MAGNETIC AND MOSSBAUER PROPERTIES OF FE_XNI_{1-X} NANOWIRES

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Motivation

Attention to magnetic nanowires (NW): quasi one-dimensional magnetism, high magnetic anisotropy, application for magnetic sensors, spintronic devices, hydrogen fuel cell electrodes, and for biomedical technologies, including antitumor therapy. One of the most effective methods for obtaining ordered NW arrays is an electrochemical deposition in the pores of the special matrix (templates).

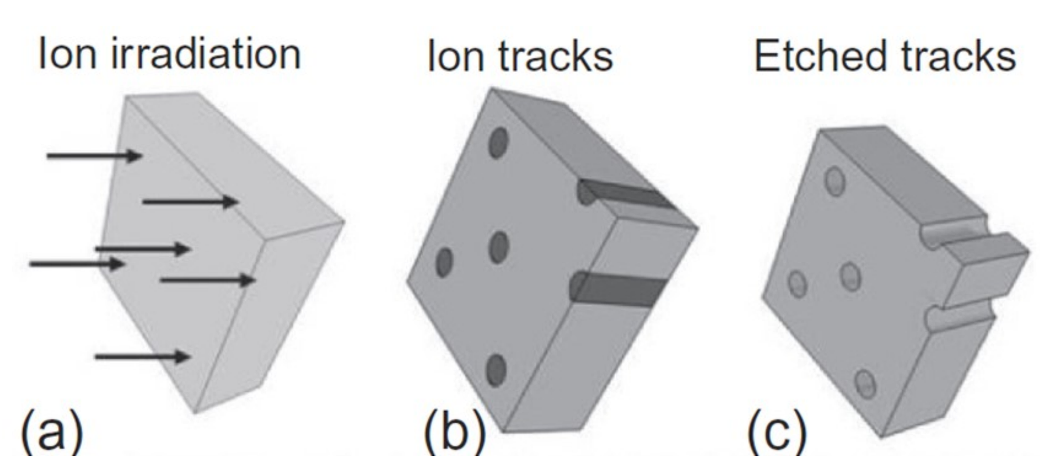
Polymer track membranes have some unique properties as a matrix. They are transparent for the visible light and X-ray radiation, very flexible, they are easily bent and can take any shape.

Experimental equipment

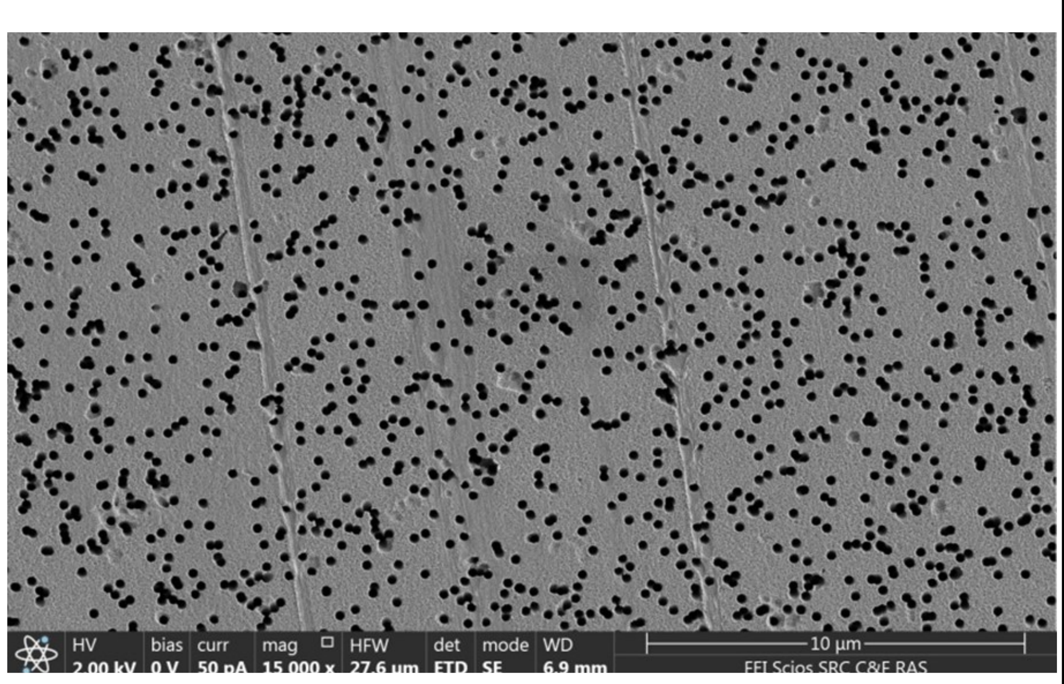
Electron microscopy of polymer track membranes and X-ray energy-dispersive analysis was carried out using SEM FEI Sicos EDAX equipped with FIB and EADX attachments. Electron microscopy of the NW arrays after removal of polymer membrane by etching in alkalis was carried out using SEM JEOL JSM 6000+ (accelerating voltage 15 kV, magnification ranging from 500X to 5000X).

