Magnetic Properties of $Ni_{0.3}Fe_{0.7}$ Alloy Nanowires

M. Almasi Kashi[a,b,*], A. Ramazani[a,b], V. Asgari[a], E. Jafari- Khamse[b]

[a]*Department of Physics, University of Kashan, Kashan, P. O. Box. 87317–51167, Iran*

[b]*Institute of Nanoscience and Nanotechnology, University of Kashan, Kashan, P. O. Box. 87317–51167, Iran*

Abstract

The effect of length variation on the magnetic properties of NiFe alloy nanowires electrodeposited into the alumina template was investigated. The diameter (45±2.5 nm) and length (~ 1.9, 7.12, 8.3, 9.5 and 13.3 µm) of the nanowires were estimated from scanning electron microscopy images. Energy dispersive spectroscopy results showed Ni_3Fe_7 composition of the alloy nanowires. The magnetic properties of the samples were investigated by vibrating sample magnetometer. It showed that with increasing the length of the nanowires from 1.9±0.1µm to 13.3±0.66 µm, coercivity reduced from 1050 Oe to 705 Oe and squareness reduced from 0.64 to 0.46. The results proved increasing the magnetostatic interaction between the nanowires with length. Progress toward the multi-domain behavior was predicted caused to drastically reduce in the coercivity.

1. Introduction

The precise control on surface geometry of the nanostructures and drastic reduction in their dimension caused to appear the unique electrical, mechanical and magnetic properties [1]. Comparing to nanoparticles and 2-D systems, nanowires are the best candidates for increasing the transferring rate of information and data storage applications [2]. Among the one dimensional systems magnetic nanowires are widely used as sensors and perpendicular magnetic memories. The magneto-electronic and spintronic recently predisposed the miniaturing of data storage devices and and improving the rate of data processing [3, 4]. Complete recovery of data and providing high volume for data storage are two basic requirements of data processing. The magnetic nanowires grown into the nanoporous alumina template have recently attracted more attention due to easy and low price of production procedure [5, 6]. It is reported that variation in the geometrical parameters of arrays such as length, diameter and interpore distances affected magnetostatic interaction between the nanowires and their single-domain behavior [7-12]. However, the effect of length variation on the

magnetic properties of the nanowires is not widely investigated in our knowledge. The effect of increasing the length of FeNi nanowires on their magnetic properties was only studied by Atalay et al. [13]. They found that increasing the deposition time in the range of 60-240 min led to increase in the length of nanowires. Increasing the length led to reduction of demagnetizing factor parallel to the wires axis and demagnetizing energy, thereby it decreases the coercivity and squareness.

In the present work, the effect of length variation on the magnetic properties of NiFe alloy nanowires electrodeposited into the alumina template is investigated. The alloy composition of the samples was estimated by energy dispersive spectroscopy (EDS).

2. Experimental

At first, the high-purity aluminum plate (99.999% and thickness of 0.3 mm) was degreased in acetone and de-ionized water. In order to remove oxide layer from the aluminum surface, the samples were etched in a 0.3 M NaOH solution for 3 min. subsequently, the samples were electro-polished by 1:4 volume mixture of $HClO_4$ and C_2H_5OH at ambient temperature.

To obtain highly ordered pores, a two-step anodization process was employed. First anodizing was performed in the 0.3 M oxalic-acid solution at 40 V and 17 °C for about 5 h. Wet chemical etching by mixture solution of phosphoric (0.5 M) and chromic (0.2 M) acids was used to remove thick oxide layer at 60 °C for 10 h.

