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The Effect of Magnetic Field on Electro-deposition of Nickel and Cobalt Nanowires

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Abstract

Anodized Aluminum Oxide (AAO) nano-porous template is fabricated and nickel (Ni) nanowires are synthesized in the nano pores of AAO template by AC electro-deposition technique in the presence and absence of magnetic field applying only in a direction parallel to nanowire axis. Cobalt (Co) nanowires are fabricated by applying magnetic field externally both in perpendicular and parallel directions to the axis of nanowires. Magnetic field can bring change in the preferential grain growth of Ni and Co nanowires. Magnetic field applied parallel to nanowire axis increases deposition rate and current density due to magneto hydrodynamic effect, while magnetic field applied in perpendicular to the surface of electrode does not bring significant change in the chemical reaction. Magnetic properties are also affected by applying external magnetic field during deposition. These changes associated with grain growth in the preferred direction of Ni and Co nanowires are discussed in this article.

Keywords: crystal structure, magnetic field, magnetic properties, preferred orientation

1. Introduction

Magnetic nano materials such as *Ni*, *Co* and iron (*Fe*) have been studied for their applications in electronic, automobile, and aerospace technology [1, 2, 3]. *Ni* and *Co* have many potential applications and they play a significant role in data storage devices and micromechanical systems in which structural properties are indispensable. *Ni* and *Co* are preferred over other materials since *Ni* has a low magneto crystalline anisotropy and *Co* has a great anticorrosion property. Electrochemical deposition is a low cost and simple method for the fabrication of magnetic nanowires using Anodized Aluminum Oxide (AAO) template. It is very important to characterize grain growth and texture of nanowires. Many researchers have analyzed the effect of electric voltage, solution pH value and temperature on the development of magnetic nanowires [4, 5]. Another essential parameter is the use of external magnetic field during AC electro-deposition of magnetic nanowires at altered angles to deal with the preferred orientation. External magnetic field provides extra energy to the growth and nucleation of magnetic nanowires, while the texture of the nanowires is also affected by the application of external magnetic field [6, 7].

In the current research work, homemade AAO template is used to fabricate nickel nanowires with average diameter of $D_1 \sim 5$ nm, in the presence and absence of magnetic field in a direction parallel to the axis of nanowires. *Co* nanowires are prepared by AC electro-deposition in which external magnetic field is applied in both perpendicular and parallel directions to the axis of nanowires. Magnetic properties of *Ni* nanowires are observed with the help of Vibrating Sample Magnetometer (VSM), which exhibits how in the presence of external magnetic field during AC electro-deposition magnetic properties of samples vary. Structural parameters of nanowires (*Ni* and *Co)* is investigated using *XRD.* XRD of *Ni* and *Co* nanowires reveals that grain grows in a specific direction, that is, along the direction of magnetic field due to magneto hydrodynamic phenomenon. Topographical, morphological and compositional information of AAO template are analyzed by using Scanning Electron Microscopy (SEM). The motivation behind the current work is to focus on the special effects of magnetic field on the textural and magnetic properties of *Co* and *Ni* nanowires and also to find the way crystal structure is tailored by varying magnetic field's strength and its angle with the nanowire axis. In future, *Co* nanowires may be electro-deposited in the existence of magnetic field at different angels, that is, 45°. The strength of magnetic field can also be increased which may enhance or make useful changes in magnetic properties of *Co* nanowires to give a variety of their potential applications.