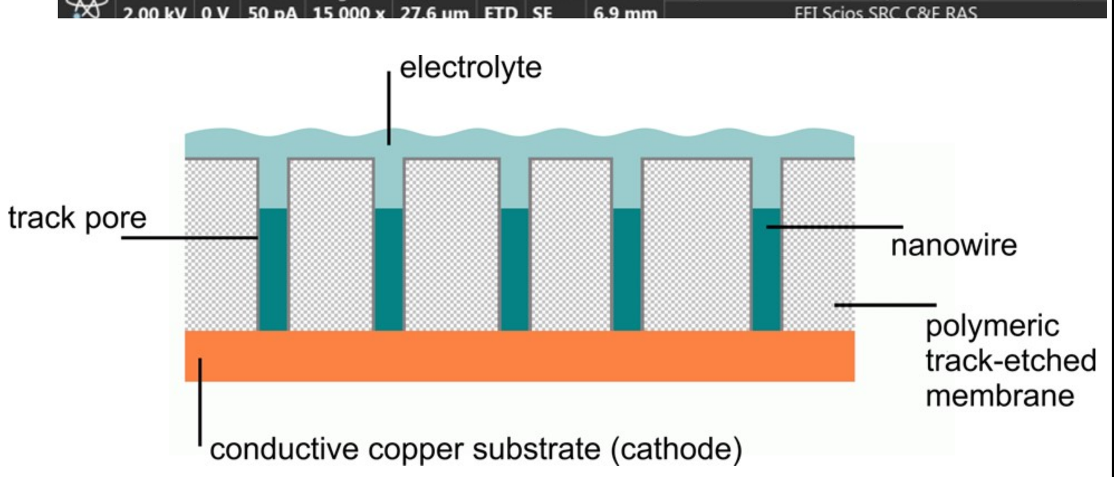
The X-ray diffraction (XRD) measurements of the samples were carried out using a RIGAKU Miniflex 600 diffractometer in the reflection geometry of Bragg-Brentano. The radiation of CuKα (λ = 1.5418 Å) was used. The interval of the diffraction angles was 2θ = 40 - 80º with 0.01º step and 1º/min. ICSD PDF-2 (2016) Ni-Fe references No. 00-047-1405 and 03-065-5131 were used to index the XRD patterns. The ^{57}Fe Mössbauer transmission spectra were obtained at room temperature using a standard MS-1104Em spectrometer in the regime of constant accelerations with a ^{57}Co(Rh) gamma-ray source (Ritverc MCo7.114). Isomer shifts are given with respect to the standard α-Fe absorber (30 μm metallic α-Fe foil Ritverc MRA.2.6 at room temperature). The collimated flux of gamma radiation was directed perpendicular to the plane of the polymer template in such a way that the wave vector of gamma quanta $k_γ$ coincided in the direction with the axis L of track pores and nanowires $k_γ \parallel L$. The computer processing of the experimental spectra was performed using the Univem MS software included with the MS-1104Em spectrometer and DISCVER software. The magnetization curves for all samples were measured at room temperature with a LakeShore 7407 vibrating-sample magnetometer at a frequency of 82 Hz. Each sample with a surface area of about 0.5 cm^2 was fixed on a flat holder, and the external magnetic field H was directed parallel or perpendicular to the plane of the sample, which corresponded to the orientation of the nanowire axes L in the membrane H ^ L (ϕ = 90º) or $H \parallel L$ (ϕ = 0º). The value of the magnetic field varied cyclically in the range from 5 kOe to -5 kOe.

