Structural and magnetic properties of electrodeposited NiFe alloy on silicon nanowires.

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Abstract

Perpendicular Silicon nanowires (SiNWs), having 20 micrometer in length, were fabricated by metal assisted chemical etching of n-type Si(100) wafers in aqueous HF-solution. In a second step, NiFe films were electrodeposited onto theses SiNWs. The structure and magnetic properties of as deposited NiFe layers were studied by X ray diffraction (XRD) and vibrating sample magnetometer (VSM). From X-ray diffraction, the FCC NiFe structure was evidenced with a lattice constant, a, equal to 3.5270 Å. From hysteresis curves, we compute the coercive field, Hc, values. We found that the $Hc_{//}$ values range from 102 Oe to 236 Oe.
Keywords: *Silicon nanowires, NiFe alloy, structure, magnetic properties.*

1 Introduction

In recent decades nanomaterials science and nanotechnology is one of the most attractive areas for scientists, both fundamental and technological level, because of the wide range of possible application. The nanowires are part of nanomaterials which have potential applications in the field of optics, electronic components, electronic connectors batteries, solar cells and magnetic recording media ...[1-3].

The nanowires are part of nanomaterials play an important role, in fact they have potential applications in the field of optics, electronic components, electronic connectors batteries, solar cells and magnetic recording media ...[1-3] One of materials most used in magnetism is the permalloy ($Ni_{80}Fe_{20}$) due to its high permeability, low coercivity and low magnetic anisotropy. In this work we studied the elaboration of silicon nanowires, and the electrochemical deposition of NiFe on the silicon nanowires. The morphological, structural and magnetic properties were investigated by different characterization techniques.

2 Experimental methods

Before etching, the Si wafers (substrates) were cleaned in trichloroethylene, acetone and ethanol baths in ultrasonic container. Ten wafers were immersed in 10% HF aqueous solution for 5 min at room temperature to remove the native oxide. In this study four samples of silicon nanowires (SiNWs) were elaborated by the metal assisted chemical etching method. The n-type Si (100) wafers were used. Indeed, the cleaned Si samples were dipped into the $AgNO_3$/HF solution for electroless deposition of Ag nanoparticles (AgNPs) at room temperature (~ 20 °C) for 1min. Subsequently, the AgNP coated Si samples were immersed into the H_2O_2/HF solution for chemical etching for 1 h at room temperature. Finally, the as-etched Si samples were soaked in 69 % HNO_3 to remove the residual AgNPs, cleaned with de-ionized water and dried under azote. These samples were used as a substrate to deposit on a NiFe alloy by electrochemical deposition. The electrolyte used is identical to that reported in the references [4, 5]. All chemicals were of analytical grade and they were used without further purification and mixed in deionized

water. To minimize the oxidation reactions, the solutions were freshly prepared each time before plating.

The deposition was carried out at room temperature, in a three-electrode-cell. A platinum mesh was used as counter electrode and an Ag/AgCl electrode as reference electrode. Different potentials were applied to deposit NiFe alloy on the SiNWs. The structural properties were studied with a Philips X-pert diffractometer in the 2θ scan mode using a Cu Kα radiation (1.54056 Å). The morphology of the samples were investigated by Philips XL 30-FEG scanning electron microscope.

The hysteresis loops were obtained at room temperature using a vibrating sample magnetometer (VSM), with an external magnetic field H applied parallel and perpendicular to the samples surfaces.

3 Results and discussions

Figure 1 shows the cyclic voltammogram of the SiNWs (work electrode) in the plating solution. In the descending potential scan (cathodic branch), it is accurse a deposition of NiFe alloy and the H$_2$ emission. While the anodic peak arising at positive potentials is the oxidation pic producing a remove of the NiFe deposit [6].
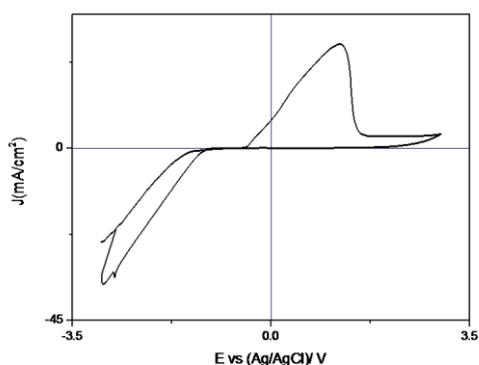

Fig. 1. Cyclic voltammetry scan for silicon nanowires in NiFe electrolyte.