2. Experimental Work

Aluminum (*Al*) strip (99.99% pure) having the thickness of 0.3 mm and an area of 1 cm × 5 cm is electro-polished in ethanol (CH_3CH_2OH) and per chlorate ($HCLO_4$) with 4/1 ratio, respectively. *Al* strip is electro-polished at 12 V for 3 minutes which gives a bright mirror like surface to it. After electro-polishing, *Al* strip is anodized to grow highly ordered nano pores. For the sake of anodization, it is kept in sulphuric acid at 20 V for a period of 24 hours with continuous fast stirring. Under optimal conditions, porous ordered alumina layer on both sides of *Al* strip is attained. Before completing anodization, voltage is decreased through a step wise procedure at the rate of 1 V per 3 min to break the barrier layer of Al_2O_3 into branched structures. In order to widen (hollow) the pores and to remove the barrier layer to some extent, the alumina templates are kept in 0.5 M phosphoric acid for the duration of 45 minutes and at room temperature of 25^0C. For deposition of *Ni* nanowires in the nanometric recesses of AAO templates, a mixture of $NiSO_4$ *(130 g)*, H_3BO_4 *(4 g) and* H_2O *(400 ml)* is used. Two samples of *Ni* nanowires $S_1= D_1$ are fabricated without the use of external magnetic field and $S_2= D_1$ in the existence of magnetic field strength 6.6 mT is applied parallel to the axis of nanowires. *Co* is filled in the pores by AC electrode position in an electrolyte solution composed of $CoSO_4.7H_2O$ *(120 g/L)* and *boric acid (45 g/L)* by applying the external magnetic field. *Co* nanowires are exposed to the magnetic field in two directions; parallel to the axis of nanowires (magnetic field strength = 90 mT) and perpendicular to the axis of nanowires (magnetic field strength =120 mT). Experimental arrangement of cobalt nanowires for AC electro-deposition when magnetic field is perpendicular and parallel to nanowires is shown in Figure 1. As a result of this process, we get two samples for each direction.

For parallel direction,

Sample 1: *Co* nanowires when applied with magnetic field give an angle of 180° with nanowires axis.

Sample 2: *Co* nanowires when applied with magnetic field give an angle of 0° with nanowires axis.

Similarly, for perpendicular direction,

Sample 3: *Co* nanowires when applied with magnetic field give an angle of 270° with nanowires axis.

Sample 4: *Co* nanowires when applied with magnetic field give an angle of 90° with nanowires axis.

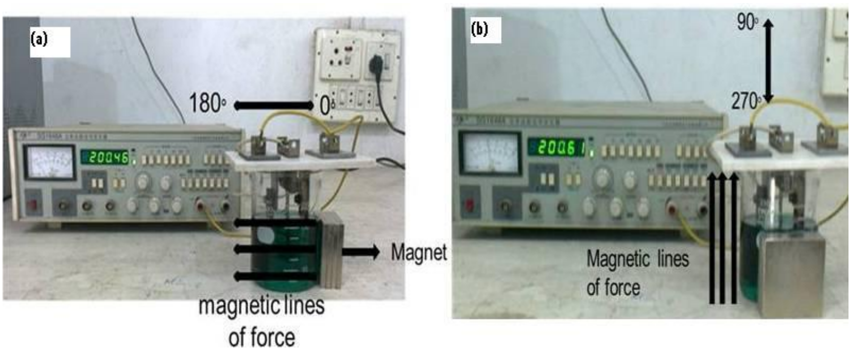

Figure 1. Experimental apparatus for AC electro-deposition of cobalt nanowires when the magnetic field is perpendicular and parallel to nanowires

3. Results and Discussion

We synthesized AAO template through two step anodization method and the diameter of pore is measured by Scanning Electron Microscopy.

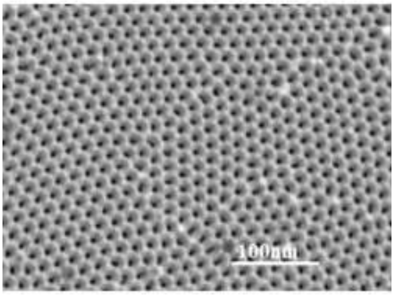

Figure 2. SEM patterns of Anodized Aluminium Oxide (AAO) template prepared in sulphuric acid

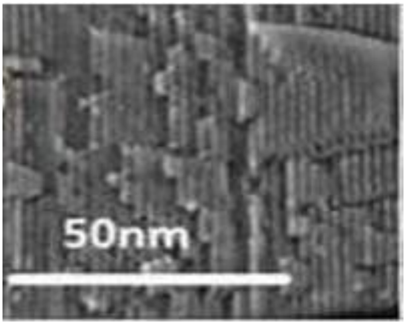

Figure 3. SEM patterns of *Ni* nanowires prepared in sulphuric acid without external magnetic field during AC electro-deposition

Figure 2 shows SEM image of AAO template fabricated in sulphuric acid having hexagonally ordered pores with diameters $D_1 \sim 5$ *nm*. Pore diameter depends upon both anodizing voltage and the time for pore opening in phosphoric acid. It is obvious from SEM micrographs that all pores are open, well ordered, compact and defect free.

