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Miniaturization of High-frequency Carrier-type Thin-film Magnetic Field Sensor Using Laminated Film

M. Takezawa, H. Kikuchi, M. Yamaguchi, and K. I. Arai

***Abstract*— We examined a laminated high-frequency carrier-type thin-film magnetic field sensor that consists of CoNbZr soft magnetic films with Nb non-magnetic conductive interlayer. The lamination can change domain structure of the sensor and obtain high sensitivity. An impedance change of 6 Ω and a gain of 43 kΩ/T was achieved when the length of the laminated sensor was 1 mm. The gain is four times larger than that of a monolayer sensor.**

***Index Terms*— lamination, domain structure, demagnetizing field, magnetic anisotropy, high-frequency carrier-type magnetic field sensor**

I. Introduction

MINIATURIZATION of a high-frequency carrier-type thin-film magnetic field sensor [1], [2] (or so-called GMI sensor) is required by high density magnetic recording systems and various sensing systems. However, a demagnetizing field in the sensor increases with decreasing the length of the sensor. Since the sensitivity of the sensor is sensitive to demagnetizing field in the length direction [3], previous thin-film sensors were larger than a few millimeters [1], [2]. Narrowing of the sensor strip is useful for reduction of the demagnetizing field. Then control of domain structure is necessary because a narrow strip with a transverse easy axis has closure domains that decrease the magnetic anisotropy. Our main idea is lamination of soft magnetic films with non-magnetic conductive interlayer that reduces the area of closure domains by permitting flux closure through the non-magnetic interlayer along the edges of the strip [4], [5].

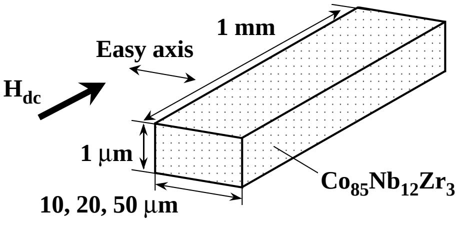
II. Experimental Procedure

Fig. 1 shows the monolayer and laminated sensor element deposited on a glass substrate by rf sputtering. The thickness of the monolayer sensor is 1 μm. In the case of laminated sensor, the thickness of each magnetic layer is 0.5 μm and that of the interlayer is either 5 or 10 nm.

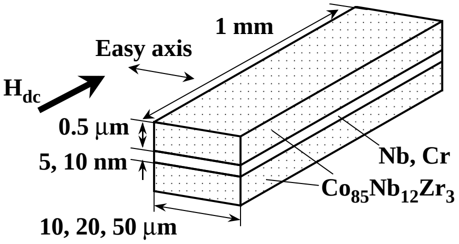
The aim of the lamination is not enhancement of the sensitivity at low frequencies [6]. We used the thin conductive interlayer to control the domain structure. The magnetic layer was an amorphous $Co_{85}Nb_{12}Zr_3$ film and the interlayer was Nb or Cr film. It has been proposed in many studies on the magnetic recording heads that SiO_2 insulator film is useful as the interlayer [7]. However, here the sensor utilizes impedance change due to skin effect at high frequencies [8]. According to the aim of this work, the interlayer should be composed from the non-magnetic conductive material.

Uniaxial anisotropy was induced by rotational field annealing of 40 kA/m at 400 °C for 2 hours and static field annealing of 40 kA/m at 400 °C for 1 hour. The films were ion milled to 1 mm long and 10, 20 and 50 μm wide rectangles with their easy axis along width direction as shown in Fig. 1. Finally the elements were annealed for 1 hour at 400 °C in a static field of 80 kA/m.

Magnetization curve was measured by using M-H loop tracer. Applying high frequency current of 100 MHz to the length direction, we measured the impedance change of the sensors using a network analyzer (HP8752A) when the sensors were subjected to an external dc field along the length direction. We observed magnetic domain structure using Bitter method.



(a) Monolayer sensor



(b) Laminated sensor

Fig. 1. Schematic view of the sensor element.

