Effect of different Current density on Properties of Electrodeposited Ni-Co-Cr Thin Films

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ABSTRACT

Ni-Co-Cr thin films were electroplated for different current density. FCC structured crystals were observed in XRD study and soft magnetic properties of NiCoCr thin films for different current density were compared. Electroplated Ni-Co-Cr films were prepared with different current density (2, 3, 4 and 5 mA/cm^2) and they were subjected to magnetic, structural, morphological and mechanical characterization analysis. Cobalt composition was minimum as 21.31 wt% for current density 5 mA/cm^2. The chromium content increased when current density was increased. Ni-Co-Cr films were evenly coated on copper surface. Thin films deposits with high current density shows high saturation magnetization and low coercivity. The microhardness of deposits increases when current density is increased.

Keywords: Crystals size, Electrodeposition, Electrolytic bath, SEM, X-ray diffraction, VSM, VHN, Face Centered Cubic (FCC).

INTRODUCTION

There is a rising interest in Ni-Co thin films with chromium for innovative applications[1]. Ni-Co thin films reveal magnetic, detecting and catalytic properties as an element of nickel and cobalt metals formed into spinel type structures. Ni-Co is a spinel compound which can give sufficient transmissivity from visible wavelength[2-5]. Ni–Co alloy are important magnetic alloy materials which are largely and commercially used in industry due to its excessive saturation magnetization, high coercive force, excessive electric permeability and minimum eddy current loss. This Ni-Co alloy are utilized in specific applications for example organic and inorganic alloy electrosynthesis, super capacitors, electro catalyst for anodic oxygen reaction, IR translucent electrodes for panel displays, switches, sensors and optical limiters[6-10]. It was proven that Ni-Co-Cr alloy has interesting magnetic properties. Ni-Coalloy

due to its soft magnetic character and its great mechanical properties, have revealed an incredible potential in MEMS, NEMS, recording devices, optical and sensors industries[11-14]. In this investigation, the magnetic, structural, elemental composition and mechanical characterization of electro plated Ni-Co-Cr films have been studied with different current density.

EXPERIMENTAL

The Ni-Co-Cr composite films were electroplated on copper substrate for different current density 2, 3, 4 and 5 mA/cm^2. The processing time of deposition was 15 minutes. In this experiment, Cu and stainless steel substrates acted as cathode and anode respectively with 1.5 cm x 7.5 cm. dimension[15-19]. The Ni-Co-Cr composite films were synthesized from electrolytic solution which contain $Cr_2(So_4)_3$ (10 g/l), $(NH_4)_2SO_4$ (40 g/l), $CoSo_4$ (15 g/l), $C_6H_8O_7$ (10 g/l) and $NiSo_4$ (30 g/l).The pH value is maintained as 6.0 in electrolytic solution by adding NH_3 and electro chemical process was processed with different current density 2,3,4 and 5 mA/cm^2. The cathode plate was taken out from the solution after 15 min. and dried for couple of minutes. Analysis with scanning electron microscope and X-ray diffractometer provide surface and structural characters of thin films. Vickers hardness test provide micro hardness of films. The vibrating sample magnetometer provides magnetic properties of Ni-Co-Cr thin films[20-21].

RESULTS AND DISCUSSION

Composition of electrodeposited thin films

From result, the cobalt compositions decrease as 37.91%, 32.15%, 27.95% and 21.31% for current density 2, 3, 4 and 5 mA/cm^2 respectively. Nickel compositions increase as 48.79%, 52.80%, 55.42% and 60.16% for current density 2, 3, 4 and 5 mA/cm^2 respectively. Chromium compositions are as 13.30%, 15.05%, 16.63% and 18.52% for current density 2, 3, 4 and 5 mA/cm^2 respectively. EDS result indicates that the films received with high current density have high nickel content. The high cobalt content of 37.91wt% was received for low current density. EDS result shows that nickel