The samples were re-anodized for 180 min in the same conditions of the first step. The pore widening was performed in phosphoric acid at 32 °C for 8 min. After that voltage was systematically reduced to 10 V to promote thinning of the barrier layer. The FeNi nanowires were electrodeposited in an aqueous electrolyte consisting of 0.4 M $NiSO_4$, 0.1 M $FeSO_4$, 45 g.l^{-1} boric acid, 1 gr.l^{-1} ascorbic acid at 30 °C. Electrodeposition was performed in a simple electrochemical cell with two electrodes; the sample and a graphite rode were used as working and counter electrodes, respectively. The reduction/oxidation voltage, reduction/oxidation time and off-time between pulses were chosen to be 13V, 2.5 ms and 20 ms, respectively. The length of nanowires was adjusted by controlling the deposited charge. Figure 1 shows current/voltage variations during the deposition process. The effect of length variation (~ 1.9, 7.12, 8.3, 9.5 and 13.3 µm) on the magnetic properties of the electrodeposited nanowires were studied.
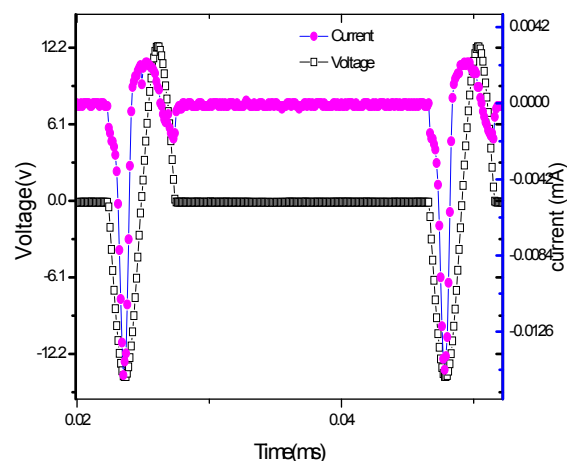

Fig. 1. The variation of current and voltage during the deposition.

The length and diameter of the nanowires was estimated using the scanning electron microscopy (SEM, model LEO 440i).
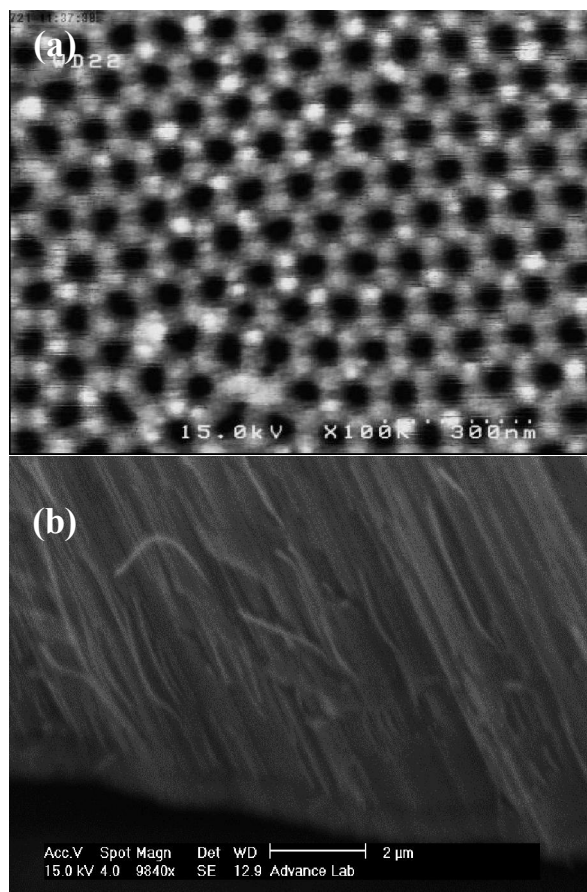
Fig. 2. (a) Top view SEM micrograph of porous alumina template and (b) cross-sectional SEM micrograph of NiFe thorough the template.

Room temperature magnetic properties of the nanowire arrays were characterized using a home-made vibrating sample magnetometer (VSM). The alloy composition of the samples were identified by Energy Dispersive X-ray Spectroscopy (EDS, model LEO 440i).

