Test-production of High Sensitivity Multi-core MI Element and Its Characteristics

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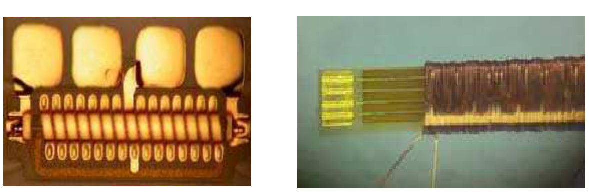
Abstract— The magnetic sensor is used in various fields such as industrial, automobile, IT and biomagnetism. The MI sensor is a magnetic sensor based on the MI (Magneto Impedance) effect discovered by K. Mori et al. in 1993. The MI element with a pickup coil produced by a plating process is used in electromagnetic compasses. Although it can detect 1–1000 μT level, higher performance in sensitivity and noise level is required. Here, the effect of wire length, magnetic property of the amorphous magnetic wire, the number of coil turns and number of cores on the sensor characteristics was investigated. Then based on the above investigations, the designed MI element was test produced. It was found that the designed element shows dramatically higher sensitivity and 1/100 noise, as compared to the currently used MI element (AMI306).

1. INTRODUCTION

The magnetic sensor is used in various fields such as industrial, automobile, IT and biomagnetism. The MI sensor is a magnetic sensor based on the MI (Magneto Impedance) effect discovered by K. Mori et al. in 1993 [1]. It can detect weak magnetic fields in the pT-mT order. According to theoretical analysis, the MI sensor is foreseen to show the $\mathrm{fT}/\sqrt{\mathrm{Hz}}$ level of noise density [2], and its performance would even be equal to SQUID.

The MI element with a pickup coil produced by a plating process (Fig. 1(a)) is used in electromagnetic compasses. Although it can detect 1–1000 μT level [3], higher performance in sensitivity and noise is required. On the other hand, a specialized high sensitivity type magnetic sensor (nT sensor) with wound coil made with copper wire of 30 μm (Fig. 1(b)) which can detect nT level [4], has also been commercialized for use in detecting AC magnetic fields and research of biomagnetic measurement using this MI element has also been reported [5].

Although the MI element (Fig. 1(b)) shows higher sensitivity the MI element (Fig. 1(a)) is more suitable for mass production in cost. Therefore in this paper, in order to develop MI element which shows higher sensitivity, with pickup coil produced by a plating process, the effect of wire length, magnetic property of the wire, coil turns and the number of cores (MI element) on sensor characteristics was investigated.



Size：L0.6×W0.3×H0.2mm Size：L10×W1.4×H0.7mm

(a) coil by plating process (b) coil by Cu wire

Figure 1: The aspects of MI element.

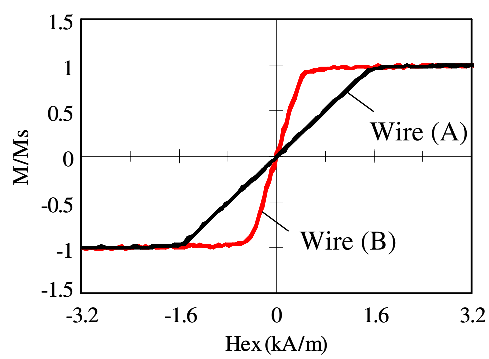


Figure 2: The hysteresis loops of wire.

2. EXPERIMENT

A nearly non-magnetostrictive amorphous magnetic wire with a diameter of 15 μm and composition Co-Fe-Si-B system produced by an in-water-rotating quenching process was purchased from UNITIKA LTD. Then two kinds of wire showing deferent magnetic properties were tailored by annealing at around 400 deg C [6]. The hysteresis loops of wire (A) and (B) with a length of 5 mm were measured by Vibrating Sample Magnetometer (Toei Scientific Industrial Co., Ltd, type: PV-M10-5) and are shown in Fig. 2. Here, in this paper, the magnetic field where the normalized magnetization by saturated magnetization showing 90% was defined as Hk, corresponded to an anisotropy field.

The MI element was produced by photolithography and plating processes. The sensor characteristics of the MI element were evaluated with an electric circuit [4] used in the nT sensor (MI-CB-1DJ). The noise density of the MI element was measured by FFT analyzer (ONOSOKKI, type: CF-5220Z) at zero magnetic fields with magnetic shielding.