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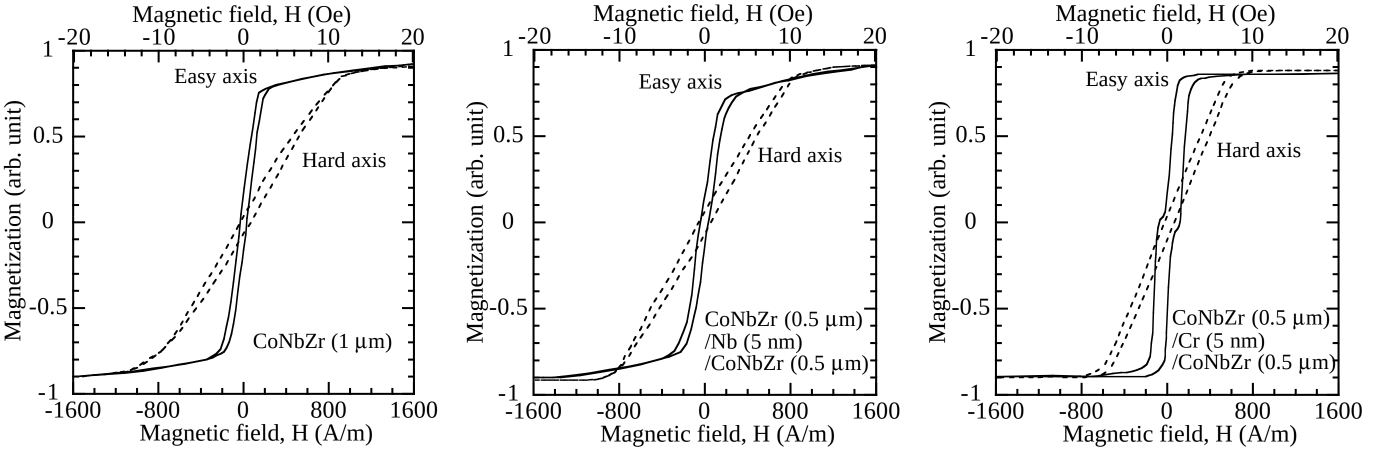
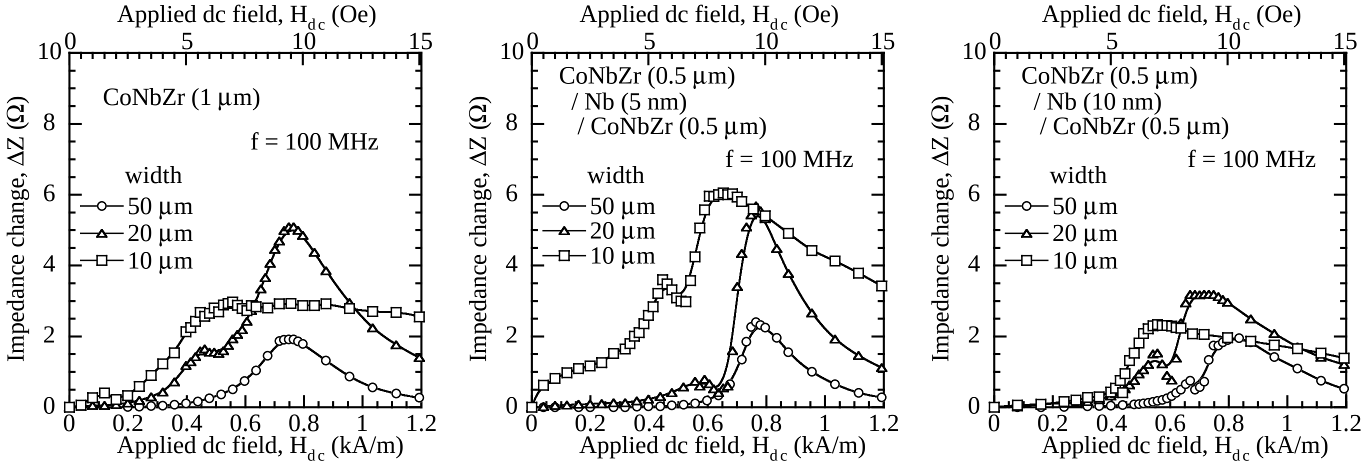


(a) CoNbZr monolayer film (b) CoNbZr/Nb/CoNbZr trilayer film (c) CoNbZr/Cr/CoNbZr trilayer film

Fig. 2. Magnetization curve of the monolayer and trilayer film



(a) Monolayer sensor (b) Laminated sensor (Nb : 5 nm) (c) Laminated sensor (Nb : 10 nm)

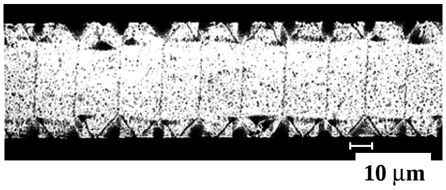
Fig. 3. Impedance change of the sensor with applied dc field.

III. Results and Discussion

Fig. 2 shows magnetization curve of 5 mm diameter film. Here the laminated film had 5 nm interlayer. In the case of monolayer and CoNbZr/Nb/CoNbZr trilayer film, the coercive force was about 30 A/m and the anisotropy field was about 800 A/m, as shown in Fig. 2(a) and (b). Obviously, the adequate anisotropy and small coercive force was obtained for high-sensitive magnetic sensor [8]. However, the coercive force of CoNbZr/Cr/CoNbZr trilayer film increased up to 100 A/m and large hysteresis was found in Fig. 2(c). Consequently, we chose Nb thin-film as the interlayer material of the laminated film.

