JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 9, No. 2, February 2007, p. 319 - 322

Comparative analysis of the behavior of AMR position sensors in real-life magnetic fields

P. DIMITROVA*, S. ANDREEV, L. POPOVA
Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tzarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria

Three types of AMR bridge sensor have been investigated: Barber-pole structures, structures with rotated anisotropy axes and shielded versions. Samples were prepared on oxidized Si wafers by technology based on the magnetization after annealing of a permalloy layer at 450 °C. The bridge response was analyzed for conditions near to the real industrial applications. The experimental characteristics obtained, and the differential response signal, are compared with curves simulated by a simulation program. Response signals suitable for further processing were obtained for structures with rotated anisotropy axis.

(Received November 1, 2006; accepted December 21, 2006)

Keywords: Thin films, Magnetoresistors, Position sensors

1. Introduction

Wheatstone-bridge structures consisting of four magnetoresistors (usually meander shaped) are widely used for building thin film AMR (Anisotropic-Magneto-Resistance) field sensors [1-3]. They require complementary behavior of the resistors in each arm of the bridge. Usually, such behavior is achieved by applying a technique known as “barber-pole” and involving the deposition of appropriately oriented shunting bars on the sensitive permalloy (Pm) stripes. Barber-pole sensors are known to be sensitive to the polarity of the measured field, and exhibit linear characteristics at low fields. However, they suffer from two main drawbacks: a complex technology and a large area required for implementing magnetoresistors with acceptable values of the resistance (e.g. several kΩ), due to the shunting and redirection of the current flow. Another possible approach for obtaining a complementary behavior is to make use of “shape anisotropy” effects for rotating the anisotropy axis of Pm stripes. Magnetoresistors formed on the same substrate and from the same Pm thin film, but with layouts oriented at 90^O to one another demonstrate the necessary complementary response to the x and y components of two-dimensional fields. Samples are prepared by means of a technology based on the magnetization of a Pm

layer after annealing at 450^{0}C [4]. The detailed analysis of the individual behavior of such resistors will be reported later [5]. The main goal of this work is to demonstrate that thin film bridge structures based on this technology and design principles could be used successfully for positioning moving magnetic parts for automation and measuring- technique purposes.

2. Experimental

A barber-pole bridge structure, implemented by the technology cited above, is shown in Fig. 1. The main characteristics of the structure and its response to a magnetic field have been reported previously [4]. In this work, the response of the structure to the real field of a permanent magnet will be further discussed.

In Fig. 2, a sensor structure with meander-shaped magnetoresistors rotated at 90^O to one another is illustrated. Four magnetoresistive meanders are cut photolithographically from the same original Pm thin film, with an initial axis of anisotropy defined by the process of magnetization. The length of the stripes of one pair of resistors is oriented along the initial axis of anisotropy, and the other pair is rotated at 90^O. After the lithography process, the couples show complementary behaviour (a field applied across the stripes of one pair affects the magnetoresistance of the other pair, as applied along the stripes and vice versa).

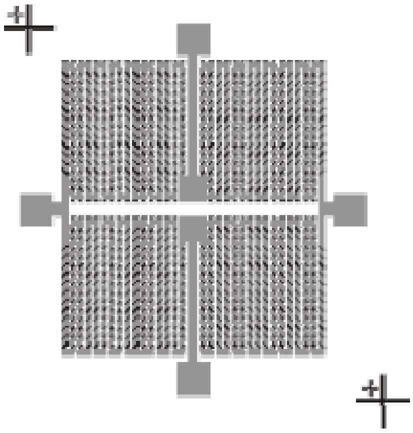

Fig. 1. Barber-pole AMR structure.

In Fig. 3, a dedicated experimental version of the structure with a rotated anisotropy axis (RAA) is shown. It is supposed that the specific location of the meanders would reduce the magnetic interaction between them. Additionally, two of the resistors are covered by square shields cut from a second Pm layer, electrically isolated from underlying structure and deposited under the same technological conditions as the sensitive layer.

Fig. 2. Structure with rotated anisotropy axes (RAA).

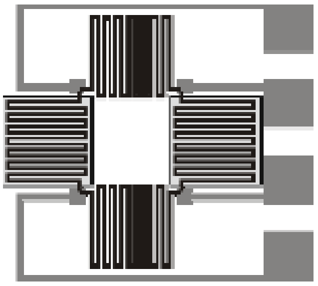

Fig. 3. Structure with rotated anisotropy axes (RAA) –experimental shielded version.

Samples of the two versions with RAA were tested at a magnetic field created by a pair of Helmholtz coils and directed perpendicular to the original axis of anisotropy (x-direction), and along the axis (y-direction). The magnitude of the field was varied in the range 0-5 kA/m, for both opposite polarities. The differential signal between the middle points of the two arms was measured as the output signal S, at a supply voltage of 5V.

