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Effect of Different Current Density on Structural and Mechanical Properties of Fe-Ni-Co Alloy Thin Films

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ABSTRACT

This research work investigates the effect of current density on electroplated Fe-Ni-Co alloy thin films. Varying current density between 2 mA/cm^2 , 3 mA/cm^2 and 4mA/cm^2, the electroplated Fe-Ni-Co thin films were prepared and morphological, structural, and mechanical characterization were analysed. The SEM micrographs of the electrodeposited films with different current density have no micro- cracks and also the films have uniform surface morphology. The predominant peaks in X-ray diffraction pattern reveal the crystalline nature of the film and structure belonging to FCC. The hardness changes of thin films were analysed by VHT. The electroplated Fe-Ni-Co thin films were strongly adherent to the substrate. The VHN result of Fe-Ni-Co thin films shows that the Fe-Ni-Co thin films coated at high current density have highest hardness value.

Keywords: Thin films, Characterization, Electrodeposition, Crystalline Size, Temperature, X-ray Diffraction, Micro Hardness, Surface Morphology.

I INTRODUCTION

Electrodeposited nanocrystalline magnetic thin films are developed due to their potential applications in power electronics, sensors, actuators and core material for writing elements in recording heads. This method offers several practical advantages over more sophisticated vacuum deposition techniques in terms of cost and growth. Electrodeposited Permalloy ($Fe_{20}Ni_{80}$) is the best known thin film alloy in magnetic thin film recording heads and MEMS applications [3].The Fe- Ni alloys are the most versatile from all the known soft magnetic materials for magnetic storage (1-6). The electrodeposition conditions such as physical conditions and chemical conditions determine the microstructure (crystallite size, uniformity and adherence) which in turn influence the physical and chemical properties of the films. The use of NiFe as the soft film which can be improved by adding a third element

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with NiFe alloy. Electrodeposited Permalloy [NiFe] is the best known thin film alloy in MEMS applications (13, 19). In this current investigation, the electrodeposition method is chosen for coating Fe-Ni-Co thin films. In this present work, the effect of different current density on FeNiCo thin films are analysed. This paper summarizes the synthesis and characterizations of electroplated FeNiCo thin films.

II EXPERIMENTAL PART

Details of chemicals used in the experiments, temperature and current density are shown in Table 1. Copper and stainless steel substrates act as cathode and anode respectively in this investigation. Electrodeposition was carried out by varying the current density (2,3,4 mA/cm^2) at 30°C for 15 minutes. The pH value of the bath was maintained to 6 by adding few drops of ammonia solution. The surface morphology of the Fe-Ni-Co thin films was examined with the help of Scanning Electron Microscope. The film composition and structural characters of thin films were measured by Energy-dispersive X-ray Spectroscopy and X-ray diffraction respectively. The hardness of Fe-Ni-Co thin films was measured by Vickers Hardness Test.The thickness of the films were determined by cross sectional view of SEM images.

Table 1. Electroplating bath details of FeNiCo thin films

S.No	Name of the Chemicals	(g/L)	Temperature (°C)	Current density	pH
1	Ferrous Sulphate	10	30	2, 3 and 4 mA/cm^2	6
2	Nickel Sulphate	30			
3	Cobalt Sulphate	15			
4	Ammonium Sulphate	40			
5	Citric acid	10			
6	Boric acid	10			

III RESULTS AND DISCUSSION

3.1 Composition of Electrodeposited Thin Films

The EDAX data of thin films are shown in Table 2. EDAX result shows that the films obtained at higher current density have high nickel content. The highest nickel content of 39.54 wt% was obtained for current density 4 mA/cm^2. EDAX result shows that Ni content increases with increasing current density. The weight percentage of Co decreases while increasing current density.

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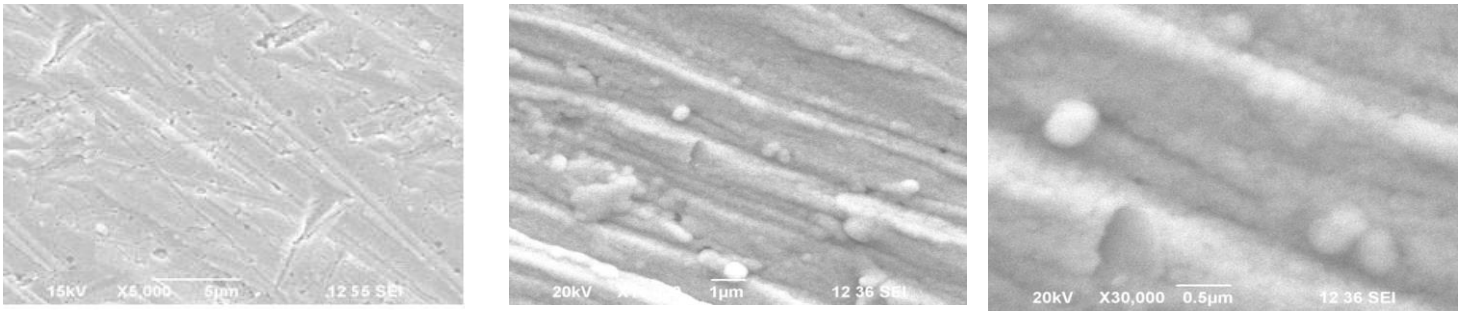
Table 2: EDAX Analysis of Thin Films

