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Electrochemically Deposited Cobalt Nanoarrays in SiO_2/*n*-Si Templates Produced by Swift Heavy Ion-Induced Modification Technology

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Nanoarrays of Co nanorods were formed by means of electrochemical deposition in the nanoporous SiO_2/*n*-Si templates. Structure and magnetic properties at room temperatures were studied by means of atomic force and scanning electron microscopies, vibrating sample magnetometry. The presence of perpendicular magnetic anisotropy component at room temperature makes Co nanorods in the nanoporous SiO_2/*n*-Si templates promising for nanoelectronic devices and biomedical applications.

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1. Introduction

New technological approaches to fabrication of template-based ordered nanoarrays (nanorods or nanowires) is of great importance not only because of the fundamental new physics involved in such highly correlated system, but also because of a diversity of applications, such as high density storage media, functional nanomaterials exhibiting quantum size effect, highly sensitive chemical sensors, nanoelectronic devices and functional bio-chemical membranes.

Nanoarrays-based structures for preparation of nanoelectronic devices are the object of particular interest because modern electronic components are approaching the size limit of standard photolithography techniques. Self-assembled template-assisted nanostructures have the potential to circumvent such limitations and thus could be used as alternative future electronic components. This paper is related to recent achievements in the template-assisted synthesis of metallic nanorods inside the nanoporous SiO_2 template with respect to fabrication of nanostructures possessing perpendicular magnetic anisotropy prospective for designing of high density storage media.

2. Experimental

Nanoarrays of Co nanorods were formed by means of electrochemical deposition into the nanoporous SiO_2 template created on the *n*-Si (100) substrate with 4.5 Ω cm resistivity. In order to produce the porous SiO_2/Si template the SiO_2 layer was thermally grown on the *n*-Si (100) substrate at 1100 °C for 10 h in oxygen atmosphere. Then the samples were irradiated by the scanned beams of 350 MeV $^{197}Au^+$ ions with the fluency of 5×10^8 cm^{-2} at the "ISL" accelerator center in the Hahn–Meitner Institute (Berlin, Germany) to produce latent ion tracks in silicon oxide [1]. In order to obtain pores in a contact with the Si substrate chemical etching of the irradiated SiO_2 layer in dilute hydrofluoric acid HF ($w = 1.35\%$) was performed for 45 min. Co deposition was carried out in the 0.5 M $CoSO_4$ + 0.5 M H_3BO_3 (Co bath) solutions by applying electric impulses with the potential −3.0 V and with the duration period 300 ms each. The electrolytes were prepared using high purity reagents and bidistilled water. In order to interpret the magnetic properties of Co nanoarrays, electrodeposition of Co film onto the surface of monocrystalline *n*-Si (100) wafers was done under similar conditions.

The study of surface morphology of templates was carried out using the atomic-force microscope (AFM) NanoScope III (Veeco Instruments) in the dynamic mode. The scale calibrations were performed with the standard silicon matrices. Structure and phase composition were studied by means of electron microscopy using the scanning electron microscope LEO1455VP (Carl Zeiss) with the four-compartment reflected electron detector and the energy-dispersive X-ray spectroscopy (EDX) analyzer Ronteg. Magnetic properties were investigated by means of vibrating sample magnetometry at room temperature using a cryogenic high field universal measuring system (Liquid Helium Free High Field Measurement System by Cryogenic Ltd.).

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3. Results and discussion

According to the results of atomic-force microscopy presented in Fig. 1a pores in the SiO_2/Si template with the average diameter 300 nm are randomly distributed over the surface and filled inhomogeneously with Co. Completely filled pores are covered with cobalt hemispherical overgrowths with the average diameter of about 1 μm. Incompletely filled pores contain a conical dome at the center that is in a good agreement with well-known dynamics of template filling by metals (Fig. 1b) [1, 2].