Figure 3 represents SEM micrographs of *Ni* nanowires prepared in sulphuric acid in the absence of external magnetic field during AC electro-deposition and these *Ni* nanowires SEM micrographs of arrays of $D_1 \sim 5$ nm including template. SEM analysis revealed that nickel nanowires are continuous, dense and regular. It is stated that the template diameter is closely comparable to nanowire diameter and the nanowires are symmetrical, parallel to each other and their growth is perpendicular to the surface of the template. By the above mentioned experimental conditions for D_1, one can roughly calculate the average distance between the nanowires to be about 10 nm. SEM image of *Ni* nanowire deposited in the presence of magnetic field is improved but not shown here

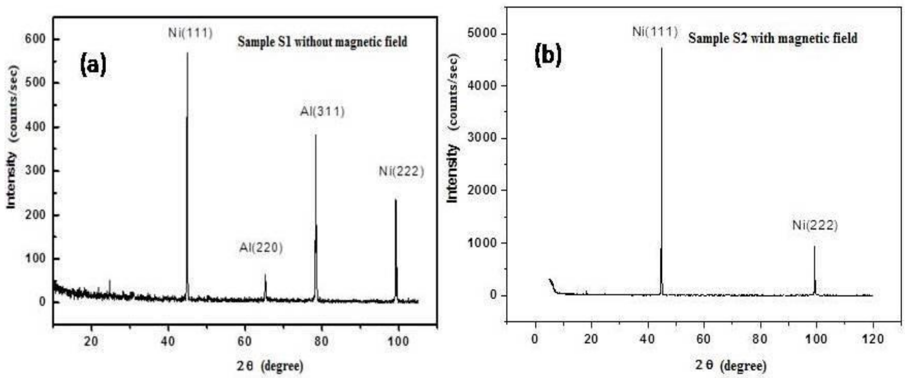

Figure 4 (a, b): XRD patterns of *Ni* nanowires without magnetic field (Sample $S_1 = D_1$) and with magnetic field (Sample $S_2 = D_1$)

Figure 4(a) describes typical XRD pattern of *Ni* nanowires sample S_1 fabricated in the absence of external magnetic field. The major peak has the highest intensity at angle 2θ = 44.5°, (111) corresponding to *Ni* and (220) corresponding to *Al* is observed in the pattern. XRD observations result in Ni nanowires growth and exhibit fcc cubic structure as peaks are intense and narrow and they also depict polycrystalline nature.

Figure 4(b) shows XRD graphs of *Ni* nanowires sample S_2 fabricated in the existence of applied magnetic field which enhances the growth texture of both *Ni* (111) and *Ni* (222) planes. This is due to magneto-hydrodynamic effect near the vicinity of the template. Moreover, enhanced *Ni* (222) texturing in the existence of applied magnetic field is described towards forced *Ni* grains growth with their easy axis parallel to the direction of the external magnetic field [8].

Figure 5(a) and 5(b) represent M-H curves of *Ni* nanowires samples S_1 and S_2 grown without applying magnetic field and in the existence of magnetic field during AC electro-deposition respectively taken with the use of VSM. In the absence of an external magnetic field during AC electro-deposition, all magnetic domains align themselves in a parallel direction due to shape anisotropy [9]. In Figure 5(b), VSM analysis shows that all magnetic domains lie along the axis parallel to nanowires axis while their magnetic properties are enhanced significantly as mentioned in table 1.

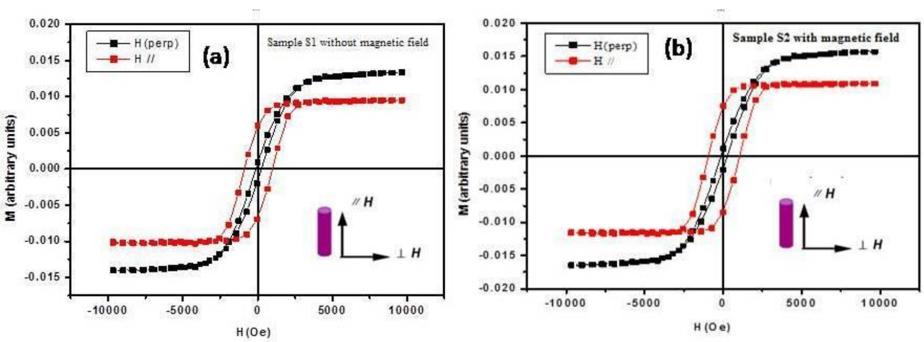

Figure 5 (a, b). M-H curve of *Ni* nanowires arrays of Sample S_1 ~D_1, Sample S_2 ~D_1

