# Asymmetric High-Frequency Carrier-Type Magnetic Field Sensor With Thin-Film Head Structure

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***Abstract*—An asymmetric giant magneto-impedance (GMI) sensor head consisting of ferro/antiferromagnetic exchange coupling multilayered films was fabricated, and its sensor characteristics were measured. Five 100-nm-thick ferromagnetic $Ni_{78}$–$Fe_{13}$–$Cu_5$–$Mo_4$ layers were multilayered between five 50-nm-thick antiferromagnetic $Ir_{22}$–$Mn_{78}$ layers by radio-frequency sputtering. The asymmetrical GMI characteristics and high sensitivity of 331 Ω/T were obtained with the sensor head. Moreover, it becomes clear that feedback control is possible with a conductive line fabricated on the sensor head. It is considered that small clearance between the sensor head and recording media can be realized by the thin-film head structure.**

***Index Terms*—Exchange-coupling field, giant magneto-impedance (GMI), thin-film head, unidirectional anisotropy.**

## I. Introduction

SINCE a high-frequency carrier-type magnetic field sensor (or so-called giant magneto-impedance (GMI) sensor) is insensitive around a zero applied field owing to the symmetrical applied field dependence, the sensor element needs a dc bias field to obtain linearity and high sensitivity [1]–[4]. To apply the bias field, the use of a bias coil [5], a bias thin-film magnet [6], or cross anisotropy [7] has been investigated. However, these methods increase substantially the electric power consumption and complicate the fabrication process of the sensor element.

To solve the problem, we have already reported about the asymmetric GMI sensor elements consisting of a ferro/antiferromagnetic exchange coupling multilayer film [8]. The unidirectional anisotropy due to the exchange bias gives rise to the asymmetric GMI profile that makes it possible to remove a large bias coil. Furthermore, the microhead structure has been required for a practical application of high-density magnetic recording, etc. Therefore, we fabricated the thin-film head-structured GMI sensor elements consisting of Ni–Fe–Cu–Mo ferromagnetic layers and Ir–Mn antiferromagnetic layers, and measured the sensor output by applying an external field in the width direction in order to evaluate the fabricated sensor element as a thin-film head for magnetic recording.

It is also important that the feedback control is possible with a conductive line fabricated monolithically on the sensor head to obtain high sensitivity and linearity. We studied the GMI profile by using the conductive line adjacent to the sensor head for the feedback control.

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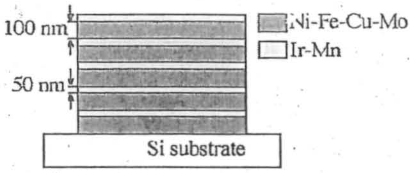


Fig. 1. Cross section of the multilayer film.

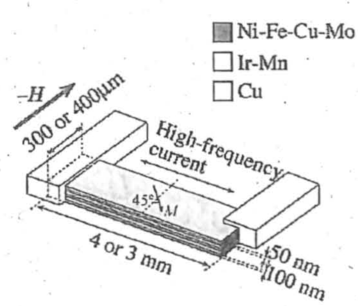


Fig. 2. Schematic view of the sensor head.

## II. Experimental Procedure

Five ferromagnetic $Ni_{78}$–$Fe_{13}$–$Cu_5$–$Mo_4$ layers were multilayered between antiferromagnetic $Ir_{22}$–$Mn_{78}$ layers by radio-frequency sputtering. Fig. 1 shows a cross section of the multilayer film. The multilayer film deposited on Si substrate was five Ni–Fe–Cu–Mo layers and four Ir–Mn layers, as shown in Fig. 1. The thickness of the Ni–Fe–Cu–Mo layer and that of Ir–Mn layer was 100 and 50 nm, respectively. To obtain a unidirectional anisotropy, we applied a dc field of 2.4 kA/m to the multilayer film during radio-frequency sputtering. We measured the magnetization curves of the multilayer film by using a vibrating sample magnetometer (VSM).

After deposition, the multilayer film was ion milled and shaped into two rectangular elements with different dimension, as shown in Fig. 2. It was made to be ion milled in the sample because the patterning after inducing the exchange bias to the multilayer film was needed. It is difficult to induce the exchange bias to the patterned film by lift-off process, since the patterned rectangle has a large demagnetizing filed along the width direction. The length was 4 and 3 mm, and the width was 300 and 400 $\mu m$, respectively. In order to obtain the asymmetrical GMI profile, the unidirectional anisotropy was induced to have the easy axis in the direction tilting at 45° with respect to the width direction. Conductive lines of Cu film patterned

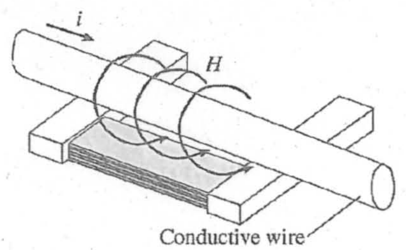


Fig. 3. Schematic view of the conductive wire for the feedback control.

