Research Article

Journal of
Environmental
Nanotechnology

Magneto-resistance in Electrodeposited Cobalt-based Alloys: Influence of Multinary Alloy Combination

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Received: 18.10.2018 Accepted: 10.01.2019 Published: 30-06-2019
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ABSTRACT

Electrodeposited alloys and multilayers, which unveil the Giant Magneto-resistance effect (GMR), gained much attention in modern technology. This type of film and multilayers has great potential in technological applications, mainly in the field of Magneto-resistive sensors, MEMS devices and Environmental weather sensors. In the past few years, cobalt-based magnetic alloys were vastly studied because they offered interesting magnetic and electrical properties over other alloys. This paper was aimed at the preparation and magnetic behavior of electrodeposited cobalt-based multinary alloys. Structural and morphological properties of the alloys were confirmed using X-Ray diffractogram and FE-SEM micrographs. The magnetic behavior of the alloys was studied using B-H loop. The magneto-resistive properties were studied using the four-probe technique. From the investigation, it was concluded that the alloys exhibit high crystalline properties with a suitable GMR effect for the application of Magneto-resistive sensors.

Keywords: Cobalt Alloys; Electrodeposition; GMR Films; Magneto-resistive Sensors; Multinary Alloys.

1. INTRODUCTION

Development of magnetic alloys with good magnetic moments are highly required in many areas such as magnetic induction writing heads, magnetic sensors and other magnetic-MEMS devices (Kim *et al*. 2003; Hong *et al*. 1999; Kohmoto, 1991; Chang *et al*. 2007). Magnetic alloys can be prepared using many methods, though Electrodeposition is used commonly. It has several advantages such as good deposition rate, film composition and cost-effectiveness; moreover, electrodeposited alloys offer good mechanical stability and magnetic properties (Tsynlsaru *et al*. 2009; Bodaghi and Hosseini, 2012). From the recent research, it was clearly concluded that cobalt-based magnetic alloys have better magnetic properties, which are essential for Magneto-resistive sensors and MEMS devices. Over the years, cobalt was alloyed with many magnetic and non-magnetic metals as binary and ternary alloys in order to obtain magnetic alloys with good magneto-resistive properties. The present work was devoted to the preparation and characterization of cobalt-based multinary alloys; the influence of alloy combination on the magneto-resistive properties was also studied.

2. EXPERIMENTAL PROCEDURE

Trisodium citrate-based sulfate electrolyte composed of cobalt sulfate, Nickel sulfate, sodium tungstate, sodium hypophosphite and boric acid were adopted to electrodeposit CoNiWP films. (Rajkumar *et al*. 2019). Commercial copper plate and nickel rod were used as cathode and anode, respectively. The chosen salts were dissolved in distilled water and the pH of the electrolyte was maintained as 5. The deposition parameters such as deposition time, temperature and current density were optimized as 30 minutes, room temperature and 10 mA/cm^2, respectively. After the deposition, cathodes were carefully removed and dried well. Structural properties of the electrodeposited CoNiWP alloys were investigated using an X-ray diffractogram. Morphological properties and constituents in the alloys were confirmed using FE-SEM micrographs and EDAX pattern. Magnetic properties such as magneto-resistivity and B-H loop were studied to know the influence of multinary combination on magnetic properties.

3. RESULTS AND DISCUSSION

XRD characterization was conducted to study the structural properties of the film. The obtained X-ray diffractogram of CoNiWP films, prepared at optimized deposition parameters, has been shown in Fig. 1. It revealed the formation of high crystalline films with (220) planes as the predominant orientation. The grain size of the deposits in the films was identified to be in the range of 18 nm, which was calculated with the Scherrer's formula.

The constituents of the film were studied using EDAX pattern, shown in Fig. 2. The presence of all relevant elements was confirmed, along with some impurities. The advent of Cu peaks is possibly from the copper substrate (Rajkumar *et al*. 2019; Ezhil Inban Manimaran *et al*. 2018). From the FE-SEM micrographs of CoNiWP films (Fig. 3), the formation of an agglomerated layer with a uniform deposition in the film was confirmed (Nor Azrina Resali *et al*. 2013). The mobility of the ions in electrodeposition caused higher deposition rates, resulting in the formation of layer-like deposition.

