

# Magnetoresistance of Electrochemically Produced NiFe and CoNiFe Nanowires

D. AVCU, F.E. ATALAY, E. AYDOGMUS, H. KAYA AND S. ATALAY

Inonu University, Science and Art Faculty, Department of Physics, Malatya 44280, Turkey

CoNiFe and NiFe nanowires were electrochemically produced by dc electrodeposition on highly ordered porous anodic alumina oxide templates. Scanning electron microscope images of nanowires after removing the alumina membrane showed that these nanowires are uniform with the diameters of about 220–300 nm and about 25–30  $\mu\text{m}$  length. The energy dispersive X-ray analysis showed that the composition of the nanowires is  $\text{Ni}_{88}\text{Fe}_{12}$ ,  $\text{Co}_7\text{Ni}_{82}\text{Fe}_{11}$ . Magnetic field was applied by an electromagnet and resistance was measured by four point technique.

DOI: 10.12693/APhysPolA.125.230

PACS: 81.07.Gf, 81.15.Pq, 75.75.-c

## 1. Introduction

Nanomaterials have become very important in the magnetic recording technology. Recently, data storage capability increased significantly while decreasing the size of magnetic grains that make up data bits. The nanomaterial geometry greatly affects its magnetic properties. One-dimensional nanowires with large aspect ratio have received much attention due to unique shape anisotropy and extremely large surface area [1]. There has been many works for ferromagnetic Co, Ni, Fe nanowires and nanotubes which were grown by electrodeposition in polycarbonate membranes [1–4] and in anodic alumina oxide (AAO) membranes [4–9] with various pore diameters. These nanowires could be used for magnetic field sensors with magnetoresistance effect. In this work, magnetoresistance properties of electrodeposited NiFe and CoNiFe alloy nanowires are investigated.

## 2. Experimental

The following procedure was performed to produce nanowires. All solutions were prepared by dissolving reagent-grade chemicals in deionized water of Milli-Q quality. The volume of the electrochemical bath was approximately 50 ml. The bath content was given in Table. The bath pH was adjusted to the required value by adding 0.1 M HCl or 0.1 M NaOH monitored with a Jenway 3520 pH meter. A three-electrode cell was used for the nanowire electrodeposition. An Ag/AgCl electrode (BAS, 3 M NaCl, and  $-35$  mV versus SCE at  $25^\circ\text{C}$ ) was used as the reference electrode. A platinum electrode approximately 5 times larger than the cathode was used as an auxiliary electrode. AAO membranes, with specified pore diameter of 200 nm and pore length of 60  $\mu\text{m}$ , were used as the cathode for the nanowire synthesis. These have an exposed area of approximately  $1\text{ cm}^2$ . The membranes were supplied by the Whatman Company. Before the electrodeposition, back side of the AAO templates was coated with Au with a thickness of 10 nm, and an adhesive carbon disc and copper foil were also stuck on for electrical contact [7]. The electrodeposition of nanowires was performed by means of an electrochemical analyzer system, an Iviumstat potentiostat/galvanostat.

TABLE

Bath contents and electrodeposition conditions for production of nanowires.

NiFe electrolyte [mM]		CoNiFe electrolyte [mM]	
Ni(SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O	100	Co(SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O	5
Fe(SO <sub>4</sub> ) <sub>2</sub> ·7H <sub>2</sub> O	5	Ni(SO <sub>4</sub> ) <sub>2</sub> ·6H <sub>2</sub> O	100
H <sub>3</sub> BO <sub>3</sub>	200	Fe(SO <sub>4</sub> ) <sub>2</sub> ·7H <sub>2</sub> O	5
NaCl	35	H <sub>3</sub> BO <sub>3</sub>	200
sodium lauryl sulfate	0.35	NaCl	35
		sodium lauryl sulfate	0.35
Operating conditions			
bath pH	2.6		
bath temperature	room temperature		
deposition duration	180 min		
deposition potential	$-2$ V vs. Ag/AgCl		
agitation paddle	5 cycles/s		

Resistance measurements were performed with four-probe techniques. A representation of the electrical contact forming process was shown in Fig. 1. After the production of nanowire arrays, top side of AAO was coated with 20 nm Au. Then electrical contacts were made on Au films on the both sides of AAO using conductive silver paint. The resistance as a function of magnetic field (MR) at different dc biased current was measured in an axial magnetic field at room temperature. The MR ratio was calculated from the following equation:

$$\frac{\Delta R}{R} [\%] = 100 \times \frac{[R(H) - R(H_{\max})]}{R(H_{\max})}, \quad (1)$$

where  $R(H_{\max})$  is the resistance measured at a magnetic field of  $H \approx 1$  T. Magnetic field was applied to perpendicular direction to AAO surface using an electromagnet in MR measurements. The perpendicular direction to AAO surface plane corresponds to the parallel direction to the long axis of nanowires.

The surface properties of nanowire arrays were investigated by scanning electron microscopy (JEOL JSEM 7001F). The quantitative chemical analyses of the alloys were performed by energy dispersive X-ray (EDX) spectroscopy.

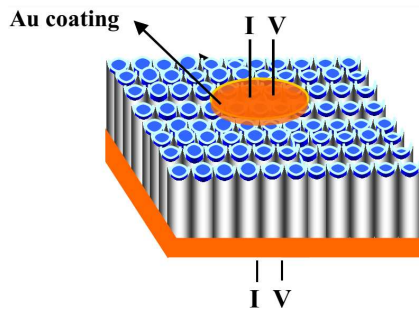


Fig. 1. The representation of the electrical contact forming process.