content increases with increasing current density. The weight percentage of chromium increases while increasing current density. Fig. 1, 2 and 3 show the variation of cobalt, nickel and chromium composition with increasing current density.
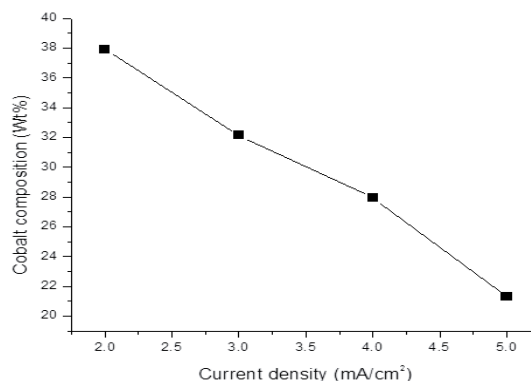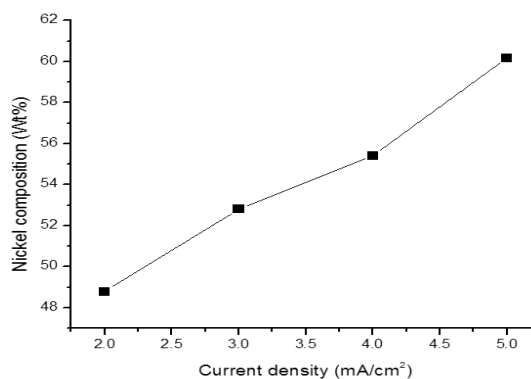

Fig. 1. Current density Vs Cobalt composition

Fig. 2. Current density Vs Nickel composition
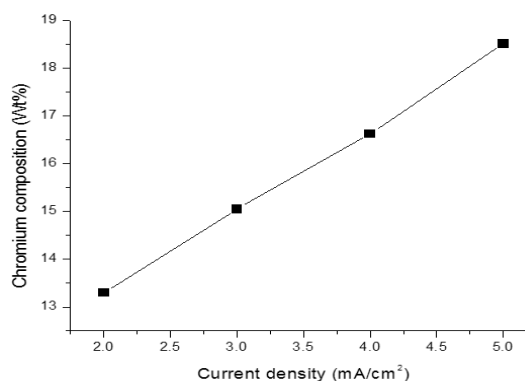

Fig. 3. Current density Vs Chromium composition

Morphological observation

The surface investigation of the Ni-Co-Cr magnetic films with various current density was observed by Scanning Electron Microscope and

SEM pictures are shown in Fig. 4.The electroplated thin films appears without cracks and uniform. They are bright in nature. It concludes that the deposition of materials on the substrate is uniform.
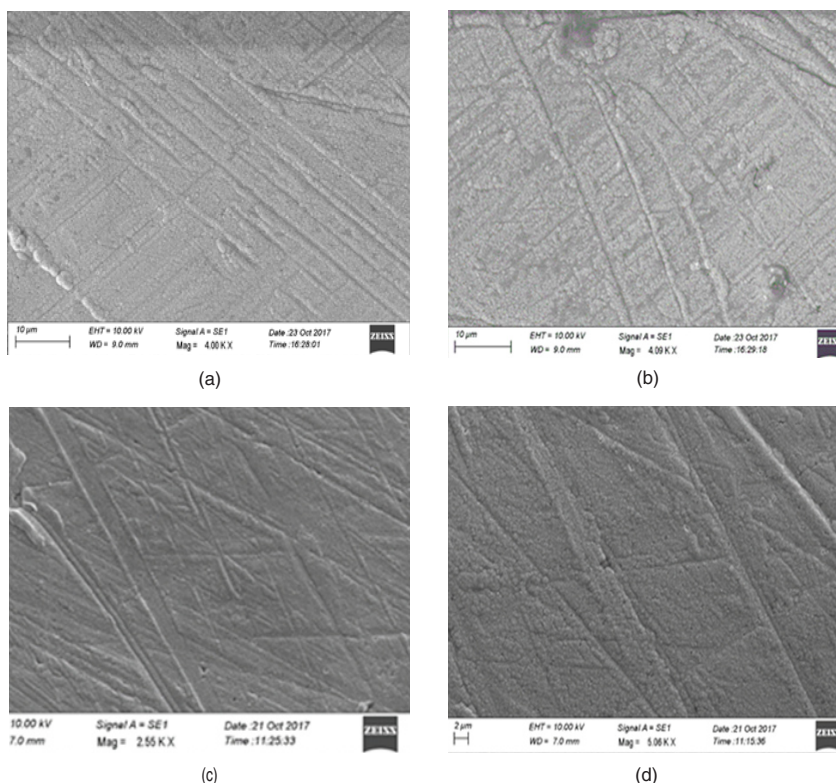