3. DESIGN OF MI ELEMENT

3.1. The Effect of Wire Length, Magnetic Property of Wire and Coil Turn on Sensor Characteristics

In order to determine the length of the MI element (wire), the effect of wire length on Hk was investigated using the wire (A). As shown in Fig. 3, Hk decreased as wire length increased and showed a trend toward saturation when the wire length exceeded 1 mm. This is because the influence of the demagnetizing field decreases. Since a demagnetizing field reduces the sensitivity of the sensor characteristics, it was found that wire length should be 1 mm or more.

Next, in order to determine the magnetic property (Hk) of wire which shows higher sensitivity as an MI sensor the output properties of MI elements produced using wire (A) and (B) were compared. The MI element consists of a wire with a length of 0.52 mm and a coil of 25 turns (17 μm coil pitch). As shown in Fig. 4, the MI element using wire (B) shows higher sensitivity compared to using wire (A). In fact, the sensitivity is strongly related to the Hk of the wire, and this is the same tendency as in the case of detecting impedance change with external magnetic fields [7].

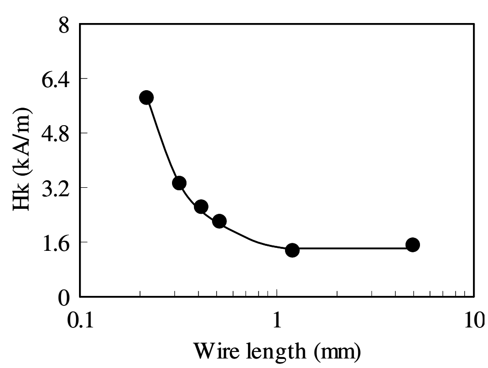


Figure 3: The effect of wire length on Hk.

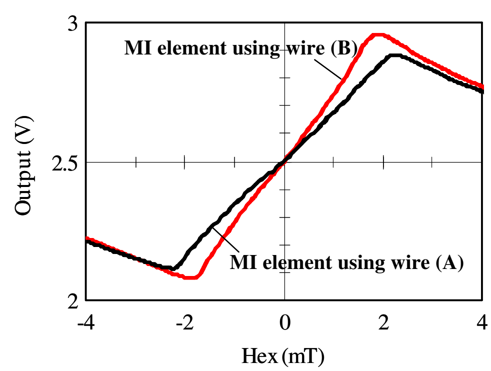


Figure 4: Output of produced MI elements.

Thirdly, in order to investigate the effect of the number of coil turns on the MI element on sensitivity, the MI elements using wire (A) of a length of 0.52 mm with 15–28 coil turns (30–15 μm coil pitch) were produced (Fig. 5). As shown in Fig. 6, although sensitivity increases as the number of coil turns increase, when the number of coil turns exceeded 21 turns, it was found that the sensitivity increase tended to be saturated. This is because the coil resistance becomes larger.

3.2. Design of MI Element

Based on the above chapters, MI elements using wire (B) were designed and a multi-core MI element was also considered. The design is shown in Table 1 and the appearance of the produced MI elements is shown in Fig. 7. Each output property is shown in Fig. 8, as compared to the commercialized MI

Table 1: Design of MI element.

	(A)	(B)	(C)
Wire length (mm)	1.2		
Number of core	1	2	4
Wire R (Ω)	12.7	25.1	50.2
Coils pitch (μm)	17		
Coil turns	66	132	250
Coil R (Ω)	6.4	11.6	23.9

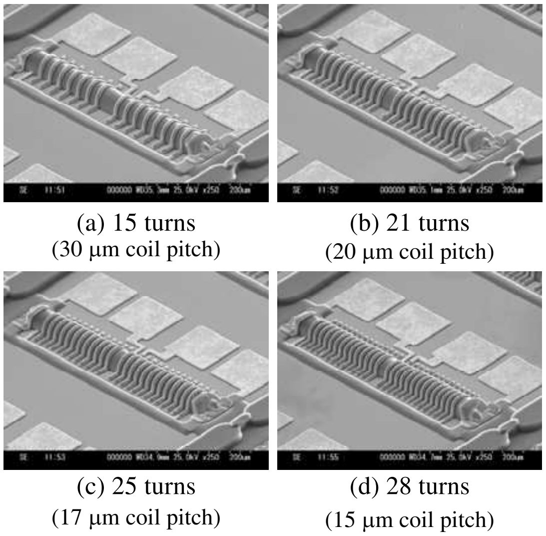


Figure 5: The appearance of MI element with several coil turn.