Synthesis



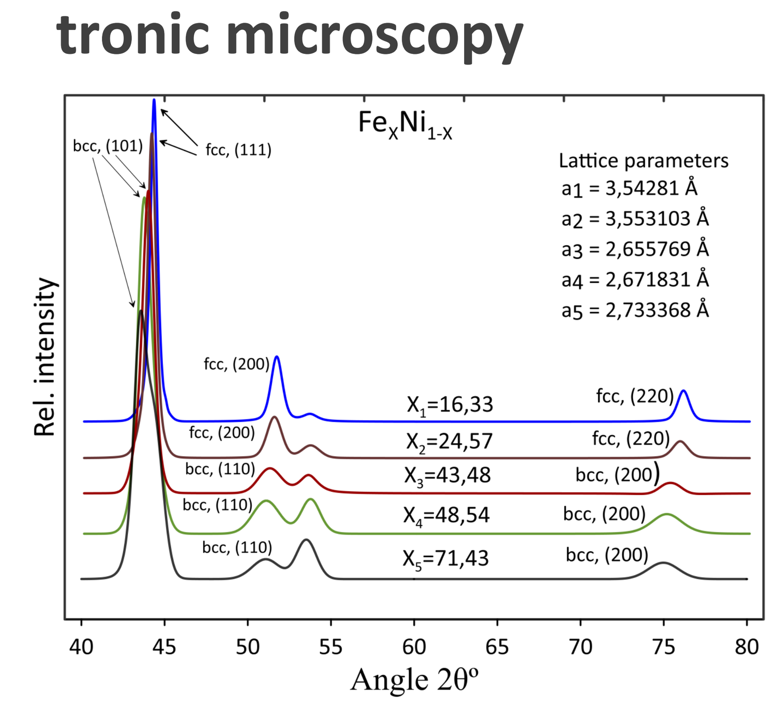
From *M. Vázquez, M., 2015. Magnetic nano-and microwires. Elsevier Science.*



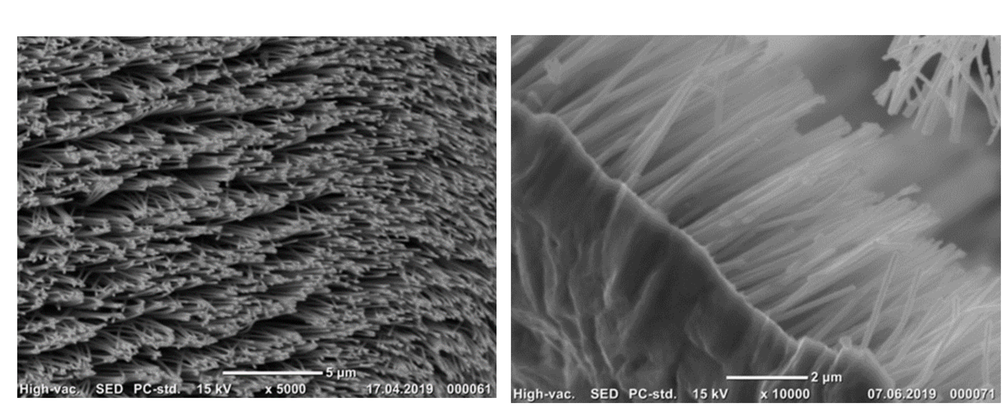


Our samples were obtained by means of polymer membrane etching technique. Such a method allows us to produce pores which is shown on electronic microscopy image above.