### 3. Results and discussion

After entire dissolution of AAO in 1 M NaOH solution, the morphology of liberated alloys nanowires were obtained as shown in Fig. 2. It was clearly observed that the nanowires were about 220–300 nm in diameter and 25–30  $\mu\text{m}$  in length. The inset of Fig. 2 shows high resolution SEM images. It can be seen that nanowires showed different structure along the wire for two electrolytes. NiFe alloy nanowires exhibit nanogranular structure, but CoNiFe alloy nanowires show much smoother surface along the wire. EDX analysis displays that the compositions of CoNiFe and NiFe are  $\text{Co}_{11}\text{Fe}_{23}\text{Ni}_{82}$  and  $\text{Ni}_{88}\text{Fe}_{12}$ , respectively.

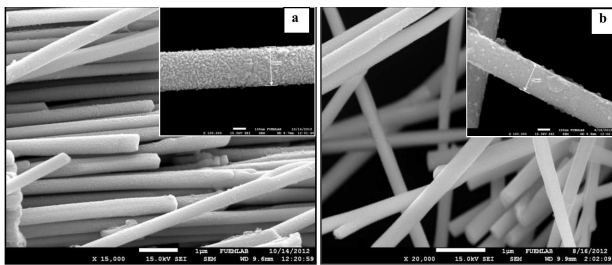


Fig. 2. SEM images of ordered (a) NiFe and (b) CoNiFe nanowires.

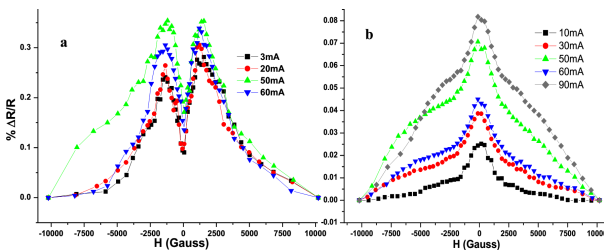


Fig. 3. Magnetoresistance curves of (a) NiFe, (b) CoNiFe nanowire arrays at various bias current.

Figure 3 shows MR curves for NiFe and CoNiFe nanowire arrays embedded in AAO. Resistance of the nanowires gradually increases with the decreasing magnetic field. It should be noted that Co addition to electrolyte changes the shape of MR curve. The maximum MR change of 0.35% was observed from NiFe nanowires at 50 mA bias current. It was also observed that double

peak behavior centered at origin for all dc bias currents. After the Co addition, maximum MR change reduced by 0.08% and single peak behavior was observed. The magnitude of MR increases gradually with increasing bias current for CoNiFe nanowires.

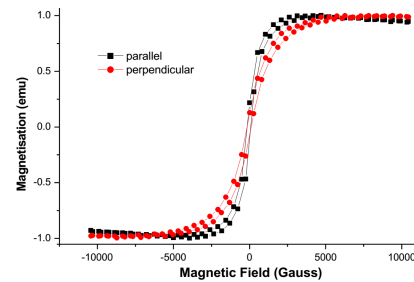


Fig. 4. Magnetic hysteresis loops of (a) NiFe nanowire arrays, (b) CoNiFe nanowire arrays.

The normalized hysteresis curves of the NiFe nanowire arrays obtained with the AAO template are shown in Fig. 4. The coercivities of the NiFe nanowire were 136 G and 117 G for the applied field perpendicular to and parallel with the nanowire arrays, respectively. It can be seen that the nanowire arrays were saturated when the applied magnetic field is higher than 5 kG.

### 4. Conclusion

NiFe and CoNiFe alloy nanowires were produced in nanoporous AAO template by electrodeposition. NiFe alloy nanowires exhibit nanogranular structure, but CoNiFe alloy nanowires shows much smoother surface along the wire. The maximum MR change of 0.35% was observed from NiFe nanowires at 50 mA bias current.

### Acknowledgments

This work was supported by TÜBİTAK under project number TBAG-111T761 and Inonu University with the project number I.U.A.F-2013/32.

### References

- [1] T. Ohgai, in: *Nanowires — Recent Advances*, Ed. X. Peng, InTech, Croatia 2012, p. 101.
- [2] A. Ertan, S.N. Tewari, O. Talu, *J. Exp. Nanosci.* **3**, 287 (2008).
- [3] B. Jaleh, A.O. Dezfuli, V.J. Hamedan, M. Najafi, E. Tamari, *Int. J. Phys. Sci.* **6**, 4775 (2011).
- [4] F. Nasirpour, in: *New Developments in Electrodeposition and Pitting Research*, Ed. A. El Nemr, Transworld Research Network, India 2007, p. 1.
- [5] F.E. Atalay, S. Atalay, *J. Alloys Comp.* **392**, 322 (2005).
- [6] G.W. She, L.X. Mu, W.S. Shi, *Rec. Pat. Nanotechnol.* **3**, 182 (2009).
- [7] F.E. Atalay, H. Kaya, V. Yagmur, S. Tari, S. Atalay, D. Avsar, *Appl. Surf. Sci.* **256**, 2414 (2010).
- [8] S. Atalay, H. Kaya, F.E. Atalay, E. Aydogmus, *J. Alloys Comp.* **561**, 71 (2013).
- [9] A.K.M. Bantu, J. Rivas, G. Zaragoza, M.A. López-Quintela, M.C. Blanco, *J. Appl. Phys.* **89**, 3393 (2001).