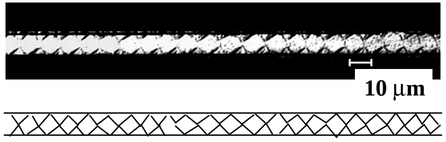
Fig. 3 shows the applied dc field dependence of the impedance for the monolayer and CoNbZr/Nb/CoNbZr laminated sensor. The impedance change of the laminated sensor whose interlayer thickness was 5 nm increased with a decrease in the sensor width and the maximum change of 6 Ω was obtained when the width was 10 μm, as shown in Fig. 3(b). The results are in reasonable agreement in the theory [3]. In the case of the monolayer sensor, however, the impedance change of the 10 μm wide element was smaller than that of the 20 μm wide element, as shown in Fig. 3(a). The maximum gain, $\Delta Z/\Delta H_{dc}$, of the 10 μm wide laminated sensor with the 5 nm interlayer was 43 kΩ/T. The gain is four times larger than the monolayer sensor. The result of the laminated sensor with 10 nm interlayer was similar to that of the monolayer sensor, as shown in Fig. 3(c).

Fig. 4 $\sim$ 6 shows the domain configurations of the monolayer and laminated sensors. The similar domain structure was shown in all 20 μm and 50 μm wide sensors because the wide strip produced small magnetostatic energy. So 20 μm and 50 μm wide sensors showed almost the same sensitivity in the monolayer and laminated sensors, as shown in Fig. 3. Fig. 4(c) indicates only 90° walls, and closure domains at the edge of the 10 μm wide monolayer sensor was as large as main domains. The reason for this is that the closure domains suppress an increase in magnetostatic energy with narrowing strip. Since the magnetization of the closure domains is aligned along the length direction, the edge domains do not contribute to the impedance change [8]. The reduction of the main domains causes the small impedance change. On the other hand, Fig. 5(c) presents 180° and 90° walls. The area of the closure domains decreased by laminating CoNbZr film with 5 nm Nb interlayer because the lamination allows flux closure to



(a) 50 μm wide

(b) 20 μm wide

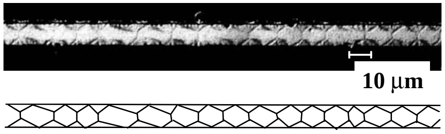


(c) 10 μm wide

Fig. 4. Domain structure of the monolayer sensor.

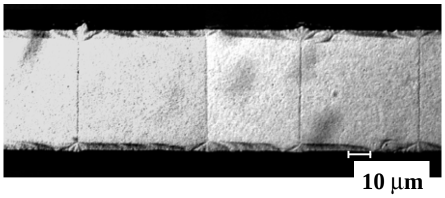
(a) 50 μm wide

(b) 20 μm wide

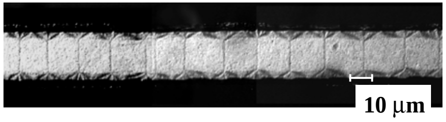


(c) 10 μm wide

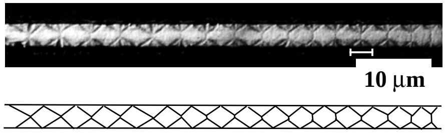
Fig. 5. Domain structure of the laminated sensor with 5 nm interlayer.



(a) 50 μm wide



(b) 20 μm wide



(c) 10 μm wide

Fig. 6. Domain structure of the laminated sensor with 10 nm interlayer.

occur between each CoNbZr layer through an antiparallel alignment of the magnetization in the adjacent magnetic layers [4], [5]. It was shown that the laminated sensor obtained uniaxial anisotropy to the width direction after etching to narrow strip. The domain structure of laminated sensor with 10 nm interlayer was analogous to that of the monolayer, as shown in Fig. 6. The reason for this is that large interlayer thickness decreases coupling between magnetic layers. It was found that the change of the domain structure due to the lamination is useful for miniaturization of the sensor and the optimum interlayer thickness exists to eliminate the closure domains. Since the skin depth varies with the frequency of the ac driving current, it is necessary to optimize the thickness of magnetic layer and interlayer, which will be discussed in future work.

IV. CONCLUSIONS

We investigated the laminated sensor consisting of CoNbZr magnetic films with Nb non-magnetic conductive interlayer. The lamination could control the domain structure and obtain the large impedance change. The laminated sensor with 5 nm Nb interlayer obtained the large impedance change of 6 Ω and gain of 43 kΩ/T. The gain is four times larger than that of the monolayer sensor.

V. ACKNOWLEDGMENTS

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