X-ray diffraction and electronic microscopy



The figure shows the x-ray diffraction curves of our five samples. The lattice parameters and the assumed phase composition are also given.

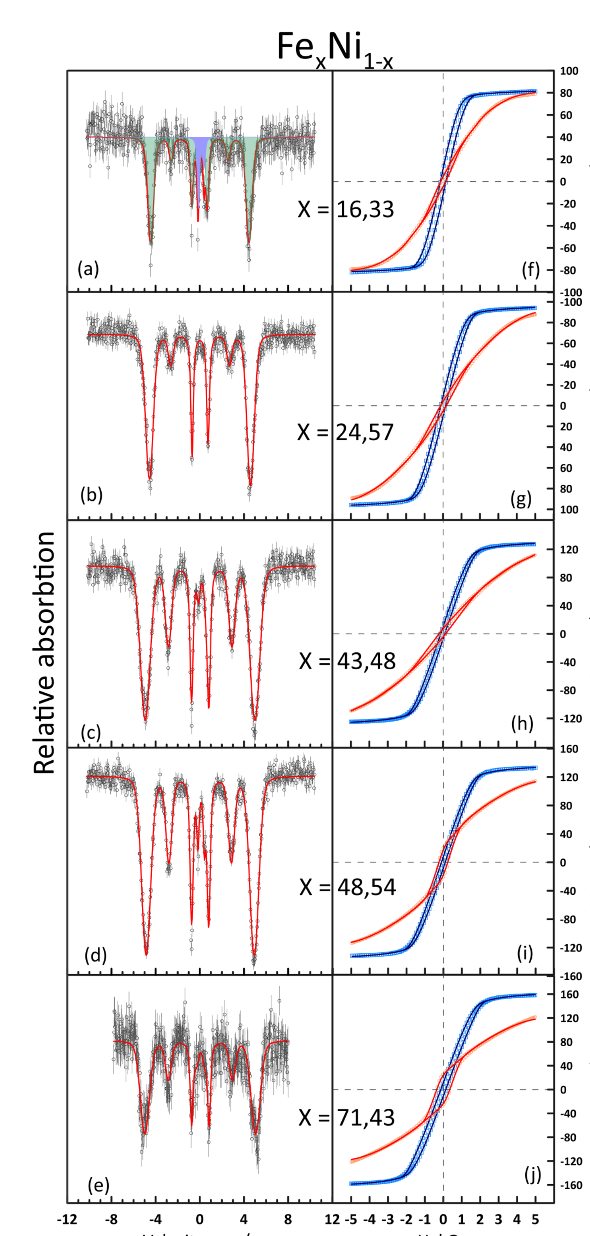


Electron microscopy images of our nanowires.

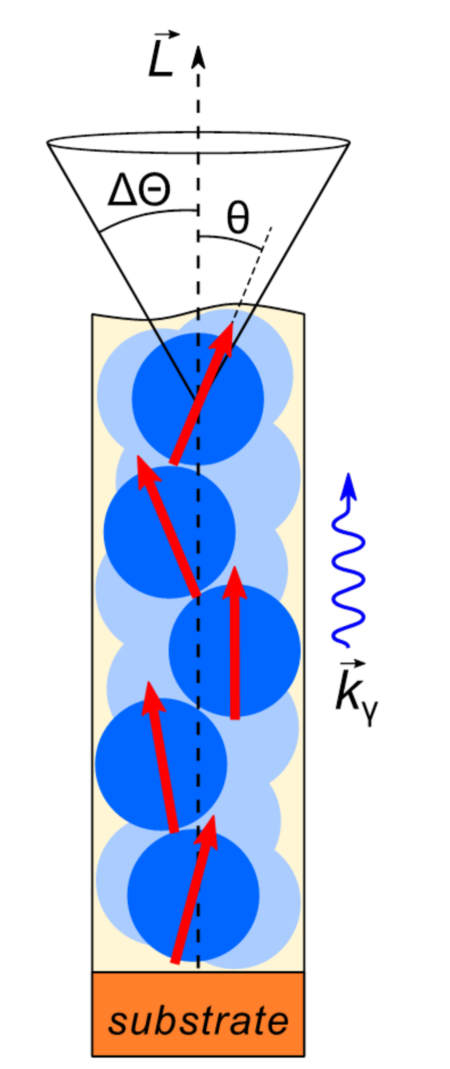
Sample number, FexNi1-x, x;	Lattice parameter, Å	Coherent scattering region, nm, Å
16,33	3,54281	20.0(1)
24,57	3,553103	17.2(2)
43,48	2,655769	11.7 (1)
48,54	2,671831	2.8(1)
71, 43	2,733368	4.68(5)