From this XRD spectrum, Fig. 2. (a), we observed that, before removed AgNPs by nitric acid, characteristic peaks of Ag were observed [8].
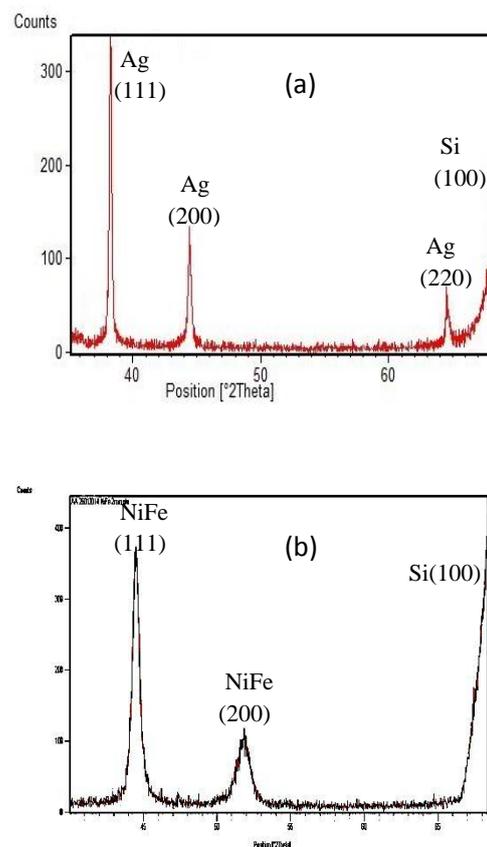

Fig. 2. Example of X-ray diffraction spectra: (a) before remove silver, (b) for NiFe/SiNWs deposit at -2V.

After HNO$_3$ cleaning, Fig.2. (b) shows characteristic peaks of bcc NiFe alloy. It is also observed that for the NiFe/SiNW a polycrystalline structure is formed. From this spectrum, we calculated the lattice constant, a (Å), equal to 3.5270 Å. This value is lower than the bulk value a$_{bulk}$=3.5385 Å [7].

The crystallite size of the NiFe/ SiNWs was determined from the widths of the diffraction peaks at half maximum (FWHM) using Scherrer's formula [9]:

$$D = \frac{0.9\lambda}{\beta cos\theta}$$

Where λ is the wavelength of the Cu Kα radiation, θ is the diffraction angle of reflection and β is the FWHM of the diffraction line adjusted by pseudo-Voigt function. For the sample deposit at -2V, D, is equal to 16.4 nm.

The figure 3 shows an example of SEM image of the NiFe/SiNWs deposit at -1.8 V. We observed spherical particles were formed on the surface of the silicon

nanowires. From the section observation, vertical silicon nanowires were observed. Also, it can be seen that some nanowires were broken possible due to the cleavage operation.

The forming process of SiNWs can be described as follow: AgNPs are firstly deposited via Ag+ reduction in the AgNO₃/HF solution, and then induce the Si at Ag/Si interfaces to be oxidized and then dissolved by HF, leaving pits into Si wafers. Due to the high density of AgNPs, their sinking into silicon substrat lead to formation of SiNWs [11, 10].
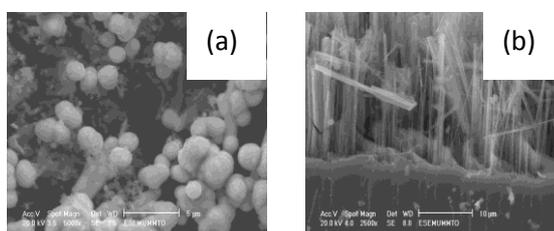

Fig. 3. Plan (a) and cross-sectional (b) view SEM images of NiFe electrochemically deposited onto SiNWs.

In figure 4, we show examples of hysteresis curves for the NiFe/SiNWs with external applied field (H), parallel to the surface of the samples.
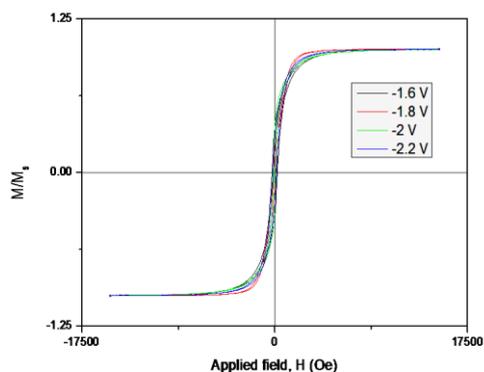

Fig. 4. Normalized magnetization loops as a function of applied magnetic field for NiFe/SiNWs for different applied tensions.

From the hysteresis loops we derived the coercive field (Hc) of the samples. The values of Hc range from 102 Oe to 236 Oe for the tension of -2 V and -1.6 V, respectively. These values are relatively high, in comparison to films [12-14].

4 Conclusion

We elaborated silicon nanowires by metal- assisted chemical etching. NiFe alloy were electrodeposit on these nanowires. The samples presented a polycrystalline structure, having a cell parameter lower than the bulk value. The morphology observed by SEM, shows the formation of spherical particles on the silicon nanowires. The magnetic measurement shows coercivity range from 102 Oe to 236 Oe.

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