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ELECTRODEPOSITED Ni-Fe-S FILMS WITH HIGH RESISTIVITY FOR MAGNETIC RECORDING DEVICES

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The magnetic properties, resistivity, saturation magnetostriction and microstructure of electrodeposited Ni-Fe-S films were investigated. The films were prepared from bath containing thiourea (H_2N-CS-NH_2) as a source of sulphur in the NiFe films. It was added adenine (H_2N-$C_4H_2N_4$-CH) as an organic additive to electrolytic bath in order to increase the resistivity and saturation magnetostriction of the films while maintaining their good soft magnetic properties. The optimum $Ni_{10}Fe_{69}S_{21}$ film exhibits higher resistivity, ρ = 170 μΩ.cm, than a $Ni_{80}Fe_{20}$ permalloy film (32 μΩcm), high saturation flux density, B_s = 1.2 T, low saturation magnetostriction $\lambda_s = 8.1 \times 10^{-6}$, low coercivity (soft magnetic film), H_c = 144 $A.m^{-1}$ and an anisotropic magnetic field, H_k = 1.04 $kA.m^{-1}$.

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1. Introduction

The present technologies in recording processes use thin film magnetic media, which have in-plane magnetization and record information in the longitudinal mode [1, 2]. Currently, two types of thin film magnetic heads, inductive and magnetoresistive (MR) are produced [3]. Inductive heads mainly proposed to be used as flying heads in hard disk drives because of their ability both to read and write. MR sensors [4,5] enjoy a number of advantages over inductive read heads. Since MR sensors detect magnetic flux directly, their output amplitude is independent of the relative speed between the head and the recording medium. In addition, the output is proportional to the sensing current, typically producing signals higher than obtained with inductive heads. Soft-film biasing or soft-adjacent-layer biasing has been found as a viable technique to improve the linearity of the MR sensor [5]. In this configuration, a soft magnetic film is placed adjacent to the MR layer (e.g., NiFe), separated by a non-magnetic spacer. To optimize the performance of the MR trilayer sensor using this transverse biasing technique the proper selection of the soft-film material is critical. The electrical resistivity ρ of the soft-film layer should be as high as possible to minimize current shunting especially if a conductive spacer is used. The minimized current shunting will lead to a higher signal output from the MR sensor. In addition, a soft film with a low (near zero) saturation magnetoresistive constant is also essential for the stable operation of the MR sensors. NiFe films exhibit excellent soft magnetic properties and can be used as a soft-film material. The major drawback in using NiFe as the soft-film material as well as the MR layer is their low electrical resistance. This will lead to a high current shunting through the soft-film, which results in a significant loss of signal amplitude of the MR sensor. This shortcoming of the use of NiFe as the soft-film can be improved, however, by adding a third element to the NiFe alloy [6].

In this work, we present results on preparation and magnetic properties of electrodeposited Ni-Fe-S alloy soft-films with high resistivity.

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2. Experimental

Ni-Fe-S films were electrodeposited on a copper substrate. The bath composition and operating conditions of electrodeposited Ni-Fe-S films are shown in Table 1. We start the preparation with a Fe film (zero Ni content). After that Ni sulphate was gradually added in the electrodeposition bath so that we can obtain Ni-Fe-S films with differently Ni, Fe and S contents. The source of sulphur in the films was thiourea [7]. Thickness of the films was about 1 μm. The composition of each film was analyzed by electron probe microanalysis (EPMA). Structural properties of films were analyzed by X-ray diffraction (XRD), electron transmission microscopy (TEM) and electron diffraction (ED).

Table 1. Bath composition and operating conditions for electrodeposited Ni-Fe-S films.

Bath composition (mol m^{-3})		Operating conditions	
$NiSO_4 \cdot 7H_2O$	0-1000	Bath temperature	Room temperature
$FeSO_4 \cdot 7H_2O$	500-1500	pH	2.5
N_2H_4CS	0-6.57	Current density	10-20 mA/cm^2
$(NH_4)_2SO_4$	100	Agitation	30 rot/min

Magnetic properties of films were measured with a computer assisted B-H loop tracer (CAHLT) and an automated torque-magnetometer (ATQM). Resistivity was measured by a four terminal method. Saturation magnetostriction λ_s was determined by change of anisotropy field under applied stress on the films [8]. Thermal stability was studied by annealing the same film at various temperatures in vacuum for 1 hour.

3. Results and discussion

Fig. 1 shows the dependence of Ni content of Ni-Fe-S films on ($NiSO_4/NiSO_4 + FeSO_4$) ratio and on current density in the electrodeposition bath.