The magnetic behavior of CoNiWP film was studied using VSM. Fig. 4 shows the magnetic hysteresis loops (B-H curve) of the film and the obtained values were presented in Table 1. It confirmed the soft ferromagnetic nature of the films. The coercivity value of the films was found to be slightly higher over ternary alloys. The aggregation of phosphorus and tungsten strongly affected the granular boundaries, resulting in the variation of coercivity. This aspect is in good contract with the microstructural properties of the film. Along with grain size, nickel was also an important factor for the low coercive nature (Shorowordi *et al*. 2017; Daheum Kim *et al*. 2003; Gurrappa and Leo, 2008).

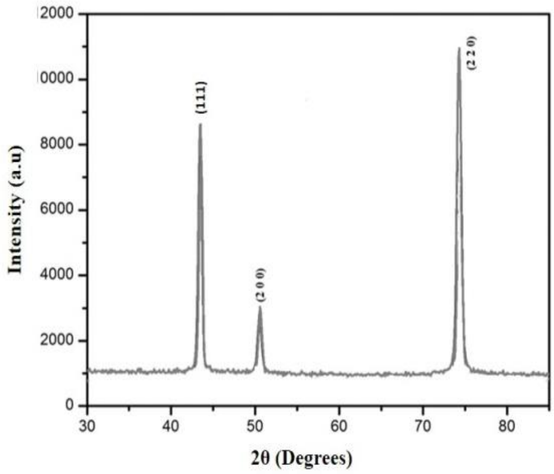

Fig. 1: X-ray Diffractogram of CoNiWP films deposited at optimized deposition parameters

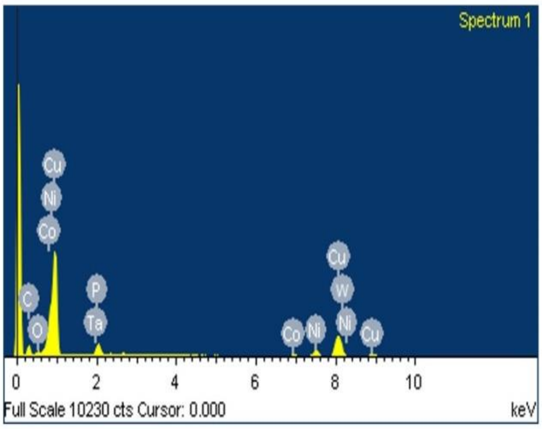

Fig. 2: EDAX pattern of CoNiWP films

Table 1. Magnetic properties of CoNiWP films deposited at optimized deposition parameters

Substrate	Current Density (mA/cm^{-2})	Deposition Time (min)	Magnetic Saturation (M_s) in emu	Remanence (M_r) in emu	Coercivity (H_c) in O_e	Squareness
Copper	10	30	1.7560	440	2784	250

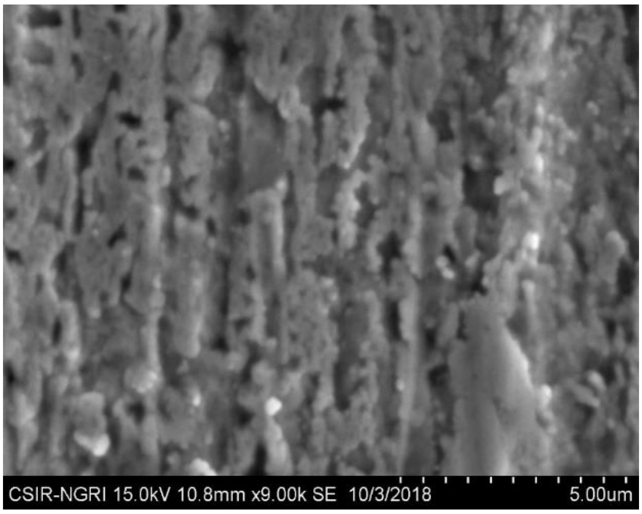

Fig. 3: FE-SEM Micrographs of CoNiWP films deposited at optimized deposition parameters