Table 1. *Magnetic Parameters of Ni Nanowires Arrays for Sample S_1 and S_2*

S_1* and *S_2	**Coercivity (Oe)**		**Remanant magnetization (emu)**		**Saturation magnetization (emu)**		**Squareness Ratio (SQ)**	
	H_c//	$H_c\perp$	M_r//	$M_r\perp$	M_s//	$M_s\perp$	SQ //	SQ ⊥
Without magnetic field	941.32	189.78	6.33E-3	1.27E-3	9.94E-3	13.68E-3	0.637	0.093
With magnetic field	993.68	200.45	7.90E-3	1.47E-3	11.34E-3	16.11E-3	0.697	0.092

The experimental data presented in table 1 shows the comparison between the magnetic properties of samples S_1 and S_2. The values of remenance (Mr), coercivity (Hc) and squareness ratio (Mr/Ms) of *Ni* nanowires fabricated in the existence of external magnetic field that is applied parallel to the nanowires axis are reported higher than that of those values fabricated without applying external magnetic field. This favors magnetic moments of the *Ni* nanowires columns which have a preferred orientation due to shape anisotropy and polycrystalline materials; the shape anisotropy dominates the intrinsic magneto-crystalline anisotropy [10]. The saturation magnetization (Ms) has lesser value in case of external magnetic field applied in a parallel direction due to the presence of magnetic force opposing nickel nanowires columns which results into a decrease in the demagnetizing field inside the nanowires [11]. The slightly different magnetic behavior is resulted by the nanowires electro-deposited in the existence of external magnetic field due to either the growth of *Ni* (111) and (222) peaks or stacking of nanocrystallites in these preferred orientations.

Furthermore, in AAO templates of diameter D_1, *Co* nanowires are fabricated during AC electro-deposition by applying external magnetic field at different angles. XRD patterns of *Co* nanowires when applied with magnetic field make an angle of 180° and 0° with nanowires axis which are shown below in Figure 6(a) and 6(b), respectively.

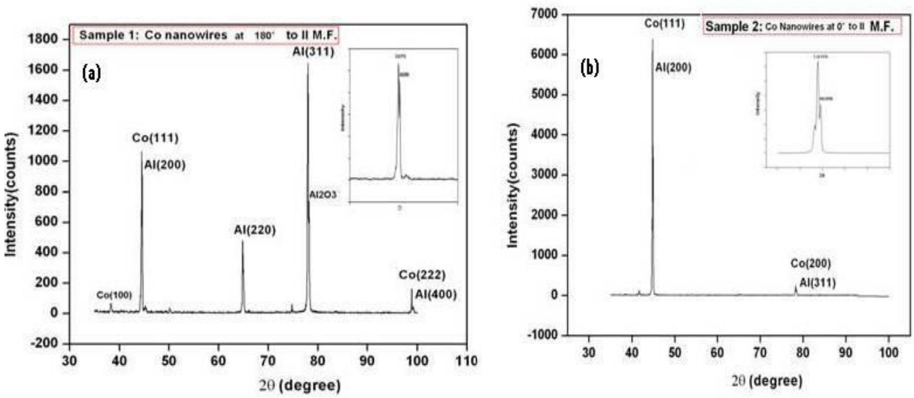

Figure 6(a, b). XRD patterns of *Co* nanowires when external magnetic field makes an angle of 180° and 0° with nanowires axis

