INFLUENCE OF DIFFERENT CURRENT DENSITY ON CHARACTERISTICS OF NiFeP NANO ALLOY THIN FILMS

C. Devi^{1,2,*} and R. Ashokkumar³

¹Research Scholar, Research and Development Centre, Bharathiar University,
Coimbatore-641 046, TamilNadu, India

²Department of Physics, Jay Shriram Group of Institutions, Avinashipalayam,
Tirupur-638660, TamilNadu, India

³PG and Research Department of Physics, Thiruvalluvar Govt. Arts College,
Rasipuram-637401, Namakkal, TamilNadu, India

*E-mails: deviphd12@gmail.com

ABSTRACT

In this study, electroplated NiFeP thin films were prepared with different density of current. Characterization of films was analyzed. The X-ray diffraction investigation exhibits that the electro plated NiFeP thin films consist of a face-centered cubic (FCC) phase with diffraction peaks (220), (200) and (111). The EDAX study shows that the maximum nickel content of 80.81 wt% was received for the density of current 5 mA/cm² g/l. The weight % of ferrous decreases while a current density was raised. The SEM result exhibits that NiFeP thin films were shiny and uniformly deposited on the cathode surface. The Vickers Hardness Tester result shows that reduction in hardness by improving current density. Moreover, VSM studies indicate an increase in coercivity of materials and decrease in magnetization by increasing current density.

Keywords: Electro deposition, VSM, Characterization, XRD, Crystal, Magnetization, SEM, and Micro hardness,

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INTRODUCTION

MEMS components, for example, sensors, microactuators, micromotors and frictionless microgears need the utilization of soft magnetic materials because electromagnetic activated MEMS, NEMS is more steady for high power and vast actuation applications. Additionally, they are less applicable to malfunction when exposed to contrary environments such as dust and humidity and can be stimulated with low-cost voltage controllers.¹⁻⁴ There is a wide range of approaches to deposit and incorporate magnetic materials into MEMS and NEMS. Electrodeposition is a suitable method to achieve the requirements of efficient coating and cost-effective processes. Electrodeposition process has many advantages, such as precisely room temperature process, fast deposition rates, sufficient low energy and ability to use complex geometries with easily handled equipment. Moreover, characteristics of materials can be changed by controlling electrolytic solution compositions and parameters of deposition. Because of these merits, electrodeposited soft magnetic materials, for example, NiFe and its combination have been largely utilized as recording head materials for hard drive productions.⁵⁻⁶ The NiFe thin films are utilized in pulse transformers storage, shielding for low-temperature measurement, a transformer for residual current devices and transducers⁷⁻¹¹. Among different Fe-based compounds, Fe-Ni alloys have pulled great attention not only in the field of technological applications but also in the fundamental research. The utilization of phosphorus with NiFe prompts to better corrosion resistance, magnetic properties and structural properties of the alloy.¹²⁻¹⁴ In this study, the effects of different current density on NiFeP films were analyzed.

EXPERIMENTAL

Electrodeposition of NiFeP composite films were setup with electrolytic baths consisting FeSO₄ (20 g/l), NiSO₄ (50 g/l), NH₄HCO₂ (40 g/l), H₃PO₃ (10 g/l), C₆H₈O₇ (10 g/l) with different current density 2,3,4

and 5 mA/cm^2 . The arrangement pH was changed in accordance with 6.0 by including NH_4OH and electro deposition was conducted at 30°C . Electro plating time interval was 15 min. In this study, copper and steel went about as cathode and anode separately with measurement $7.5 \text{ cm} \times 1.5 \text{ cm}$ ¹⁵⁻¹⁷. Following 15 minutes, the cathode plate was detached from an electrolytic bath and dried for a couple minutes. The crystal phase nature and particle size of material deposition were identified and examined by the device X-ray diffractometer (XRD) with Cu K_α radiation. Morphological investigation of Ni-Fe-P films was completed by Scanning Electron Microscope (SEM) and hardness of material deposits was determined by Vickers Hardness Test. The chemical composition of Ni-Fe-P thin films was examined by EDAX (Energy-dispersive X-ray Spectroscopy) and magnetic properties investigated by the device vibrating sample magnetometer.¹⁸⁻²²

RESULTS AND DISCUSSION

Elemental Composition of NiFeP Thin Films

The elemental composition of NiFeP films was found by EDAX analyzer. From result, the ferrous compositions decrease as 22.63%, 18.78%, 14.92% and 11.76% for current density 2, 3, 4 and 5 mA/cm^2 respectively. Nickel compositions increase as 67.84%, 70.96%, 76.32% and 80.81% for current density 2, 3, 4 and 5 mA/cm^2 respectively. Phosphorus compositions are as 9.53%, 10.26%, 8.76% and 7.43% for current density 2, 3, 4 and 5 mA/cm^2 respectively. So it is concluded that films with high current density exhibit high nickel content and low ferrous content. Fig 1, 2 and 3 show the variation of ferrous, nickel and phosphorus composition with increasing current density.