This table contains lattice parameters and estimated values of coherent scattering regions.

Mossbauer and magnetic measurements



The figure presents the results of the magnetometry and Mössbauer spectroscopy. Magnetic parameters obtained as a result of processing experimental data using the generalized Stoner Wohlfarth model.



Our model is based on the fact that nanowires consist of nanometer clusters (domains), each of which has a specific magnetic moment.

FexNi 1-x, x	M0, emu/g	K*10^{-6} erg/sm^3	D, nm	ΔD/D	Θ grad.	P0, c^{-1}	b	h_0	KV/k_BT
16,33	83.38(5)	1.52(1)	7.31(6)	0.099(4)	35.3(3)	180(20)	-0.152(3)	1.19(1)	7.4(1)
24,57	97.94(5)	1.49(1)	7.21(6)	0.095(5)	39.0(2)	73(8)	-0.277(4)	1.41(2)	7.1(1)
43,48	129.26(6)	1.52(1)	7.26(5)	0.087(4)	45.5(2)	55(5)	-0.49(4)	1.78(2)	7.4(1)
48,54	136.51(5)	1.57(1)	7.06(4)	0.093(4)	44.8(2)	45(4)	-0.53(3)	1.82(2)	7.0(1)
71, 43	170.81(5)	1.64(1)	7.21(3)	0.103(3)	46.1(1)	46(3)	-0.71(3)	2.12(2)	7.7(1)

This table shows calculated magnetic parameters, obtained in the framework of generalized Stoner Wohlfarth model. More detains see in our work Frolov et. al 2019 in JMMM.

Results:

I) X-ray diffraction results

With an increase in the concentration of iron in the NW, the crystal lattice changes from Nickel to iron; the lattice parameter in all cases increases, in the case of samples with concentration x= 43,48; 48,54; 71, 43 it approaches the table value for iron. In all cases, an increase in the amount of iron in the NW leads to a broadening of the peak (a decrease in the linear size of the crystallites). It is also worth noting that in all cases the intensity of the first peaks is higher than the table ones, which is presumably due to the chosen crystal direction.

Conclusions:

1) At all concentrations, there is a phase of the alloy-a solid solution of Nickel in iron. The parameter of the iron-Nickel alloy lattice is weakly (at the error level) shifted with increasing iron concentration towards pure iron;

2) At low concentrations of iron (in samples with x=16,33; 24,57), two phases are observed: in addition to the iron-Nickel alloy phase, a pure Nickel phase is detected.

II) Magnetic and Mossbauer spectroscopy results

Nanowires have pronounced ferromagnetic properties, and the magnetic moments of Ni-Fe nanoparticles are oriented mainly along the wire axis. Such materials can be cosidered as quasi-one-dimensional nanostructured ferromagnetic systems. A generalized Stoner-Wohlfarth theoretical model was used to describe the magnetic properties and calculate the basic physical parameters of nanowires. Our experimental data and theoretical calculations are in good agreement. The values of the magnetic anisotropy energy do not depend on the concentration of iron ions. This means that we can regulate magnetic properties by composition changing, and their stability (rigidity) — only by shape of NWs.

Acknowledgements

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