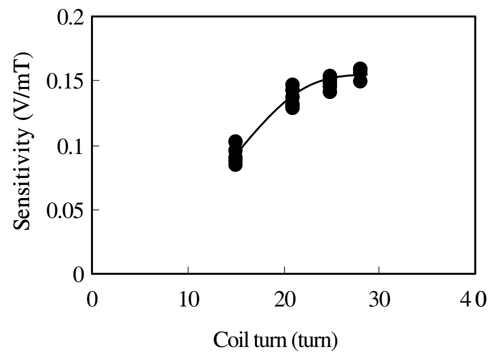


Figure 6: The effect of coil turn on sensitivity.

sensor (AMI306 [8]). As shown in Fig. 8, the sensitivity increases as the number of cores increases and it is found that the multi (4)-core MI element shows dramatically higher sensitivity than AMI 306.

3.3. The Noise Level of the Developed MI Element

The noise density of the multi (4)-core MI element was measured and it is shown in Fig. 9, as compared to AMI306 and commercialized nT sensor (MI-CB-1DJ). As shown in Fig. 9, the devel-

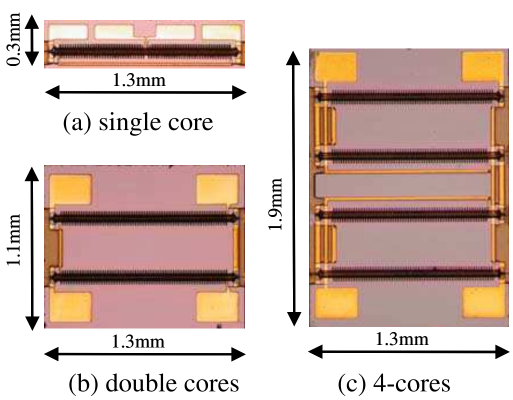


Figure 7: The appearances of designed MI elements.

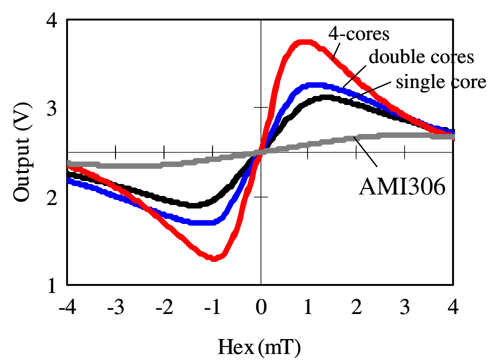


Figure 8: Output of designed MI elements.

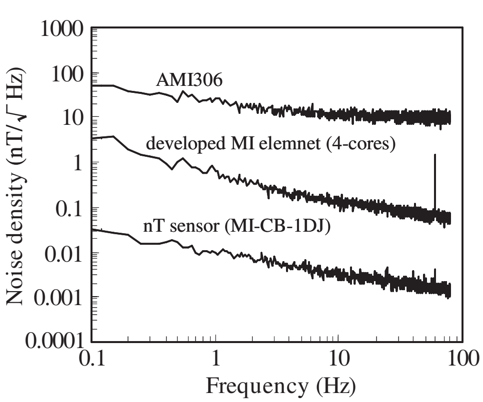


Figure 9: Noise density of 4-cores MI element.

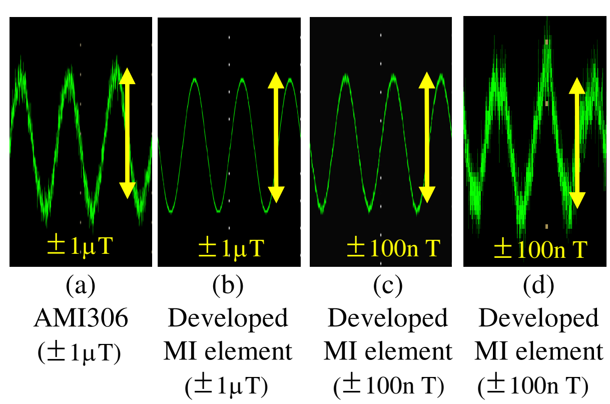


Figure 10: Sensor outputs of developed MI element corresponded to magnetic fields.

oped MI element shows 1/100 the noise level of AMI306. In addition, the sensor outputs of the developed MI element when several magnetic fields (±1 μT, ±100 nT, ±10 nT) at 30 Hz are applied by a Helmholtz coil are shown in Fig. 10. Considering the viewpoint of each noise level, it is found that the developed MI element would have sufficient magnetic resolution in the case of ±100 nT.

4. SUMMARY

In this paper, based on the effect of wire length, magnetic property (Hk) of wire and the number of coil turns on sensor characteristics, an MI element that could detect magnetic fields of ±100 nT order was developed. This developed MI element is expected to be used not only as an electromagnetic compass, for which increasingly higher levels of performance are being required, but also in automobile or industrial markets.

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