Design of a double core linear magnetometer based on asymmetric magnetoimpedance effect in nanostructured Finemet ribbons

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ABSTRACT

The techniques used to produce magnetic sensors encompass many aspects of physics and electronics and are going to develop with each passing year. In this paper, we introduce a double core giant magnetoimpedance sensor. The sensing elements are provided by heat treating the FeCuNbSiB (Finemet) ribbons at 560°C for 1 h to achieve a high magnetic permeability associated with the nanostructured state. Sensor cores are exposed to a dc current bias in order to provide asymmetric giant magnetoimpedance (AGMI) behaviour. The sensor detects both direction and amplitude of the magnetic field with a sensitivity of 2 mV/Oe.

1. Introduction

Due to their broadening technological capabilities, the nanocrystalline FeCuNbSiB (Finemet) alloys have attracted a lot of attention [1]. Their high stability with respect to frequency and temperature ($\mu' \approx 10^6$ from $-40 \, ^\circ C$ to 150 $^\circ C$, to several tens of kHz) and their remarkable magnetic permeability, have made them confidently suitable for use in magnetic sensor elements [2,3].

Design of magnetic sensors based on the giant magnetoimpedance (GMI) effect has become an attractive proposition because of low cost, easy implementation and the possibility of attaining high sensitivities [4–7]. Among the various GMI profiles, considerable attention has been paid to the asymmetric GMI (AGMI) which is promising for the development of weak magnetic field sensors [5]. AGMI can be achieved by: (i) applying dc/ac biased current/field and (ii) postproduction techniques [4]. Noticeably, it has been found out that applying a dc biased current can not only suppress the magnetic and electrical noises in magnetic sensors but also create a linear AGMI response [5–7]. Recently, novel designs of double core GMI current sensors have been introduced [7–9]. They are able to suppress noises and eliminate a large part of spurious signals by means of signal balancing in the coupled elements [7–9].

Designing a double core magnetic field sensor based on the AGMI effect can better improve the sensor performance. The main purpose of this paper is to design a double core AGMI magnetic field sensor. This sensor can determine both amplitude and direction of magnetic field, simultaneously. The sensing elements are made of Finemet ribbons annealed at 560°C for 1 h which have shown an excellent linear AGMI response.

2. Sensor structure

The double core magnetometer consists of two sensing elements of 30 mm long and 2 mm wide Finemet nanostructured ribbons. The GMI ratio of the elements has been depicted in Fig. 1. It has been defined as $\Delta Z/Z (%) = \left(\frac{Z(H)/Z_{Max}}{-1}\right) \times 100$ in which $Z$ is the field dependent impedance and $H_{Max}$ is 40 Oe. The GMI ratio as high as 130% has been achieved at frequency of 250 kHz, for 17 mA dc biased current and 31.5 mA ac sensing current with excellent linear response and without hysteresis.
In order to study the thermal stability of sensing elements, we have measured the GMI voltage of each sensing element at temperatures between 20°C and 60°C. According to Fig. 2, a little deviation which is less than 2% can be observed at different applied magnetic fields.

To design the sensor, ribbons are located at the top and bottom of a dielectric plate and the ends of each one are attached to probes, as indicated in Fig. 3. The electrical circuit of the sensor includes a double sine-wave current generator working at 250 kHz which can produce ac current with constant amplitude. GMI voltage of both ribbons is entered into a microcontroller and after signal processing, both direction and amplitude of magnetic field can be determined.

3. Measurements and results

Field dependence of GMI voltage at frequency of 250 kHz has been depicted in Fig. 4 for both sensing elements. The elements are oppositely biased by dc current of 17 mA. By applying magnetic field along the elements length, the voltage of one probe decreases whereas another one increases. Using this technique, the detection of the field direction becomes possible. If $V_2 > V_1$ then the magnetic field is in positive direction. It is noticeable that in the sensor region $\frac{(V_1 + V_2)}{2} = 111$ mV. Using this value we can control the operation region of the sensor. Nevertheless, out of the operation region the sensor can still determine the direction of the magnetic field.

![Fig. 1. Field dependent GMI ratio at different frequencies for dc biased current of 17 mA and ac sensing current of 31.5 mA.](image)

![Fig. 2. Temperature dependent GMI voltage.](image)

![Fig. 3. AGMI double core sensor illustration.](image)

![Fig. 4. Sensor response against applied magnetic field. The sensor region is depicted as an interval between P1 and P2.](image)

![Fig. 5. Comparison of sensor response with exact magnetic field.](image)
In order to calibrate the GMI voltage versus magnetic filed, its slope in the sensor region has been taken into account. Fig. 5 shows a comparison between exact magnetic field and sensor response in the working range (between \(2.5\) Oe and \(2.5\) Oe). This figure demonstrates a satisfactory agreement. The sensor resolution is approximately \(0.05\) Oe and its voltage sensibility is about \(2\) mV/Oe. It is important to note that the sensor resolution depends on its electric circuit.

4. Conclusion

Double core magnetic field sensor was developed based on the AGMI effect in the nanostructured Finemet ribbons. We have shown that appropriate sensor design in connection with a suitable signal conditioning could noticeably improve the GMI sensor capability. This double core sensor can determine both amplitude and direction of the magnetic field. The sensor operation is approximately invariant in the selected temperature range. Signal processing improvements can enhance the field resolution of the sensor. This sensor can detect the longitudinal magnetic field, and to determine the magnetic field orientation, more improvement is required.

References