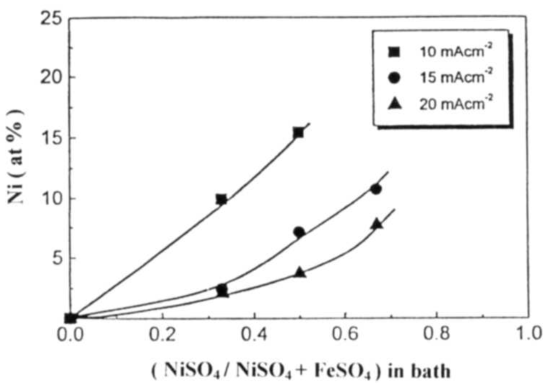

Fig. 1. Dependence of the Ni content of Ni-Fe-S films on $NiSO_4/NiSO_4 + FeSO_4$ ratio in electrodeposition bath.

The Ni content in the Ni-Fe-S film decreases when the current density increases. In this experiment, we varied the Ni content in Ni-Fe-S films as a function of current density from 10 mA·cm^{-2} to 20 mA·cm^{-2}.

Fig. 2 shows the dependence of saturation magnetic flux density B_s (Fig. 2a) and of coercivity H_c (Fig. 2b) of Ni-Fe-S films on Ni content. The Ni-Fe-S film with 10 at % Ni content, which was electrodeposited from a bath with 10 mA·cm^{-2} current density has suitable soft magnetic properties with a very low coercivity of 40 Am^{-1} and high saturation magnetic flux density of about 1.2 T. This value for B_s of $Ni_{10}Fe_{69}S_{21}$ film is higher than of a permalloy $Ni_{80}Fe_{20}$ film (~ 1 T).

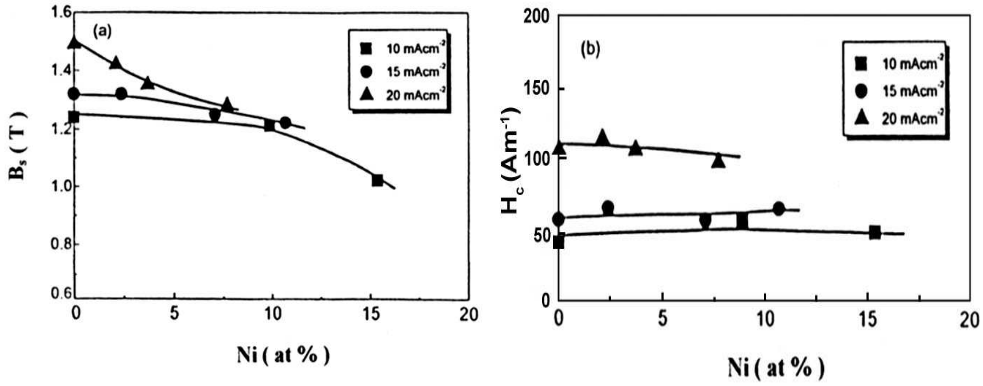

Fig. 2. Dependence of B_s (a) and H_c (b) of Ni-Fe-S films on the Ni content.

Fig. 3 shows the dependence of saturation magnetostriction λ_s of Ni-Fe-S films on the Ni content.

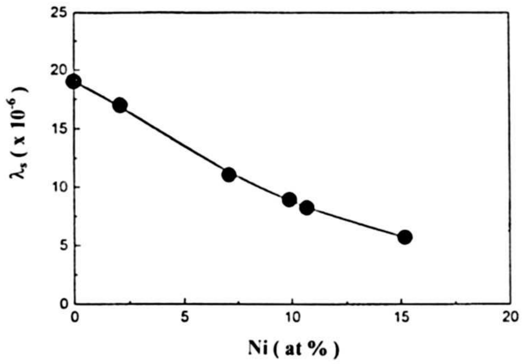

Fig. 3. Dependence of saturation magnetostriction λ_s of Ni-Fe-S films on the Ni content.

The saturation magnetostriction λ_s decreases with Ni content increase. For an optimum NiFeS film with 10 at % Ni content $\lambda_s = 8.1 \times 10^{-6}$.

Fig. 4 shows the dependence of resistivity ρ of a $Ni_{10}Fe_{69}S_{21}$ film on the adenine concentration in the bath.

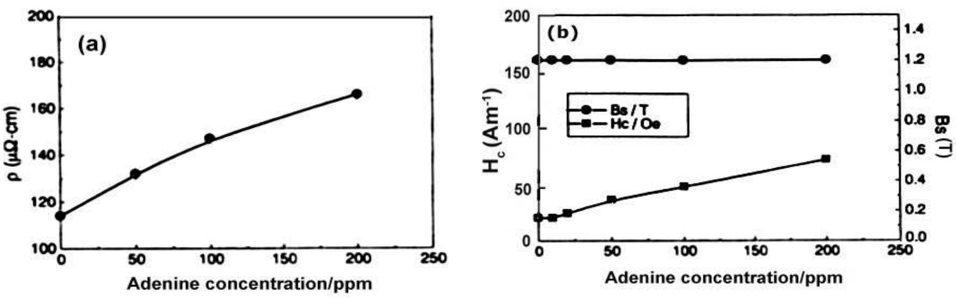

Fig. 4. Dependence of resistivity ρ (a) and of B_s and H_c (b) of $Ni_{10}Fe_{69}S_{21}$ film on adenine concentration.