(a)

(b)

(c)

(d)

Fig. 4. SEM images for electrodeposited Ni-Co-Cr thin film for different current density
(a) 2 mA/cm² (b) 3 mA/cm² (c) 4 mA/cm² (d) 5 mA/cm²

Structural analysis

The crystal structure of Ni-Co-Cr alloy thin films was found by XRD analysis. Fig. 5 demonstrates crystal patterns of the Ni-Co-Cr alloys which electrodeposited from electrolytic bath. The XRD studies indicates that electrodeposited magnetic alloys have different crystal orientations. XRD peaks of the alloys shows a preferred orientation along the (111), (200), (220), and (311) planes.

From XRD data's, grain size values of the alloys on substrate were calculated using the full width at half maximum intensity(β), wavelength(λ) and Bragg's angle(θ)

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

The average crystallite size is around 17 nm. The particle size decreases as 20.38, 18.13, 15.93 and 13.10 for current density 2, 3, 4 and 5 mA/cm² respectively. Dislocation density and strain of Ni-Co-Cr alloy increase when current density increases. XRD data's are shown in Table 1.When the current density is 5 mA/cm², the crystalline size of thin film is 13.10 nm.

Mechanical properties

Micro hardness investigation of deposits has been done by Vickers hardness tester. The hardness values of thin films prepared with increasing current density are 54, 69, 76 and 95 VHN respectively. So it is confirmed that the hardness increases with increasing current density due to lower strain associated with thin films. Fig 7 indicates the variation of hardness with increasing current density.

Magnetic properties of the deposits

The magnetic hysteresis loops for Ni-Co-Cr alloy thin films with different current density are

shown in Fig. 8. It is noted that magnetization value increases as 0.619 x 10^{-3} emu/cm^2, 1.692 x 10^{-3} emu/cm^2, 4.919 x 10^{-3} emu/cm^2 and 10.04 x 10^{-3} emu/cm^2 for current density 2,3,4 and 5 mA/cm^2 respectively The film coated with high current density exhibits the low coercivity and high magnetization. The coercivity value decreases as 478G, 375G, 263G and 178 G for current density 2,3,4 and 5 mA/cm^2 respectively. The retentivity values are 0.177 x 10^{-3} emu/cm^2, 0.570 x 10^{-3} emu/cm^2, 0.8174 x 10^{-3} emu/cm^2 and 4.690 x 10^{-3} emu/cm^2 for current density 2, 3, 4 and 5 mA/cm^2 respectively. Squareness values are 0.2859, 0.3368, 0.1661 and 0.4668 for current density 2, 3, 4 and 5 mA/cm^2 respectively.
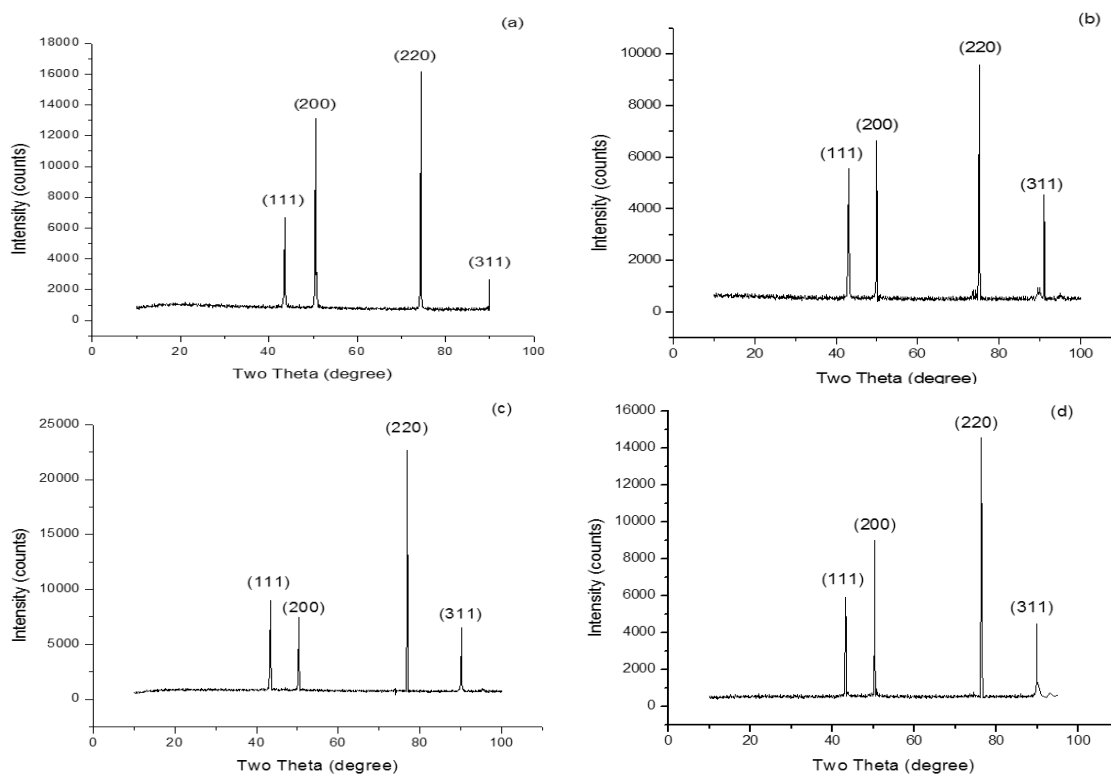