Length (µ m)	1/9	3.8	7/1	9/5	13/3
Fe (at%)	68.7	70.2	72.4	72.8	71.7
Ni (at%)	31.3	29.8	27.6	27.2	28.3

Table 1. Alloy composition of the NiFe nanowires with different lengths (the 5% error for all the values has considered).

3. Results and discussion

A top view SEM micrograph of porous alumina template before the widening and a cross-sectional view of NiFe nanowires embedded in the template are shown in Fig. 2. Hexagonally arranged configuration is observed in which pore size and interpore distances are estimated to be about 45±2.5 and 100±5 nm, respectively (Fig. 2a). The cross-sectional view indicates non-intercrossing and parallel pores with high aspect ratio.
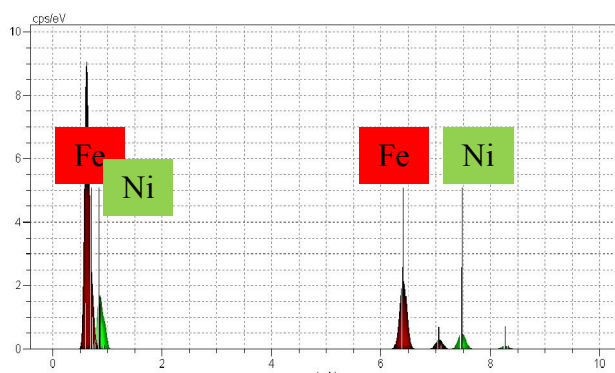

Fig. 3. Typical EDS spectrum of the NiFe alloy nanowires.

The length of nanowires deposited in template with pore size of 45nm was estimated to be ~ 1.9±0.1 µm, while that of the nanowires deposited into template with pore size of 75±3.75 nm was 7.12±0.36, 8.13±0.41, 9.5±0.48 and 13.3±0.66 µm as a function of deposited charge. Since magnetic properties of the alloys were affected by their composition, then the elemental investigation was performed by EDS analysis. Aluminium was removed from backward of the samples to intense the Fe and Ni peaks in the EDS spectrum.

For that a mixture of HCl and saturated $CuSO_4$ solutions was used. Typical EDS spectrum of the NiFe alloy nanowires after removing the alumina template is shown in Fig. 3. Alloy composition of the samples as a function of the length of nanowires is tabulated in Table. 1. It can be seen

that nanowires composed of ~70±3 percent Fe and ~30±3 percent Ni. The error of measurements relatively remains constant for all lengths of the nanowires.
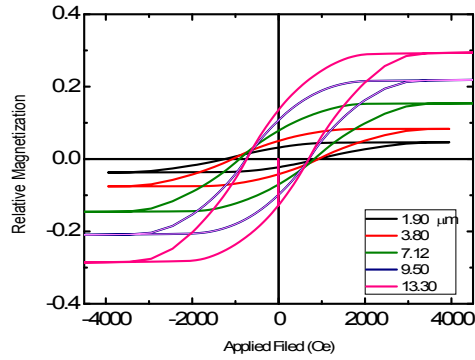

Fig. 4. Hysteresis loops of the NiFe alloy nanowires with different lengths.

Figure 4 shows hysteresis loops of the samples with different lengths. To measure hysteresis loops external magnetic field up to 3kOe was applied parallel to wires axis. As can be seen coercivity and squareness vary with nanowires length.

Variation of these parameters as a function of the length of nanowires is presented in Fig. 5. The results show that with increase in the length of nanowires in the range of 1.9-13.3 μm, coercivity reduces from 1050Oe to 705Oe. High coercivity of the short nanowires is related to thin roots formed during the thinning step.