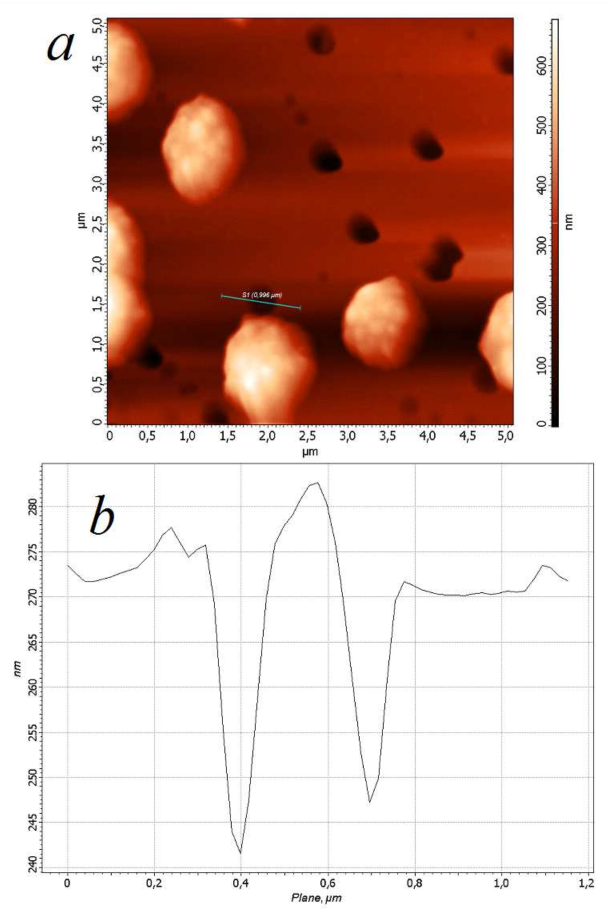

Fig. 1. AFM image of SiO_2/Si template surface filled with Co (a); surface shape of incompletely filled pore in SiO_2/Si template (b).

The results of scanning electron microscopy (SEM) are presented in Fig. 2. The SEM images reveal that Co nanorods look like truncated cones with the base diameters of ≈ 200 nm and ≈ 250 nm and the height of about 300 nm. Completely filled pores are covered with cobalt hemispherical overgrowths with the average diameter almost 1 μm. These results are in good agreement with the above mentioned AFM data.

Magnetization curves presented in Fig. 3 were obtained in parallel ($\boldsymbol{B} \parallel \boldsymbol{n}$) and perpendicular ($\boldsymbol{B} \perp \boldsymbol{n}$) orientations relatively to the surface normal of n-Si substrate for Co nanoarrays and Co film. As it can be seen in Fig. 3a the magnetization curves of Co film on the n-Si substrate are typical of those of objects with magnetic anisotropy of easy plane: the magnetization curve does not saturate when the magnetic field is applied parallel to the surface normal $\boldsymbol{B} \parallel \boldsymbol{n}$ (perpendicular to the n-Si substrate) and saturates at small values of magnetic field induction when

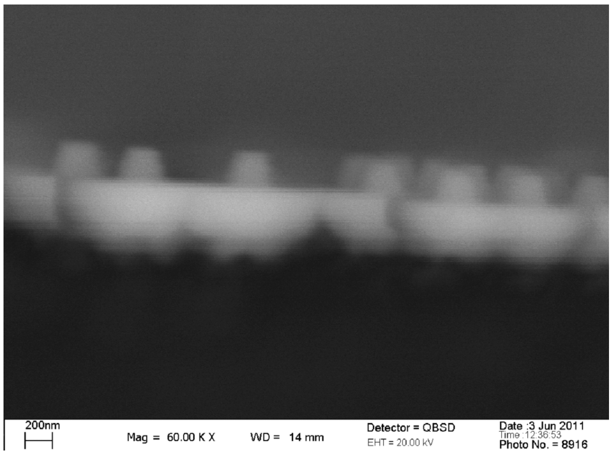

Fig. 2. SEM image (side view) of Co nanoarrays in SiO_2/n-Si template.