Finally, the response (S) of the samples was measured in relation to the position of a cylindrical magnet with length L=4mm and diameter D=20 mm moving along its central axis. Samples were positioned at 5 mm from the surface of the magnet in the plane of the cross section of the cylinder.

3. Results and discussion

Experimentally obtained output signals of the structure with RAA for x- and y- oriented fields (according to the definition above) are presented in Fig. 4.

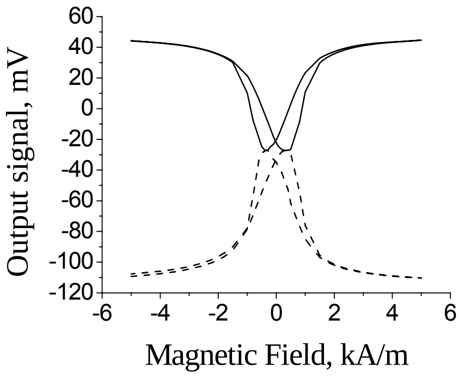

Fig. 4. Response of a RAA structure to x- and y- oriented fields (x-field – solid line, y-field - dashed line).

The solid curve is the result of the resistance decreasing with increasing field H (the AMR effect) of the pair of resistors with the conserved original anisotropy axis (along the stripes). The dashed line demonstrates the same course, but this is possible only when the anisotropy axis of the other pair of resistors is rotated by 90^{O} (again along the length of their stripes). The course of the curves at magnetic fields around zero could be described by introducing an effective dispersion of the anisotropy that is several times larger than the intrinsic dispersion of the layer. It is shown in our previous work [4] that long single-path resistors implemented by this technology demonstrate practically negligible dispersion. Thus, the introduced effective dispersion is mainly a lump result of the magnetic interactions between the closely situated resistors with different orientations of the stripes.

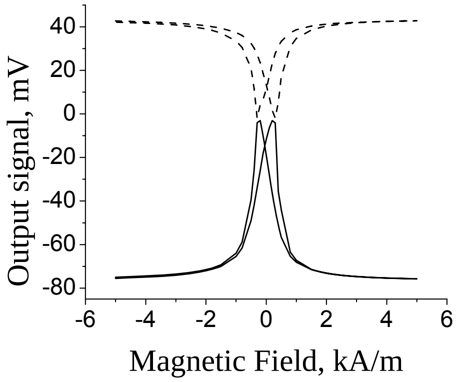

Fig. 5. Response of a RAA structure – experimental shielded version to x- and y- oriented fields (x-field – solid line, y-field - dashed line).

The experimentally observed output signals from the shielded version under the same conditions, Fig. 5, show basically the same character as the curves in Fig. 4, with two main differences:

- The course of the curves around the zero reveals a much smaller effective dispersion than that for the curves from Fig. 4. This is expected because of the specific positioning of the resistors. Each resistor is exposed directly to the applied external field and the interaction between the resistors is much weaker than in the RAA structure in Fig. 3.

The smaller amplitude of the dashed curve (featuring mainly the AMR effect in the shielded resistors) shows that the shields are shunting the field as expected, and this could be applied for additional tuning of the structure characteristics. For more efficient shunting, the parameters of the shunting layer should be optimized.

The output signal of the Barber-pole structure investigated under the influence of the magnetic field of a moving cylindrical magnet under the conditions described in the experimental section is shown in Fig. 6. On the x- axis, the distance from the center of the magnet is shown (along the length of the cylinder). The field possesses a cylindrical symmetry and, in the plane of the cross section where the sensor is placed, the field is described by two components – axial along the axis of the magnet and radial - in a perpendicular direction (along the radius).

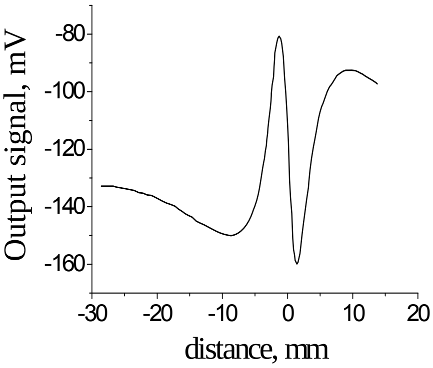

Fig. 6. Response of a Barber-pole AMR structure to the field of a moving cylindrical magnet.

Due to the sensitivity to the polarity of both components of the field, the output signal contains detailed information about the position of a magnet in the near vicinity. At large distances, it monotonically tends to the offset value, and is not shown in the figure. This complex behavior requires sophisticated successive processing for automation purposes.