Fig.-1: Current Density Vs Ferrous Composition

Fig.-2: Current Density Vs Nickel Composition

Morphological Observation

The surface appearance of NiFeP thin films with increasing current density was analyzed by Scanning Electron Microscope (SEM) images and they are shown in Fig.-4. The coating on the surface is shiny and uniform. Thin films appear crack free.

Fig.-3: Current Density Vs Phosphorus Composition

(a)

(b)

(c)

(d)

Fig.-4: SEM images of NiFeP Film for Current Density (a) 2mA/cm² (b) 3mA/cm² (c) 4mA/cm² (d) 5mA/cm²

Structural Characters

Structural characteristic (from XRD Data) data's of thin film materials prepared with distinct current density are shown in figure 5. The information of crystals in thin film deposition concluded by XRD pattern which is shown in fig 5. FCC phase is the nature of crystals which deposited on substrate. The particle size increases as 30.15, 36.93, 43.73 and 51.09 nm for current density 2, 3, 4 and 5 mA/cm² respectively. The nano crystallite deposits were obtained and the average crystallite size is around 40 nm.

Fig.-5: NiFeP Alloy Films- XRD Patterns with Different Current Density (a) 2 mA/cm² (b) 3 mA/cm² (c) 4 mA/cm² (d) 5 mA/cm²

The crystallite sizes, strain and dislocation density are tabulated in Table-1. The strain decreases as 1.201×10^{-3} , 0.980×10^{-3} , 0.828×10^{-3} and 0.709×10^{-3} for current density 2, 3, 4 and 5 mA/cm² respectively. While current density is increased from 2 to 5 mA/cm², the crystallite size increases because of decreasing in ferrous content during electro deposition process. Fig.-6 shows the variation of crystal size with increasing current density.

Table-1: NiFeP Alloy Films -Structural Properties

S. No.	Current density (mA/cm ²)	2θ (deg)	d (Å ⁰)	Particle Size(D) (nm)	Strain (10 ⁻³)	Dislocation Density (10 ¹⁴ / m ²)
1	2	49.83	1.904	30.15	1.201	11.01
2	3	49.17	1.736	36.93	0.980	07.33
3	4	50.82	1.852	43.73	0.828	05.23
4	5	49.36	1.813	51.09	0.709	03.83

Mechanical Properties

Micro hardness measurement of NiFeP deposits was done by Vickers hardness tester. The hardness values of thin films prepared with increasing current density are 109, 92, 73, 58 VHN respectively.

Decreasing value of hardness is concluded due to increases in particle sizes. Figure-7 shows the variation of hardness with increasing current density.

Fig.-6: Current Density Vs Crystal Size

Fig.-7: Current Density Vs Vickers Hardness

Magnetic Characteristics

The hysteresis curves for Ni-Fe-P thin films for distinct current density 2,3,4 and 5 mA/cm² are shown in figure 8. It is noted that magnetization value decreases as 87.2×10^{-3} emu/cm², 24.4×10^{-3} emu/cm², 13.0×10^{-3} emu/cm² and 2.99×10^{-3} emu/cm² for current density 2,3,4 and 5 mA/cm² respectively. So it is confirmed that the films received with a lower current density provide higher magnetization values. The coercivity value increases as 174G, 242G, 349G and 410 G for current density 2,3,4 and 5 mA/cm² respectively. The retentivity values are 13.4×10^{-3} emu/cm², 2.78×10^{-3} emu/cm², 5.09×10^{-3} emu/cm² and 0.97×10^{-3} emu/cm² for current density 2, 3, 4 and 5 mA/cm² respectively. Squareness values are 0.1536, 0.1139, 0.3915 and 0.3244 for current density 2, 3, 4 and 5 mA/cm² respectively. Crystallite size of film deposits comes to a decision about magnetization and coercivity. If the grain size of magnetic materials is big, the domain wall movement confirms the magnetic characters of that materials. The magnetization value decreases by increasing current density. Also coercivity increases by increasing current density.

The grain size of deposits is increased by rising current density. Because of smaller crystalline size, Ni-Fe-P thin films received with low current density 2 mA/cm² have higher saturation magnetization and low

coercivity. From results, it is confirmed that the best soft magnetic characters can be received with low current density.

Fig.-8: NiFeP Thin Films - Magnetic Hysteresis Curves with Different Current Density
(a) 2 mA/cm² (b) 3 mA/cm² (c) 4 mA/cm² (d) 5 mA/cm²

CONCLUSION

An alloy thin films NiFeP have been prepared by electro deposition technique. The properties of NiFeP films were analyzed. EDAX result has indicated the increase in nickel content with an increase of current density. The high nickel composition of 80.81 wt% was found with current density 5 mA/cm². FCC phase is the nature of crystals which deposited on substrate and average size of particles is around 40 nm. The thin films received with current density 2 to 5 mA/cm² are shiny and deposited uniformly on the surface. They appear to the crack-free surface. The micro hardness values of alloy films obtained with increasing current density are 109, 92, 73 and 58 VHN respectively. The saturation magnetization value decreases from 87.2×10^{-3} emu/cm² to 2.99×10^{-3} emu/cm² when current density raises from 2 to 5 mA/cm². From results, it is confirmed that the best soft magnetic characters can be received with low current density.

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