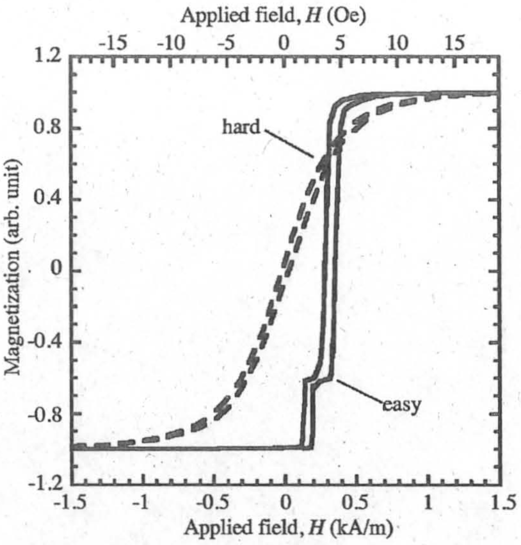


Fig. 4. Magnetization curve of the multilayer film.

by lift-off process were deposited on the magnetic film to construct the thin-film head structure. Moreover, 0.4-mm-diameter conductive wire for feedback control was also deposited on the magnetic line, as shown in Fig. 3. The space between the wire and the magnetic line was approximately 500 $\mu$m.

We measured the applied field dependence of impedance of the sensor heads using a network analyzer (ADVANTEST R3765CG). The high-frequency carrier current and external dc field were applied to the sensor head in the length and width direction, respectively. To obtain an adequate skin effect, the carrier frequency of the sensor heads was 500 MHz. The GMI profile was measured at a room temperature, since the exchange bias has a strong dependence with the temperature.

## III. Results and Discussion

### A. Shape and Size Effect of the GMI Sensor Characteristics

Fig. 4 shows a magnetization curve of the unpatterned multilayer. We can see from the figure that a unidirectional anisotropy was obtained with an exchange-coupling field of 320 A/m. The unidirectional anisotropy is large enough for the asymmetrical GMI characteristics.

Fig. 5 shows applied field dependence of impedance of the sensor head 4 mm long and 300 $\mu$m wide. It is noted in the figure that the plus direction of the applied field is the direction of the arrow indicated in Fig. 2. The solid line shows the impedance change when the applied field is decreased from $+2.0$ to $-2.0$ kA/m, and the dotted line shows the impedance change caused by increasing the applied field from $-2.0$ to $+2.0$

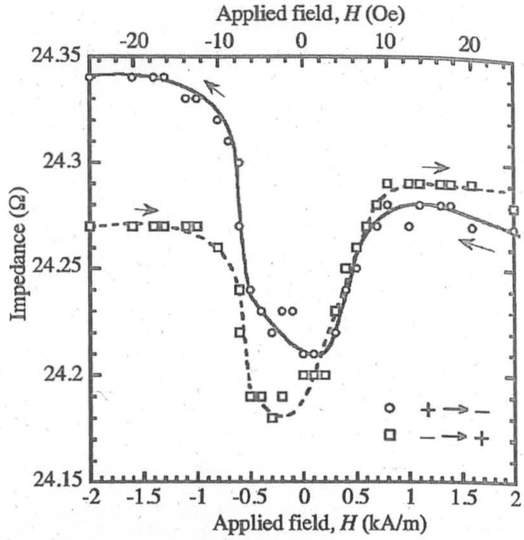


Fig. 5. Applied field dependence of the impedance at 4-mm-long sensor head.

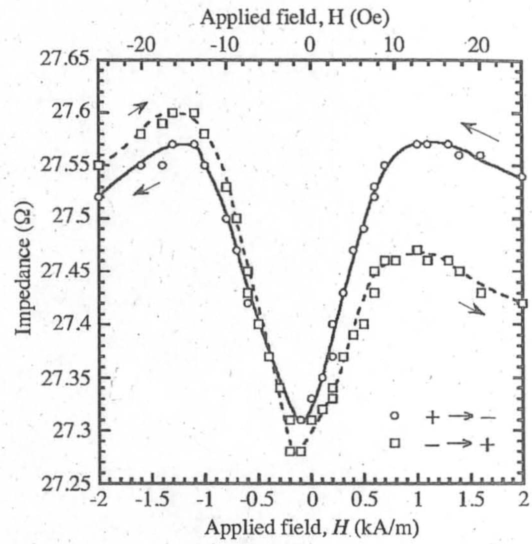


Fig. 6. Applied field dependence of the impedance at 3-mm-long sensor head.

kA/m. The external field was applied to the sensor head in the width direction. We can see from this figure that an asymmetrical characteristic and sensitivity of 50 $\Omega$/T in the weak field region near $H = 0$ were obtained by the thin-film head-structured sensor element. The asymmetrical GMI profile was obtained owing to the exchange bias of the Ni–Fe–Cu–Mo/Ir–Mn multilayer film.