S. No	Current Density mA/cm^2	Co Wt%	Ni Wt%	Fe Wt%
1.	2	68.45	19.87	11.68
2	3	58.34	30.21	11.45
3	4	46.72	39.54	13.74

3.2 Morphological Observation

The surface morphology of the electroplated Fe-Ni-Co alloy thin films with different current density is analysed by SEM pictures are shown in fig 1.The electroplated thin films are smooth and uniform. FeNiCo alloy thin films are uniform, bright and crack free. It is concluded from SEM analysis that the deposition of thin films on the substrate is uniform in nature.



(a) **(b)** **(c)**

Figure 1: SEM Images for Electrodeposited Fe-Ni-CoThin Film for Different Current Density

(a) 2 (b) 3 (c) 4 mA/cm^2

3.3 Structural Analysis

The crystal structure of the electro deposited Fe-Ni-Co alloy thin films was determined by XRD analysis. X- ray diffraction patterns of Fe-Ni-Co films obtained with different current density are shown in fig 3. The presence of sharp peaks in XRD pattern reveals that the films are crystalline in nature. The crystalline size of the deposits was calculated from XRD using Scherrer's formula

$$D=0.954\lambda/\beta\cos\theta$$

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Where, θ is the Bragg's angle, λ is the X-ray wavelength, β is the full width at half maximum intensity of the diffraction peak located at 2θ. The XRD patterns of Fe -Ni-Co films reveal the existence of FCC phase with (111), (200) and (220) diffraction peaks.

The result shows that the crystalline sizes of the Fe-Ni-Co deposits obtained by electrodeposition process are in the nano scale and the average crystallite size is around 21 nm.

