasing due to current lines bending. In the self-aligned sensor nonuniform distribution of magnetization is exist. Since these magnetic heterogeneities have same periodicity as current distribution heterogeneities. It can be assumed the sensitivity increasing may be due to mutual compensation of current and magnetization heterogeneities. The comparison shows that the self-aligned structures characteristics have a greater slope and greater sensitivity. The investigated structures had a wide range of sensitivity values from 3.0 (mV/V)/(kA/m) to 9.4 (mV/V)/(kA/m), in the bias field value of 1 kA/m. It is established the main influence on the sensor sensitivity has the permalloy strips width. The self-aligned structures sensitivity does not depend on the size of the shunt strips. The sensitivity does not exceed of 9.4 mV/V/kA/m in the magnetic bias field of 0.5 kA/m and 7.15 mV/V/kA/m in the magnetic bias field of 1.5 kA/m for all studied structures. The hysteresis value is 1% and 0.5% in the magnetic bias fields of 0.5 and 1.5 kA/m respectively (structures with the magnetic strip width 30 nm and the distance between the shunt strips 2 µm).

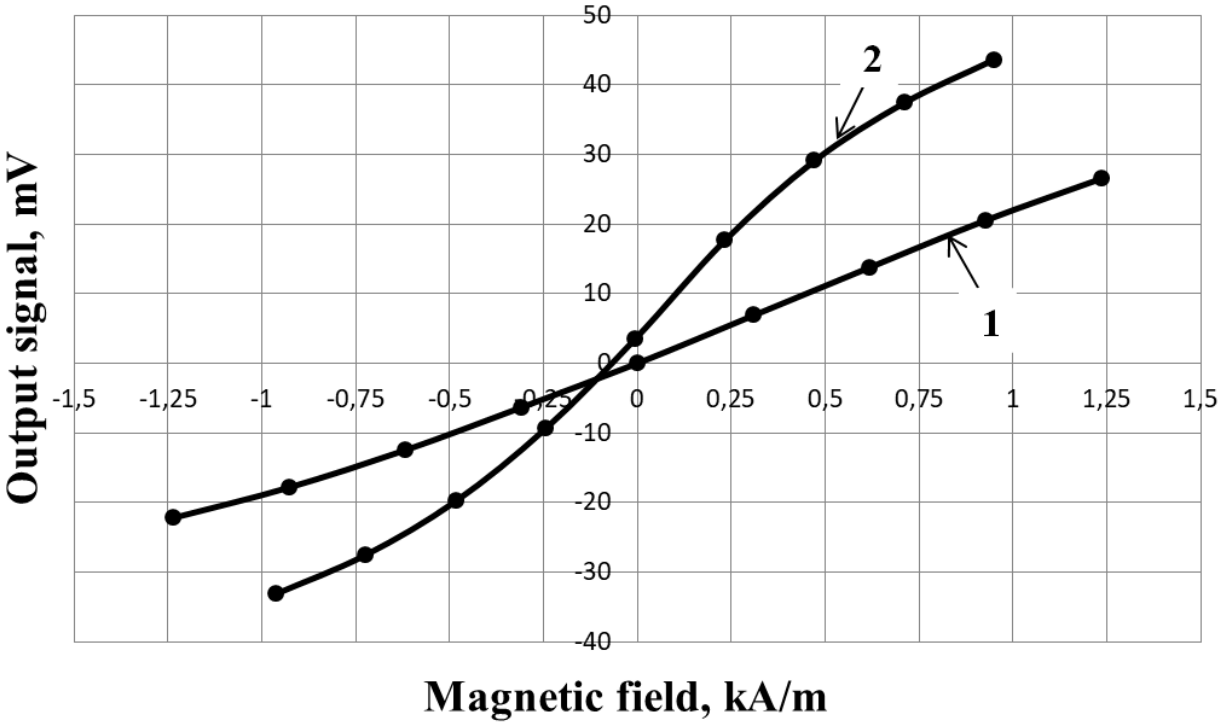


Fig. 5. The transfer characteristics classic (1) and self-aligned (2) structures in the bias field value of 1 kA/m.

Summary

It was found that with an increase of the substrate temperature from 270 to 390 °C the magnetoresistance increases from 1.2 to 2.3% and the coercive force from 1.6 to 5.3 Oe. Based on the results of experiments the substrate temperature 320 °C was determined as optimal for the installation of Phase II AJA 150. The magnetic field sensor based on the investigated permalloy films was manufactured. This sensor has a sensitivity value 9.4 (mV/V)/(kA/m) in the bias field value of 1 kA/m instead of 3.0 (mV/V)/(kA/m). Successful testing of experimental samples of magnetoresistive structures in speed and phase sensors was carried out.The results presented in this study give grounds to consider that the developed magnetoresistive sensors can be used as magnetic-field sensors in very different fields of application including the automobile electronics, etc.

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