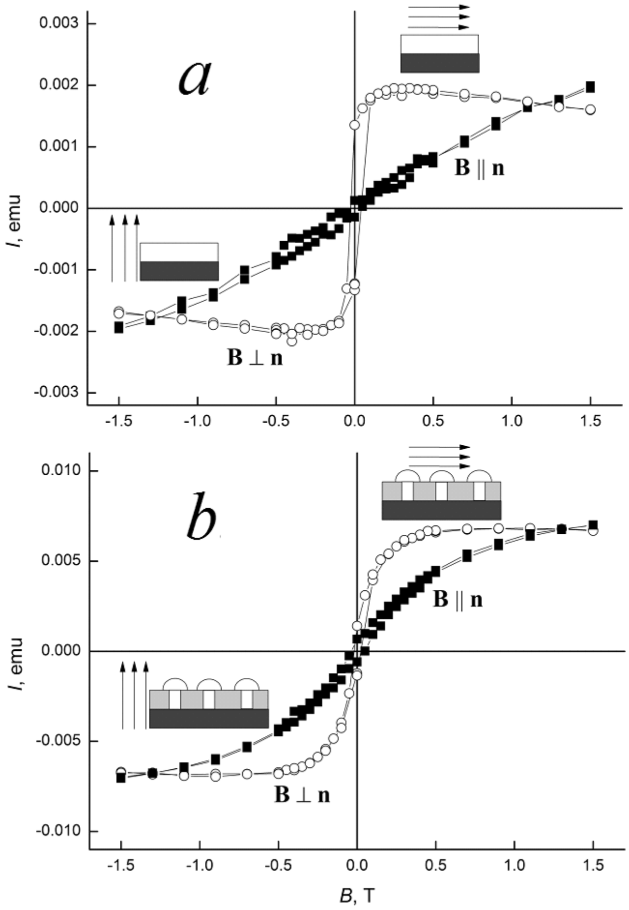

Fig. 3. Magnetization curves of Co film on n-Si substrate (a) and Co nanoarrays in SiO_2/n-Si template (b).

the field is applied perpendicular to the surface normal $\boldsymbol{B} \perp \boldsymbol{n}$ (parallel to the n-Si substrate) [3]. The value of coercive force for both orientations is 400 Oe.

For Co nanoarrays in the SiO_2/n-Si template (Fig. 3b) in the case of parallel orientation relative to the surface normal $\boldsymbol{B} \parallel \boldsymbol{n}$ (magnetic field is applied perpendicular to the surface of SiO_2/n-Si template) the magnetization curve appears saturated at ≈ 1.5 T. The coercive force for such orientation is about 500 Oe. When the magnetic field is applied parallel to the n-Si substrate ($\boldsymbol{B} \perp \boldsymbol{n}$), the magnetization curve saturates at smaller values of field induction opposed to the orientation $\boldsymbol{B} \parallel \boldsymbol{n}$ but at greater values in comparison with the Co film at similar orientation in the magnetic field. The coercive force of the $Co/SiO_2/n$-Si sample for such orientation is 200 Oe. Based on the dependence of magnetization on the B orientation, one should conclude about the presence of the perpendicular magnetic anisotropy component (partial magnetic anisotropy of easy axis parallel $\boldsymbol{n}$) that can be explained as a consequence of the shape anisotropy of formed cobalt nanorods. At the same time more saturated appearance of magnetization curve in parallel to the n-Si substrate orientation ($\boldsymbol{B} \perp \boldsymbol{n}$) in comparison with the case of orientation $\boldsymbol{B} \parallel \boldsymbol{n}$ can be explained in terms of magnetic exchange interaction between cobalt hemispherical overgrowths that cover the completely filled pores in the SiO_2/n-Si template.

4. Conclusion

The presence of perpendicular magnetic anisotropy component was revealed for massives of nanoarrays of Co nanorods formed by means of its electrochemical deposition in the nanoporous SiO_2/n-Si templates. Based on the microstructural study, perpendicular magnetic anisotropy should be assigned to the shape anisotropy of formed Co nanorods. The simultaneous presence of partial magnetic anisotropy of easy plane can be explained by magnetic exchange interaction between the Co hemispherical overgrowths. These results can be used in complicated 3D magnetoresistance applications.

Acknowledgments

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