Fig. 5. XRD Patterns of Ni-Co-Cr thin films for different current density
(a) 2 mA/cm^2 (b) 3 mA/cm^2 (c) 4 mA/cm^2 (d) 5 mA/cm^2

Fig. 6. Crystals size as a function of current density

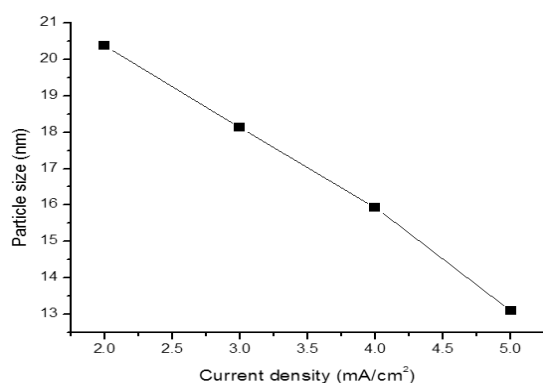**Fig. 7. Vickers Hardness as a function of current density**

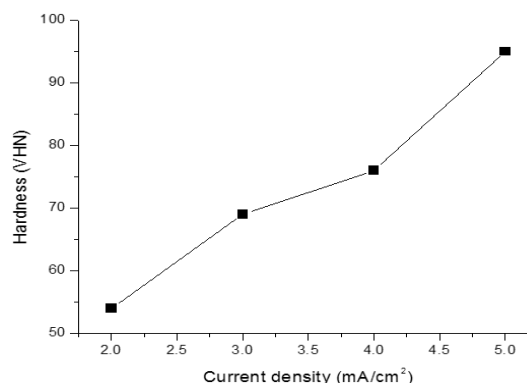It was observed that the magnetization and retentivity increase by increasing current density. From VSM result, it is concluded that films prepared with high current density exhibits a higher value of saturation magnetization and low coercivity.