The resistivity increases with adenine concentration increase. This increase takes place from 110 μΩcm for zero adenine concentration in the bath up to about 170 μΩcm for 200 ppm adenine concentration in the bath. The presence of adenine in the bath does not affect B_s but determine an increase of H_c up to 144 Am^{-1}. Therefore, optimum $Ni_{10}Fe_{69}S_{21}$ films obtained from a bath with 200 ppm adenine concentration exhibits suitable soft magnetic properties with B_s = 1.2 T, H_c = 144 $A.m^{-1}$ and high resistivity of about 170 μΩcm. The adenine presence in the electrodeposition bath probably determines the carbon absorbtion in $Ni_{10}Fe_{69}S_{21}$ film and this may be a cause of coercivity increasing [9].

Fig. 5 shows the cross-sectional TEM micrographs and ED patterns for a $Ni_{10}Fe_{69}S_{21}$ film obtained from a bath (a) without and (b) with 200 ppm adenine in concentration. As shown in Fig. 5a, the optimum NiFeS (10 at % Ni) film appears to consist of an amorphous structure.

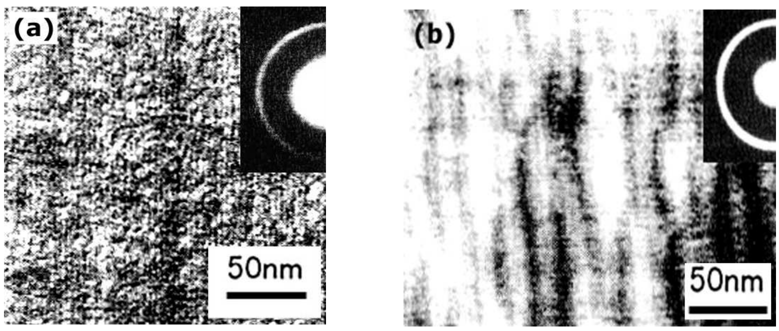

Fig. 5. Cross-sectional TEM micrograph and ED pattern for an optimum $Ni_{10}Fe_{69}S_{21}$ film electrodeposited in a bath (a) without and (b) with adenine content.

Comparatively with Fig. 5a, Fig. 5b indicates that the adenine presence in the electrodeposition bath causes the formation a fibrous structure in the film.

Fig. 6 shows XRD patterns of electrodeposited $Ni_{10}Fe_{69}S_{21}$ film as a function of the ann-annealing temperature. Up to 200 ^{0}C the film exhibits a good stability of their softness when only coercivity increase up to 160 Am^{-1}. Above this temperature the coercivity increase simultaneously with film crystallization and a bcc-Fe phase appears.

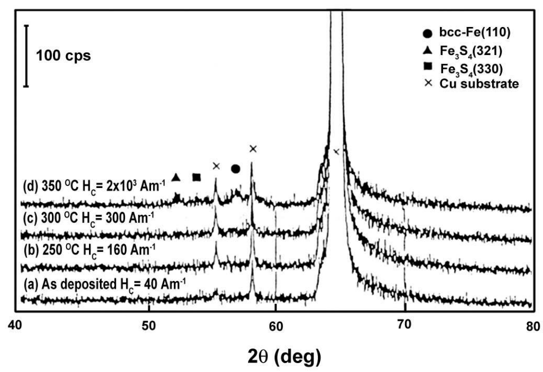

Fig. 6. XRD patterns of optimum $Ni_{10}Fe_{69}S_{21}$ film electrodeposited in a bath with adenine as a function of the annealing temperature: (a) as deposited, (b) 250 ^oC, (c) 300 ^oC and (d) 350 ^oC.

4. Conclusions

There were prepared by electrodeposition $Ni_{10}Fe_{69}S_{21}$ films with low coercivity, H_c = 40 Am^{-1} and high saturation magnetic flux density, B_s = 1.2 T because the films have a high Fe content (69 at %). The saturation magnetostriction of the films was very low, $\lambda_s = 8.1 \times 10^{-6}$ because the films have a low Ni content (10 at %). The electrical resistivity was increasing comparatively with a permalloy film, ρ = 110 μmΩ, because a third element, sulphur, was including in the alloy film.

The electrical resistivity of optimum magnetic soft film, $Ni_{10}Fe_{69}S_{21}$, was increased by adding in the electrodeposition bath of an additive, adenine, without affects the saturation magnetic flux density. However, the coercivity exhibits a little increase, up to 144 Am^{-1} and the electrical resistivity exhibits a significantly increase up to 170 μmΩ for 200 ppm adenine concentration in the electrodeposition bath.

The $Ni_{10}Fe_{69}S_{21}$ films have suitable soft magnetic properties for magnetic recording devices: B_s = 1.2 T, H_c = 144 Am^{-1}, $\lambda_s = 8.1 \times 10^{-6}$, ρ = 170 μmΩ and good thermal stability after annealing at less 250 ^{0}C in vacuum.

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