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DESIGN AND FABRICATION OF ANISOTROPIC MAGNETORESISTIVE MICROSENSOR ON OXIDIZED SILICON WAFER

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In this paper is presented a contribution towards the developing candidate magnetic sensors. Using the anisotropic magnetoresistive effect we have designed an anisotropic magnetoresistive microsensor for the detection of small magnetic fields. The high values of resistance and the strong control of the flow current direction to the magnetic anizotropy axes were obtained by using conventional photoetching, resulting a bridge of thin layer permalloy resistance. We apply bias magnetic fields with opposed bias directions to adjacent arms of the bridge, in order to create the necessary asymmetry resulting the unbalance of the bridge when a external magnetic field is applied.

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1. Introduction

Sensors and transducers are subjected to an increasing interest because of their importance in many technological applications. Recently Hrisoforou [1] reviewed the magnetic effects in physical sensor design and development at the International Workshop on Amorphous and Nanostructured Magnetic Materials (Iasi – Romania 2001)

Since the development of MicroTechnology of Integrated Circuit (MTIC) were researched and developed new magnetoresistive microstructures, which are used as a magnetic field sensors in servomotors, rotative mechanisms and other automatic equipments. Solid state magnetic field sensors have an inherent advantage in size and power compared to search coil, flux gate and more complicated low-field sensing techniques such as Superconducting Quantum Interference Detectors (SQUID). As a physical phenomenon, this sensors are based on the anizotropic magnetoresistive effect of thin ferromagnetic layers, deposit on the silicon monocrystalin substrate.

Anisotropic magnetoresistance (AMR) occurs in ferrous materials. It is a change in resistance when a magnetic field is applied in a thin strip of ferrous material. The magnetoresistance is a function of $\cos^2\theta$ where θ is the angle between magnetization M and current flow in the thin strip. It has been observed that the resistivity strongly depends on ferromagnetic moments alignment of the adjacent layers, the surface roughness and the nature at atomic scale of the interfaces is considered very important for the magnetic behavior.

The aim of this work is the design and processing by microtechnology of magnetoresistive microsensor for the detection of small magnetic fields. The high values of resistance and the strong control of the flow current direction to the magnetic anisotropy axes were obtained by using conventional photoetching resulting a thin layer of a permalloy plane resistance.

2. Experimental

Using the anisotropic magnetoresistive effect was designed a magnetoresistive microsensor with thin layers of permalloy for detection of small magnetic fields: 0.1- 5 mT. We have used

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deposition-induced uniaxial magnetocristaline anisotropy so as to obtain a zero sensing field a $\pi/4$ angle between the magnetization in the layer and current path. The conductor is wide enough to avoid the shape demagnetization of the element, which would counteract the canted induced anisotropy [2-4].

The magnetoresistive response of the sensing layer is:

$$\Delta R/\Delta R_{max}=\sin\varphi\cos\varphi+1/2,$$

where φ is the angle between magnetization and current in the sensing layer and $\sin\varphi=H_y/H_K$.Here H_y *stands* for the sensing field, which has been vertically oriented and H_K anisotropy field. The sensor performance is determined by the geometry of the strip, the anisotropy, resistivity and magnetoresistance of the material, the exchange and demagnetizing energies.

We have obtained the high values of resistance and the strong control of the flow current direction to the magnetic anisotropy axes by using conventional photoetching, resulting a thin layer of a permalloy resistance. Four of these microstructures are interconnected to form a bridge. We apply bias magnetic fields with opposed bias directions to adjacent arms of the bridge, in order to create the necessary asymmetry resulting the unbalance of the bridge, when an external magnetic field is applied.

These MR sensors are made by etching a permalloy layer in which an easy axis was induced during deposition.

In order to minimize the demagnetizing field of these miniature sensors we have used the canting of current path with respect to the easy axis.

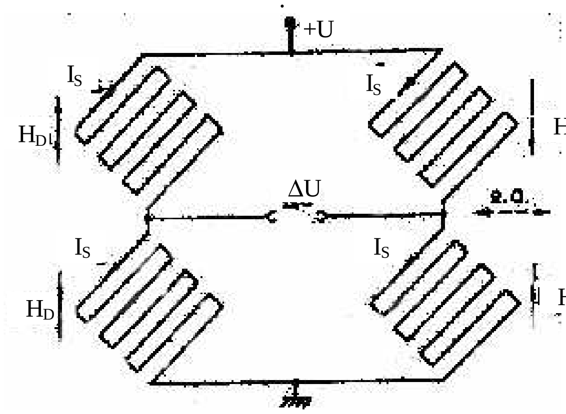

Fig. 1. Full-bridge meander patterned magnetoresistive sensor

Canted current bias exhibits the following advantage:

a) no use of external bias field;

b) a smaller number of terminals leads;

c) an accurate achievement of the canting angle through photolithographic process;

d) an auxiliary internal field, which maintain the permalloy layer in a single-domain state.

Thin layers of permalloy have been prepared by vacuum evaporation and RF sputtering methods. As for evaporated films, the same behaviour of the galvanomagnetic as functions of the layer processing was found for NiFe films deposited by RF sputtering.

Silicon wafers have been used, as substrates. They were oxidized in dry oxygen atmosphere for a period of time, t_1, after that, in the presence of oxygen with water vapours for another period of time, t_2. The oxidation is a very important technological step in manufacturing silicium integrated circuits.

The sensitivity of the sensors increases for the same area and dissipated power when the canted gold strips are used for conducting layer. Fig. 2 shows the mask for fabrication the canted gold strip layer.