Table 1: Structural characteristics of Ni-Co-Cr alloy thin films

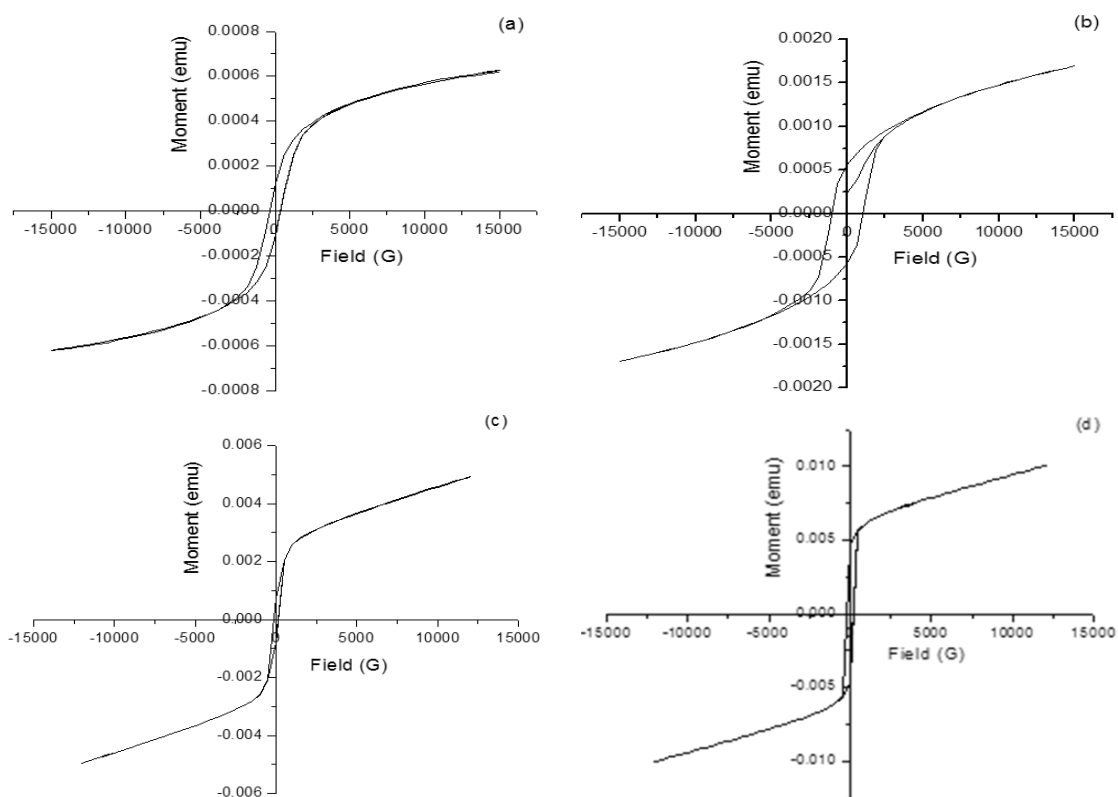| S.No	Current Density (mA/cm^2)	2θ (deg)	d(A^0)	Particle Size (D)(nm)	Strain (10^{-3})	Dislocation Density (10^{14} / m^2)
1	2	75.40	1.288	20.38	1.776	24.08
2	3	75.07	1.262	18.13	1.997	30.42
3	4	76.92	1.259	15.93	2.273	39.41
4	5	76.31	1.291	13.10	2.764	58.27

Fig. 8. Magnetic hysteresis loops for Ni-Co-Cr thin film for different current density (a) 2 mA/cm^2 (b) 3 mA/cm^2 (c) 4 mA/cm^2 (d) 5 mA/cm^2

CONCLUSION

The surface, elemental composition mechanical and magnetic characters of Co-Ni-Cr thin films have been investigated by varying current density (2, 3, 4 and 5 mA/cm^2) at 30°C for 15 minutes. The thin films received with various current density are evenly coated and shiny. FCC structure was crystal formation of Ni-Co-Cr composite films. Microhardness increases with increasing current density. When current density was increased from 2 to 5 mA/cm^2, the crystallite size values decreases from 20.38 nm to 13.10 nm. The crystallite size are reduced with increasing current density. This happens due to nano crystalline structure and low film strain associated with Ni-Co-Cr alloy thin films.When current density was increased from 2 to 5 mA/cm^2, the magnetization values increases from 0.619 x 10^{-3} emu/cm^2 to 10.04 x 10^{-3} emu/cm^2. This happen due to nano structured crystal deposition. So it is concluded that soft magnetic nature of thin films is enhanced by increasing current density.

ACKNOWLEDGEMENT

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