Figure 6(a) represents XRD pattern of *Co* nanowires which make an angle of 180° with external magnetic field. The XRD pattern shows that the intensity of *Co* (111) plane, that is, 1100 counts is greater than that of Co (222) plane, that is, 100 counts in the presence of external magnetic field. Figure 6(b) represents XRD pattern of *Co* nanowires which make an angle of 0° with the external magnetic lines of force. The data confirms that the crystal structure of *Co* nanowires is face centered cubic FCC and also its intense and narrow peaks depict good polycrystalline nature. The XRD pattern in Figure 6(b) shows that the intensity of *Co* (111) plane, that is, 6500 counts is greater than that of Co (222) plane, that is, 200 counts in the presence of external magnetic field. The biggest effect of the Lorentz force on convective mass transport of electrolyte can be realized when external magnetic field is applied parallel to the electrode surface as studied in literature [12, 13, 14, 15]. XRD patterns of *Co* nanowires when external magnetic field makes an angle of 270° and 90° with nanowires axis are represented below in Figure 7(a) and 7(b), respectively.

Figure 7(a) represents XRD pattern of *Co* nanowires that make an angle of 270° with magnetic lines of force. The XRD pattern shows that the intensity of *Co* (111) plane is maximum, that is, 900 counts in the presence of the external magnetic field. Figure 7(b) represents XRD

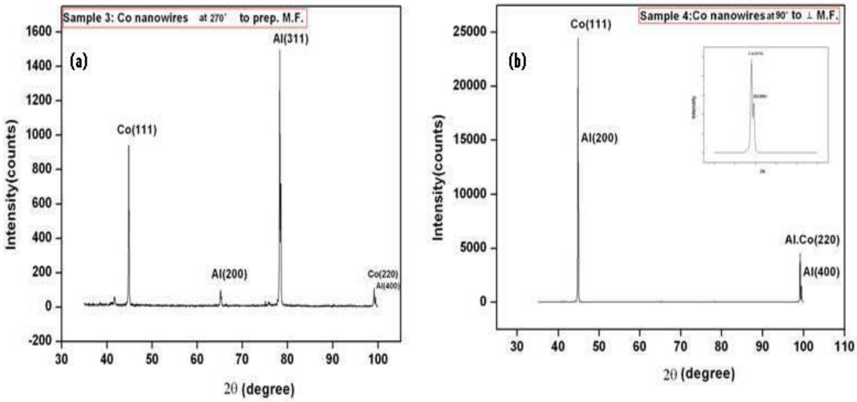

Figure 7(a, b). XRD patterns when external magnetic field makes an angle of 270° and 90° with *Co* nanowires axis

pattern of *Co* nanowires that make an angle of 90° with external magnetic lines of force. The data confirms that the crystal structure is FCC and its nature is polycrystalline. The XRD analysis exhibits that the intensity of *Co* (111) plane is maximum, that is, 24000 counts in the existence of external magnetic field. Hence, when magnetic field is applied perpendicular to the electrode surface then there are no rapid changes in the development of *Co* nanowires. It is obvious that the grains grow in a specific direction, that is, in the direction of magnetic field while the remaining are emitted. The intensity of nanowires is greater in that direction due to the process of mass transfer than the intensity of those nanowires in the opposite direction of external magnetic field.

4. Conclusion

Ni nanowires are prepared by AC electro-deposition technique by switching on and off an external magnetic field, while *Co* nanowires are synthesized by applying external magnetic field in different directions. SEM analysis gives information about the surface morphology. AAO template pores structure is self-ordered hexagonal. XRD analysis results in *Ni* and *Co* nanowires growth and patterns show that their crystal structure is FCC which has good polycrystalline nature. Without the application of external magnetic field, the reported values of intensity for *Ni* (111) and (222) planes are smaller as compared to the values reported in the existence of external magnetic field. The increase in the intensity of *Ni* and *Co* nanowires is the result of induced convective solution flow due to magneto-hydrodynamic phenomenon near the vicinity of the template which is mainly the result of Lorentz force. Furthermore, in the presence of applied magnetic field, enhanced *Ni*

(111) and (222) texturing specifies the forced growth of *Ni* grains with their c-axis parallel to the orientation of the applied external magnetic field. VSM analysis of nanowires *(Ni)* fabricated in the existence of external magnetic field indicates that their remanence, coericivity and saturation magnetization is enhanced as compared to *Ni* nanowires fabricated without applying the external magnetic field.

Acknowledgments

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