Squareness also follows the same treatment (reduces from o.65 to o.46) with increasing the length of nanowires [13]. The magnetostatic interaction between the nanowires depends on the length of nanowires as [14]: $\Delta H_u = M_s r^2 \left(a(D)l + b(D) \right)$ (1) where r and l are radius and length of the nanowires and a and b are constant. According to the Klim relation the

magnetostatic interaction between the wires increases with length. Also, proceeding toward the multidomain behavior is predicted to reduce the coercivity [15].
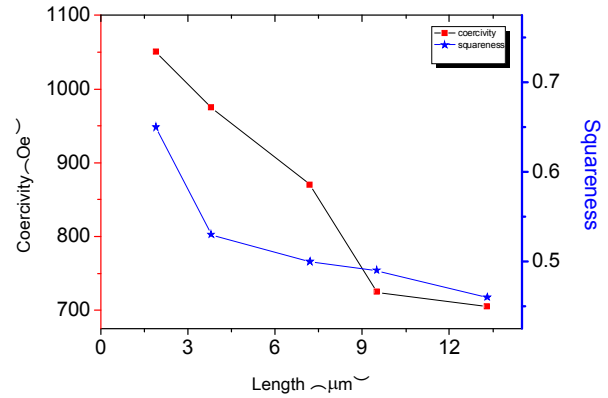

Fig. 5. Variation of the coercvity and squareness as a function of length of NiFe alloy nanowires.

4. Conclusions

The effect of length variation on the magnetic properties of FeNi nanowires the electrodeposited into the porous alumina template was investigated. The obtained results listed as follows:

• Squareness of the nanowires decreased with increasing the length of nanowires which implies increasing the magnetostatic interaction between array nanowires.

• Proceeding toward the multi-domain behavior is predicted to reduce the coercivity.

References

[1] A. P. Li, F. Müller, A. Bimer, K. Nielsch, U. Gösele, Adv. Mater. 11 (1999) 483-487.
[2] H. Masuda, K. Fukuda, Science. 268 (1995) 1466-1468.
[3] G. D. Sulka, S. Stroobants, V. Moshchalkov, G. Borghs, J. P. Celis, J. Electrochem. 149 (2002) D97-103.

[4] T. M. Whitney, J. S. Jiang, P. C. Searson, C. L. Chien, Science. 261 (1993)1316-1319.

[5] M. Darques, L. Piraux, A. Encinas, P. BayleGuillemaud, A. Popa, U. Ebels, Appl. Phys. Lett. 86 (2005) 072508-072511.

[6] D. Golodnitsky, N. V. Gudin, G. A. Volyanuk, Plat. Surf. Finish. 85 (1998) 65-70.

[7] A. N. Correia, S. A. S. Machado, Electrochim. Acta. 45 (2000) 1733-1740.

[8] L. Sun, P. C. Searson, Appl. Phys. Lett. 74 (1999) 2803-2806.

[9] Q. F. Liu, C. X. Gao, J. J. Xiao, D. S. Xue, J. Magn. Magn.Mater. 260 (2003) 151-155.

[10] D. Jain, H. K. Daima, S. Kachwaha, S. L. Kothari, Dig. J. Nanomater. Bios. 4 (2009) 557-563.

[11] R. Lavín, J. C. Denardin, J. Escrig, D. Altbir, A. Cortés, H. Gómez, IEEE TRANSACTIONS ON MAGNETICS,44(2008) 1-5

[12] O. C. Trusca, D.Cimpoesu, J.H. Lim, X. Zhang, J. B. Wiley, IEEE TRANSACTIONS ON MAGNETICS, 44 (2010) 2730-2733.

[13] F. E. Atalay, H. Kaya, S.u. Atalay , S.u.Tari, J. Alloys Compd, 469 (2009) 458–463

[14] M. Ciureanu, F. Béron, P. Ciureanu, R. W. Cochrane, D. Ménard, A. Sklyuyev. A. Yelon, J. Nanoscience and Nanotechnology. 8 (2008) 5725–5732

[15] M. Almasi Kashi,S. Alikhanzadeh Arani, A. Ramazani, J.Current Appl. Phys.(2012).