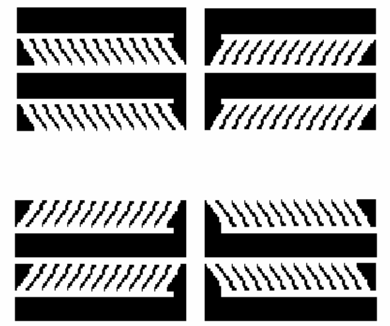

Fig. 2. Detail of mask for deposition of gold strips, x100.

The permalloy films were characterized for surface texture, grain size and roughness by Atomic Force Microscopy (AFM) and Scanning Microscopy (SEM). The magnetization measurements have been performed at room temperature using a VSM. We have performed both Planar Hall Effect, and magnetoresistance measurements on thin films, at room temperature in the setup with four contacts. We show the dependence of the PHE as a function of the field at different out of planes angles and discuss the origin of the hysteresis.

3. Results

Our experimental results have lead to the manufacturing process of these magnetoresistive microsensors, which have as main steps :

- surface oxidation of the silicon substrate;
- process of masking for chip delimitation;
- deposition of a titanium adhesive layer; deposition of permalloy magnetoresistive layer;
- masking and photoetching of the permalloy sensor;
- deposition of a titanium/tungsten adhesive layer onto permalloy sheet;
- deposition of the gold conducting layer;
- lift-off photoetching of the canted gold strips; encasing of magnetoresistive microsensor.

Fig. 3 shows the magnetoresistive bridge after photoetching of the permalloy layer. Fig. 4 shows the magnetoresistive bridge, after photoetching of the gold strips.

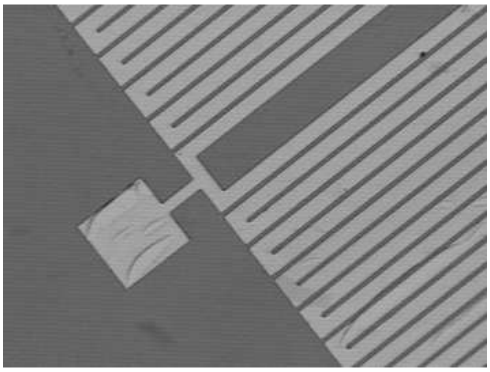

Fig. 3. Detail of permalloy bridge, x100.

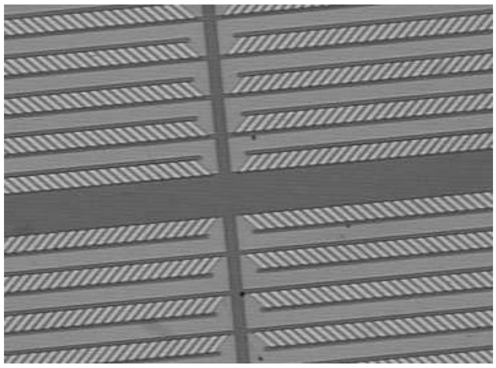

Fig. 4. Detail of magnetoresistive microsensor, x100.

Figs. 5 and 6 show the magnetoresistance measurements on thin films, at room temperature, for different condition of deposition of permalloy thin layer.

For the study of magnetoresistive phenomenon there were measured a number of permalloy samples deposited on oxidized silicon underlayer. The measured samples were not photoetched in order to obtain the planar resistance structures. The resistance have been measured in magnetic field using the "four probes method". A small constant current is applied between the two probes of the edges (of the four probes), and the voltage between the middle probes is measured. The voltage measured is proportional to the magnetoresistance of the measured layer.

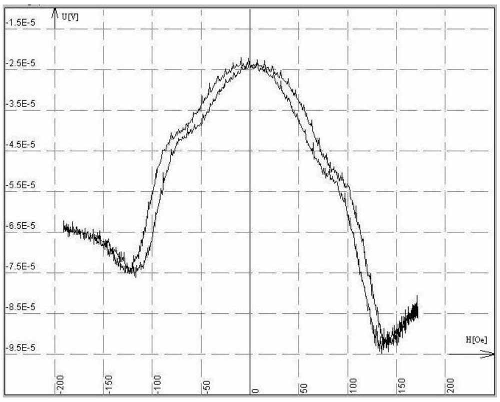

Fig. 5. Magnetoresistance of evaporated permalloy thin film, 100 nm, V_i=10mV.

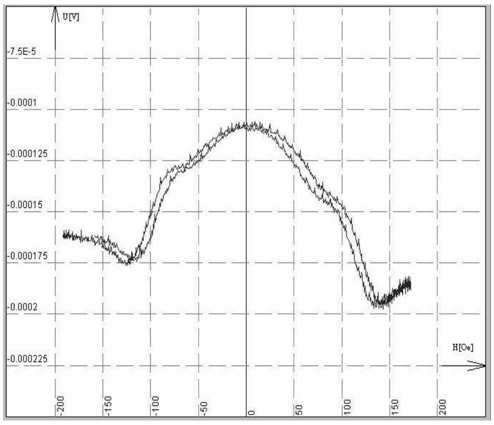

Fig. 6. Magnetoresistance of permalloy thin film, 100 nm, deposited by RF sputtering, V_i = 10 mV.

5. Conclusions

Using the anizotropic magnetoresistive effect we have designed a anisotropic magnetoresistive microsensor for the detection of small magnetic fields. The high values of resistance and the strong control of the flow current direction to the magnetic anizotropy axes were obtained by conventional photoetching of permalloy layer and canted gold strips, resulting a bridge with four active arms.

In the magnetic field we have measured the magnetoresistance of the permalloy/oxidized silicon samples and we obtain the maximum magnetoresistive effect at a magnetic field of 10^{-3} - 10^{-4} T. The anisotropic magnetoresistance of permalloy thin films strongly depends on the conditions of high vacuum deposition, roughness and composition. We have studied thin layer permalloy bridge with four active arms for magnetometer application.

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