Effect of Carbon Inclusion on Properties of Electrodeposited CoNiFeMo-based Soft Magnetic Thin Films

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Recently, with the rapid increase of the magnetic recording density, the coercivity, $H_c$, of recording media has become larger and larger. To write on such high-$H_c$ media, soft magnetic films as write core materials are required to have high saturation magnetic flux density, $B_s$, and/or high electrical resistivity, $\rho$, enough to generate magnetic field with high recording rate. Many soft magnetic thin films, including soft magnetic CoNiFe thin films with $B_s$ of 2.0-2.1 T [1], have been reported so far, and we have succeeded to develop CoNiFeMoC thin films with $B_s$ of 1.6-1.8 T and $\rho$ of 130 $\mu$cm $\Omega$ [2]. On the other hand, carbon inclusion into the films has known to affect their properties such as corrosion resistance, film density, ductility, and etc. Among them, high ductility is an important requirement for micropattern formation. However, the ductility of above-mentioned CoNiFeMoC thin films was low compared with CoNiFe, 80-Permalloy (Ni$_8$Fe$_{12}$), and 45-Permalloy (Ni$_45$Fe$_{55}$), which are commonly used as write core materials. In this study, effects of carbon inclusion on properties of CoNiFeMoC-based thin film were investigated at first, and then, optimized CoNiFeMoC-based thin film was applied to fabricate magnetic recording head actually.

CoNiFe-based thin films were prepared by electrodeposition with rotating disk electrode system. The substrates were Cu foils (8 $\mu$m thick) or glasses sputtered with Ti (10 nm)/NiFe (100 nm). The thickness of films was 1.0 and 0.4 $\mu$m for the evaluation of ductility and other properties, respectively. The composition of present bath was based on that of the CoNiFeMoC bath previously reported. Magnetic properties were measured by vibrating sample magnetometer (VSM). Resistivity was measured by four-probe method. Film composition was estimated by X-ray fluorescence analysis and inductively coupled plasma emission analysis, and content of carbon and sulfur was determined by combustion analysis. Ductility of the films was examined by using the mechanical ductility tester.

Firstly, to reduce the carbon inclusion into the CoNiFeMoC thin film, saccharin was added to the bath. Carbon content of the film decreased with increase in saccharin concentration of the bath, from 2 at% to 0.4 at%, over addition of 1-g dm$^{-3}$ saccharin, while sulfur content increased gradually with increase in saccharin concentration, and the content was 0.3 at% up to 3-g dm$^{-3}$ saccharin addition.

Secondly, the ductility of CoNiFeMoC-based thin films with various carbon-content was investigated (Fig. 1). The ductility of CoNiFe film from additive-free bath is about 0.6-% elongation. This value was almost the same as that of Ni$_4$Fe$_{20}$. On the other hand, the ductility of conventional CoNiFeMoC, from saccharin-free bath, is 0.1-% elongation. From the investigation on CoNiFeC films, the relationship that ductility of the films decreased gradually with increasing carbon content was elucidated.

As for the CoNiFeMoC film from saccharin-containing bath, with 0.4 at% carbon, its ductility of 0.4-% elongation was much higher than that of CoNiFeMoC film, and equivalent to that of Ni$_4$Fe$_{20}$. It should be noticed that inclusion of Mo is less effective in ductility. Finally, magnetic recording head was fabricated actually. Fig. 2 shows SEM images of magnetic recording head with applying (a) CoNiFeMoC and (b) CoNiFeMoCS to upper core. For CoNiFeMoC film from saccharin-free bath, many cracks were observed in the core patterns. In particular, the crack observed at pole tip, as shown in Fig. 2(a), indicated that the fabrication of the upper core by using this film was impossible. On the other hand, no crack was observed in the core patterns with CoNiFeMoCS film. As it is expected that crack in core patterns is due to poor ductility of the film, enhancement of ductility is essential to form the patterned films with stepwise structure. It is considered that the stress of the films deposited on the stepwise concentrates on their bending part(s) and the cracks were occurred because of the ductility not enough to bear such a stress.

In summary, the improvement of ductility of CoNiFeMoC thin films was achieved by the addition of saccharin in the bath with lowering carbon content of the films. Thus-prepared ductility-enhanced CoNiFeMoCS thin film was shown to be useful for practical application to magnetic recording head as core.

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References


![Ductility vs. Carbon Content](image1.png)

Figure 1. Ductility of electrodeposited CoNiFeMoC-based thin films as a function of carbon content.

![SEM Images of Magnetic Recording Head](image2.png)

Figure 2. SEM images of magnetic recording head using (a) CoNiFeMoC (ductility: 0.1-% elongation) and (b) CoNiFeMoCS (ductility: 0.4-% elongation) as upper core.