Dynamic Domain Observation in Narrow Thin Films

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Abstract—We examined a domain structure of high-frequency carrier-type thin-film magnetic field sensors that consist of narrow rectangular CoNbZr thin film to clarify a magnetization process of the sensor head. Moreover, the cause of disagreement between measured and calculated sensitivities was investigated. The measured impedance change of the sensor head can be explained qualitatively in consideration of the wall displacement owing to the growth of the closure domain.

Index Terms—Closure domain, domain structure, magnetization process, narrow thin film.

I. INTRODUCTION

A HIGH-FREQUENCY carrier-type thin-film magnetic field sensor [1]–[4] (or so-called MI sensor) is required in various sensing systems because the sensor has a high sensitivity, coilless configuration, and so on. However, the measured sensitivity of the sensor with small width is lower than that in calculated value based on the bias susceptibility theory and Maxwell’s equation [3]. To solve the problem, it is necessary to clarify a magnetization process of the sensor head when the magnetic field is detected. In this paper, we observed dynamically and statically a domain structure of the sensor head when the magnetic field was applied without high frequency carriers (without the skin effect) and investigated the sensitivity of the sensor head in detail.

II. EXPERIMENTAL PROCEDURE

A. Fabrication and Measurement

An amorphous Co$_{85}$Nb$_{12}$Zr$_3$ thin film was deposited on a glass substrate by rf sputtering. Uniaxial anisotropy was induced by a rotational field annealing of 40 kA/m at 400 °C for 2 hours and then a static field annealing of 40 kA/m at 400 °C for 1 hour. The 1 μm thick film was ion-milled to 1 mm long and 50 and 20 μm wide rectangles with the easy axis along the width direction. Fig. 1 shows the fabricated sensor heads. Finally the elements were annealed for 1 hour at 400 °C in a static field of 80 kA/m.

A magnetization curve was measured using an M–H loop tracer. Sensitivities defined by an impedance change for unit field application was measured by measuring the impedance of the sensor head using a network analyzer (HP8752A) when the sensor heads were subjected to an external dc field along the length direction.

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of the brightness of the domain images. Because the Kerr rotation angle of the thin-film is smaller than a few degrees, the relation between the Kerr effect signal and the magnetization are almost linear in this study. So we can investigate the magnetization process of the sensor head after the fabrication process by the domain observation.

III. RESULTS AND DISCUSSION

Fig. 3 shows images of the dynamic domain observation in the 50 μm wide sensor head. Bright and dark fine stripe images which were created by domain wall displacement appeared at 50 Hz, as shown in Fig. 3(a). The wall motion causes the disagreement between measured and calculated sensitivities because the calculation only considers magnetization rotation due to a strong skin effect with the high frequency carrier with several ten MHz in which domain wall motion is strongly suppressed. The domain wall also moved at 100 kHz, as shown in Fig. 3(b). It seemed that the wall displacement results from a growth of closure domains because the magnetization in the closure domain is aligned along the length direction. When the width of the sensor decreased to 20 μm, the wall displacement became large, as shown in Fig. 4. The reason is that the small width of the sensor head produces a large magnetostatic energy.

Fig. 5 shows the static domain structure of the 50 μm wide thin film. Bright and dark stripe domains whose width was about 5 μm and gray triangular closure domains whose side was about 2 μm appeared when the dc field was not applied, as shown in Fig. 5(a). Since an area of the main stripe domains was large compared to that of the closure domains, an adequate magnetic anisotropy along the width direction was obtained for the high-sensitive magnetic film [3]. When the applied field was 0.40 kA/m, the triangular closure domains became large and the contrast of the stripe domains decreased. Furthermore, the side of the triangular closure domains increased to about 10 μm and the color of the stripe domains varied toward gray when the dc field increased to 0.64 kA/m, as shown in Fig. 5(c). The reason for the increase of the closure domains with increasing the field applied along to the length direction is that the direction of the magnetization in the closure domains is the same as that of the applied field. The saturated domain image was shown in Fig. 5(d) in the dc field of 1.2 kA/m. We can see from the domain images that both the wall displacement owing to the growth of the closure domains and the magnetization rotation in the main stripe domains occurred in the applied field along the hard axis of the film.

Fig. 6 shows the static domain structure of the 20 μm wide film. The magnetization process that is composed of the magnetization rotation and the wall displacement was also observed. By looking at Fig. 6(b) and (c) we can get a sense of the large influence of the wall displacement on the magnetization process in comparison with the 50 μm wide film. The main reason for this is that narrow thin films with a transverse easy axis have high magnetostatic energy and the occurring of the closure domains can reduce the energy.

Fig. 7 shows the applied field dependence on the brightness of the domain images and the magnetization. The magnetization curve was measured for a circular thin film with 5 mm diameter when the field was applied along the hard axis. The anisotropy field of the thin film was about 0.8 kA/m, as shown by the dotted line. The brightness curve of the 50 μm wide film was nearly equal to the magnetization curve. However, the curve of the 20 μm wide film shown by the broken line seemed to include a
Excited field, $H_{ex}$ (Oe)

- Meas. - - - Calc. (previous)

$Z = 0.7Z_m + 0.3Z_c$ (1)

where $Z_m$ and $Z_c$ are the calculated impedance of the main and the changing domain area.

Fig. 9 shows the dependence of the measured and calculated impedance change of the 20 $\mu$m wide film on the excited field. The calculated value with and without the wall displacement in mind shows by the solid line and broken line. The measured impedance change had two peaks, which was also shown by the calculated value with the consideration of the wall displacement. Moreover, the results of the 50 $\mu$m wide film had only one peak. So, we can deduce from the data that the disagreement between the measured sensitivity and conventional calculation is caused by the growth of the closure domains.

**IV. CONCLUSIONS**

We observed the domain structure in thin film applying the ac and dc field to examine the magnetization process. As the results, it becomes evident that the wall displacement caused the disagreement between measured and calculated sensitivity.
Therefore, it is necessary to eliminate the closure domains and restrain the wall displacement to obtain high sensitivity.

REFERENCES