On the other hand, higher sensitivity can be obtained for a short and wide shaped sensor head. Fig. 6 shows dependence of impedance for the 3-mm-long and 400-$\mu$m-wide sensor head on the applied dc field. The sensitivity of the sensor head was 331 $\Omega$/T, which was six times larger than that of the 4-mm-long sensor head. The high sensitivity was obtained for the short and wide sensor head because of the small demagnetization along the width direction. Furthermore, it is clear from the Fig. 6 that the hysteresis of the impedance change of the 3-mm-long sensor head was small compared to that of the 4-mm-long sensor head Figs. 4 and 5. The magnetostatic energy along the width direction of the sensor head increases

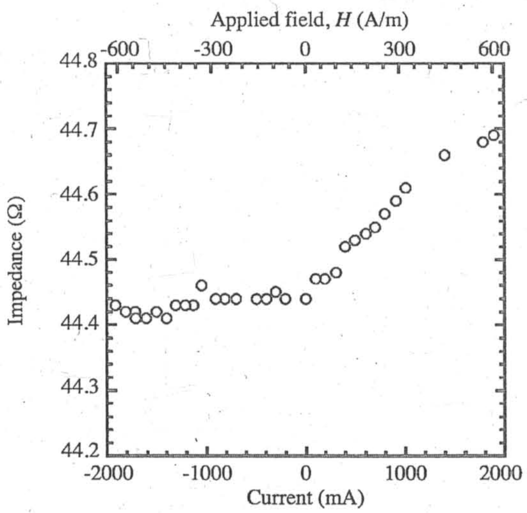


Fig. 7. Dependence of the impedance on the current flowing in the conductive wire adjacent to the magnetic line of the sensor head.

with the decreasing the sensor width. Therefore, the reducing the sensor width decreases the unidirectional anisotropy and increases the coercivity of the sensor head. As a result, the short and wide geometry of the sensor can decrease the hysteresis of the impedance change and increase the sensitivity.

### B. Feedback Control

Fig. 7 shows the dependence of the impedance of the 3-mm-long sensor head at 700 MHz on the current flowing in the conductive wire adjacent to the magnetic line of the sensor head. The impedance decreased monotonously when the current decreased from +2.0 to −2.0 A, as shown in Fig. 7. In this case, the applied field to the sensor head is estimated to be about +600 to −600 A/m. The result shows that the feedback control by conductive line fabricated on the sensor head monolithically can be realized.

## IV. Conclusion

It is concluded that the asymmetrical characteristics and high sensitivity of 331 Ω/T around the applied field of zero could be obtained due to the unidirectional anisotropy with the head-structured GMI sensor. It was also proved that feedback control is basically possible with conductive line fabricated monolithically on the sensor head. It seems that small clearance between the sensor head and recording media can be realized by the thin-film head structure.

## References

[1] H. Kikuchi, M. Takezawa, M. Yamaguchi, and K. I. Arai, "Analysis of the high-frequency impedance of micromachined films," *J. Magn. Soc. Jpn.*, vol. 21, pp. 789–792, Apr. 1997.

[2] M. Senda, O. Ishii, Y. Koshimoto, and T. Toshima, "Thin-film magnetic sensor using high frequency magneto-impedance (HFMI) effect," *IEEE Trans. Magn.*, vol. 30, pp. 4611–4613, Nov. 1994.

[3] T. Uchiyama, K. Mohri, L. V. Panina, and K. Furuno, "Magneto-impedance in sputtered amorphous films for micromagnetic sensor," *IEEE Trans. Magn.*, vol. 31, pp. 3182–3184, Nov. 1995.

[4] T. Morikawa, Y. Nishibe, H. Yamadera, Y. Nonomura, M. Takeuchi, and Y. Taga, "Giant magneto-impedance effect in layered thin films," *IEEE Trans. Magn.*, vol. 33, pp. 4367–4372, Sept. 1997.

[5] A. Takayama, T. Umehara, A. Yuguchi, and H. Kato, "Integrated thin film magneto-impedance sensor head using plating process," *IEEE Trans. Magn.*, vol. 35, pp. 3643–3645, Sept. 1999.

[6] M. Takezawa, Y. H. Kim, K. Ishiyama, M. Baba, N. Ajiro, M. Yamaguchi, K. I. Arai, N. Wako, and I. Abe, "Integration of high-frequency carrier-type thin-film magnetic field sensor with SmCo thin-film bias magnet," *IEEE Trans. Magn.*, vol. 35, pp. 3682–3684, Sept. 1999.

[7] D. P. Makhnovskiy, A. S. Antonov, A. N. Lagar'kov, and L. V. Panina, "Field-dependent surface impedance of a bilayer film with an antisymmetric bias magnetization," *J. Appl. Phys.*, vol. 84, pp. 5698–5702, Nov. 1998.

[8] M. Takezawa and J. Yamasaki, "Antiferromagnetic coupled high-frequency carrier-type magnetic field sensor using Ni–Fe/Fe–Mn multilayer," *IEEE Trans. Magn.*, vol. 38, pp. 3150–3152, Sept. 2002.