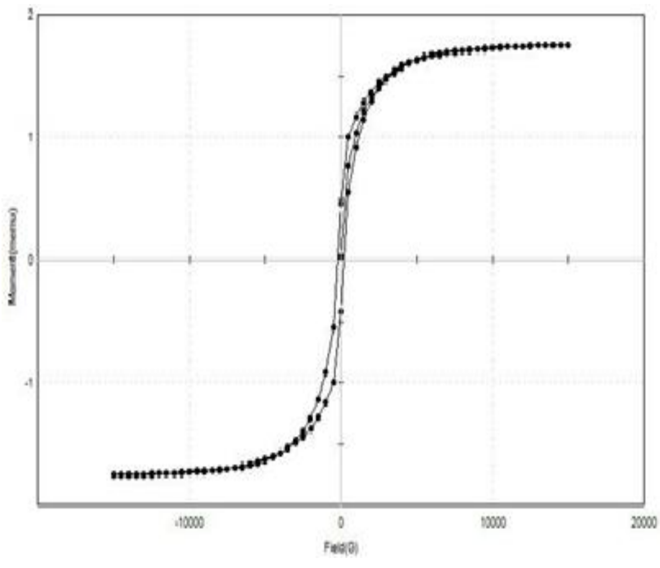

Fig. 4: Hysteresis loop of CoNiWP films deposited at optimized deposition parameters

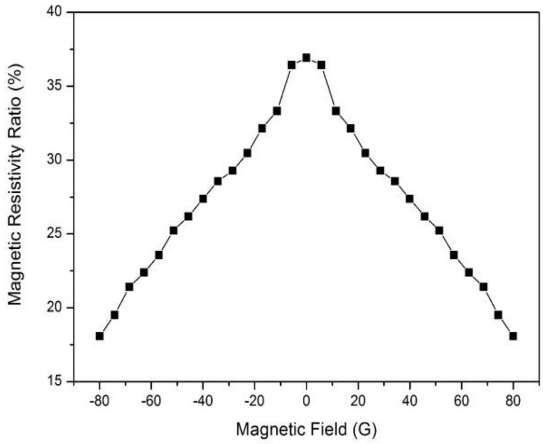

Fig. 5: Magneto-resistance of CoNiWP films deposited at optimized deposition parameters

Fig. 5 shows the magneto-resistance response of CoNiWP film prepared at optimized deposition parameters. It has been recorded at fields below 80 Gauss and the resistance values were calculated with the formula $(R_H-R_0)*100/R_0$. CoNiWP films exhibit GMR characteristics similar to the ternary films reported earlier. The variation in resistance was recorded as 18% to 36 %, and the resistance values were found to be gradually decreasing with respect to the applied field. The presence of phosphorus and tungsten in the multinary combination strongly affected the GMR behavior; but, the resistances of the films were significantly lower compared to previously reported cobalt-tungsten alloy films.

4. CONCLUSION

Structural changes and magneto-resistance of electrodeposited CoNiWP alloy films were investigated by the galvanostatic technique. From the investigation, it was found that the CoNiWP films have good crystalline nature. Morphological studies revealed that the films deposited were uniform and well-covered over the substrate. EDAX pattern confirmed the presence of relevant peaks. B-H loop of the CoNiWP alloy was recorded using a Vibrating sample magnetometer and it confirmed the ferromagnetic nature in the alloys. Magneto-resistivity studies using the four-probe method revealed the GMR effect in the alloys. Hence, it was clearly concluded that the preparation of multinary alloy is quite similar to ternary alloys, but it strongly influenced the film deposition and microstructure, resulting in the formation of CoNiWP films with GMR nature and marginally better magnetic properties compared to ternary combinations.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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