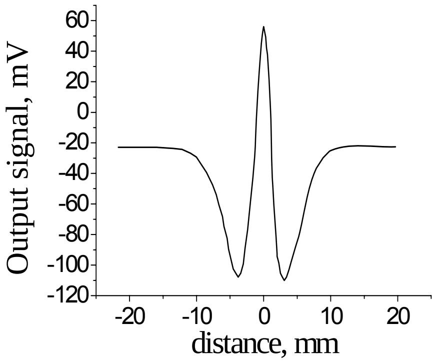

Fig. 7. Response of a RAA structure to the field of a moving cylindrical magnet.

In Fig. 7, the output signal of the RAA structure from Fig. 2 is represented. As was mentioned, in this structure the necessary complementary behavior was achieved using resistors which were non-sensitive to the polarity of the field. As a result, the output signal has a simpler shape. Coming from afar (from both directions) the magnetic field makes very slight changes to the signal in one direction from the offset value (positive in the specific case shown in the figure). At some distance in relation to the magnet (around 10 mm in the specific case) a rapid change starts in the opposite direction (negative), followed by a sharp positive peak corresponding to the centre of the magnet. Such a shape of the signal is easily processed for switching purposes. For instance, a simple threshold circuit is needed to stop the magnet at some position with great accuracy (because of the steep peak around the centre). The effects of the anisotropy dispersion shown in Fig. 4 do not affect the signal in the vicinity of the magnet, because they correspond to large distances and low variations of the signal from its offset value.

The output signal of the experimental shielded version, shown in Fig. 8, has generally the features of the signal from Fig. 7. However, it proves the possibility of additional tuning of the shape of the signal to the specific application needs.

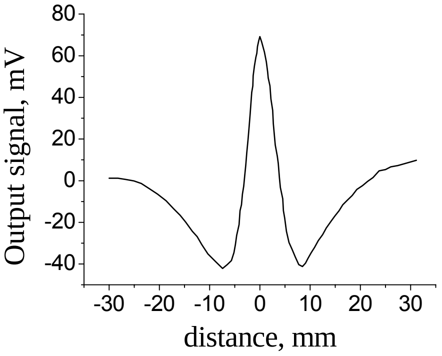

Fig. 8. Response of a RAA structure- experimental shielded version to the field of a moving cylindrical magnet.

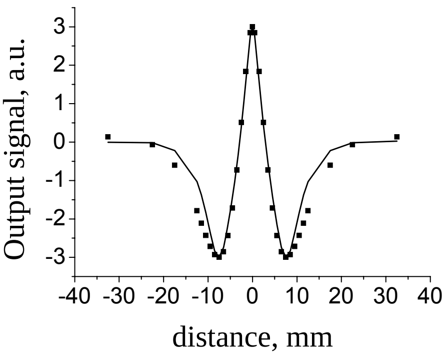

Fig. 9. Computer simulation of the response of RAA structures to the field of a moving cylindrical magnet: solid line – RAA structure from Fig. 2; dots – experimental shielded RAA structure.

Computer simulation of the output signals of both versions with RAA was carried out making use of a dedicated program for numerical solving of the equation for the magnetization vector energy of the sensitive stripes in an applied external field [1].

In Fig. 9, results of the simulation of the output signals of both structures with RAA are presented. The simulation process consisted of computing the minima of the energy equation with an appropriate value of the dispersion of the anisotropy, and successive calculations of the changes of the resistances and the signal.

4. Conclusions

AMR sensor structures with a rotated anisotropy axis demonstrate easily processed response signals, when exposed to the influence of the magnetic field of moving magnetic parts, for the purposes of automation and measurement techniques. The hysteresis of the characteristics due to the intrinsic dispersion of the anisotropy of such structures does not affect the response signal in the region near to the magnet that is of interest in the most of the positioning applications.

The versatile layout and the relatively simple technology allow further optimization of the characteristics and tuning to the specific needs of the application.

Computer modelling of the integral behavior of the magnet – sensor system is of great importance for creating optimized application-specific systems. For design purposes, a relatively simple model could be used, if an appropriate value of the effective dispersion of the anisotropy is assumed.

References

[1] S. Tumanski, Thin Film Magnetoresistive Sensors, B. E. Jones, W. B. Spillman (eds) IOP Publishing Ltd (2000).
[2] P. A. Holman, Magnetoresistance (MR) Tranducers and How to Use Them as Sensors, 1st ed. Honeywell Intern. Inc. (2004).
[3] J. Neamtu, W. Kappel, V. V. Alecu, E. A. Patroi, J. Optoelectron. Adv. Mater. **6**, 983 (2004).
[4] S. Andreev, J. Koprinarova, P. Dimitrova, J. Optoelectron. Adv. Mater. **7**, 317 (2005).
[5] P. Dimitrova, S. Andreev, L. Popova, to be published.

---

[*] Corresponding author: petiadim@issp.bas.bg