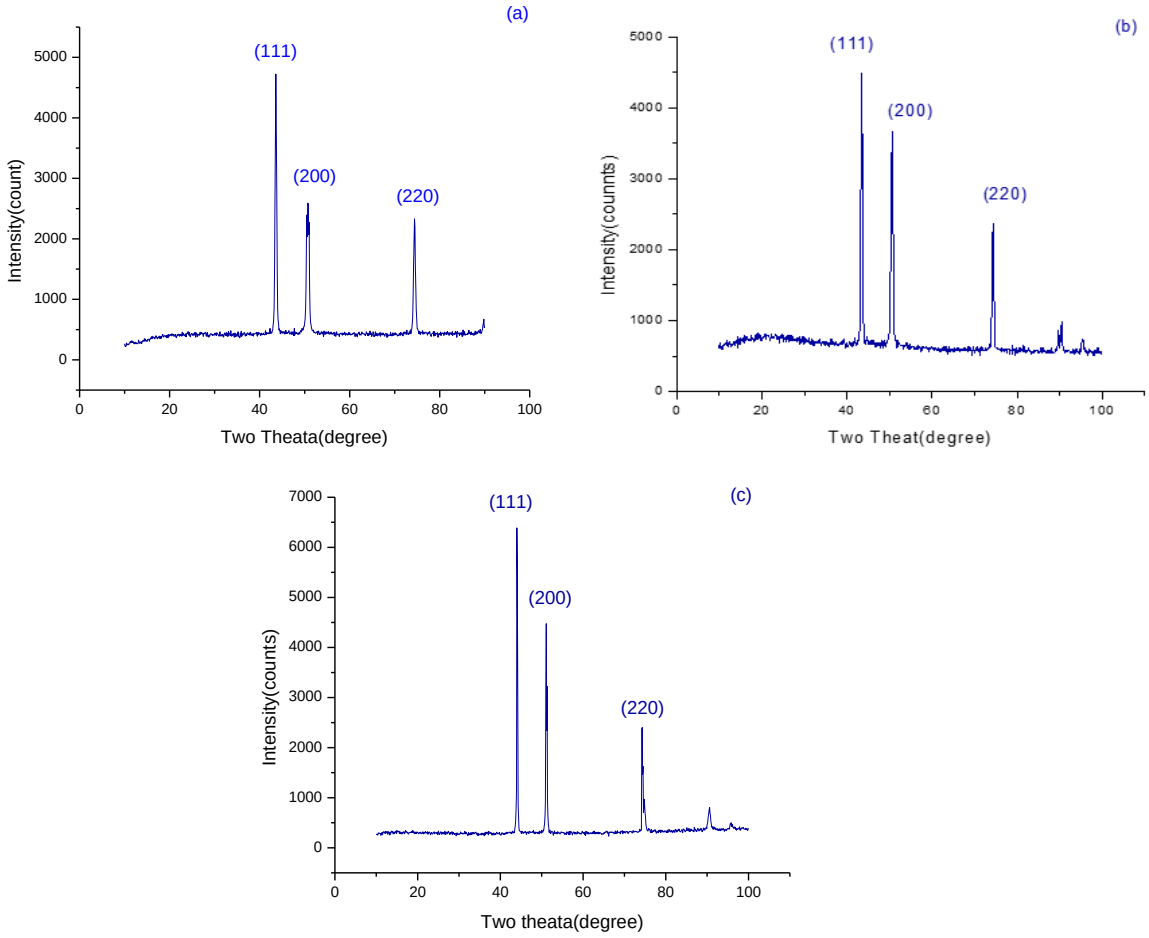

Fig.2 XRD Patterns of Fe-Ni-Co Thin films for Different Current Density

(a) 2 (b) 3 (c) 4 mA/cm^2

The crystal size of Fe-Ni-Co alloy films is tabulated and shown in table 3.When the current density is increased, the crystalline size of thin films decrease due to onset orientation of crystals during electrodeposition

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Table.3: Structural characteristics of NiCoFe alloy thin films

S. No	Current Density mA/cm^2	2Θ (deg)	d (A^0)	Particle size, D (nm)	Strain (10^{-3})	Dislocation density (10^{14} / m^2)
1	2	43.310	1.5634	23.32	1.578	21.87
2	3	41.637	1.5430	20.18	1.673	19.13
3	4	43.187	1.2345	19.28	1.345	17.45

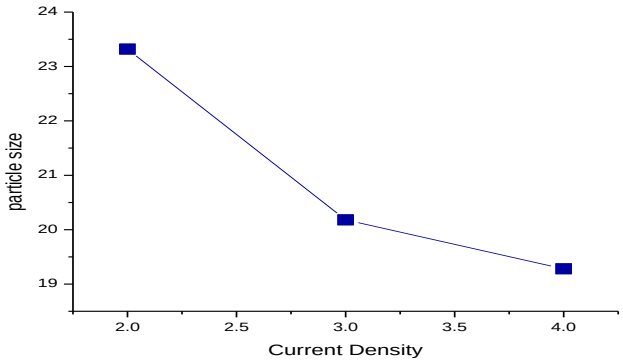

Figure 3. Crystalline Size as a function of Current density

3.4 Mechanical Properties

Hardness of Fe-Ni-Co films are examined by Vickers hardness tester (micro hardness tester). The results show that the hardness increases with increasing current density.This effect occurs due to lower stress associated with electrodeposited films. The hardness of Fe-Ni-Co thin films with different current density is shown in table 4.

Table.4: Mechanical Properties of electrodeposited Ni-Co-Fe thin films

S.No	Current Density (mA/cm^2)	Vickers Hardness (VHN)
1	2	76
2	3	87
3	4	102

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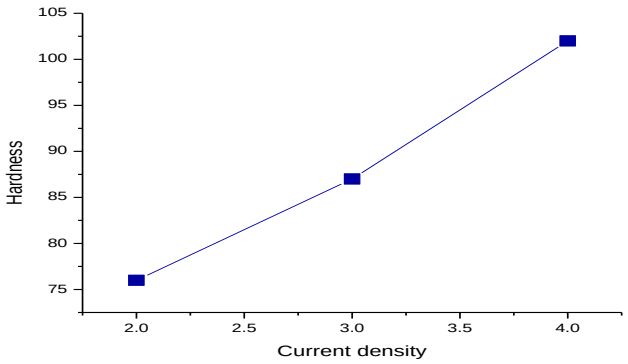

Figure 4. Vickers Hardness as a function of current density

IV CONCLUSION

Electrodeposited Fe- Ni-Co thin films were prepared by varying the current density (2, 3,4 mA/cm^2) at 30°C for 15 minutes. The crystalline size decreases with increasing current density. The thin films obtained with different current density are uniform, bright and crack free. FCC was the dominant structure of Fe-Ni-Co alloy thin films. Hardness increases with increasing current density. When current density was increased from 2 mA/cm^2 to 4 mA/cm^2, the particle size values decrease from 23.32 nm to 19.28 nm. This happens due to nano crystalline structure and low film stress associated with Fe-Ni-Co alloy thin films.This article summaries the optimized operating condition of electroplated bath and characteristics of Fe-Ni-Co. The Fe-Ni-Co thin films can be used in various electronic devices, actuators and memory devices.

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