Our research efforts are currently focused on the functionalization of natural polymers, namely polysaccharides, to promote their interaction with biological systems. Osteoprogenitor and stem cells were immobilized within alginate microspheres conjugated with oligopeptides including the Arg-Gly-Asp (RGD) sequence. Polymers were further modified to improve their biodegradability. After immobilization and under dynamic cell culture conditions, immobilized cells were viable, proliferated and differentiated. Immobilized cells further synthesized an extracellular matrix and expressed bone phenotypic markers, which indicates the capability of this approach to promote the regeneration of bone tissue. Current efforts are focused on promoting vascularization of bone tissue by using angiogenic factors as well as endothelial cells.

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CHARACTERIZATION OF FERROMAGNETIC COMPOSITE MATERIALS FOR BIOMEDICAL APPLICATIONS

JULIA LEDOTOVA¹, MARIUSZ WOJCIK²

¹ NC PHEP BELARUSIAN STATE UNIVERSITY, 220040 MINISK, BELARUS,
² AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF MATERIALS SCIENCE AND CERAMICS, 39, MICKIEWICZA AL., 30-059 CRACOW, POLAND
E-MAIL: JULIA@HEP.BY

Abstract

The quick advances in material sciences have provided a broad framework for implementing multifunctionality in materials. Multifunctional materials embedded in an adaptive composite system have presented an exceptional possibility in engineering consideration problems. It is believed that broadly discussed in literature [1-9] ferromagnetic nanomaterials possessing giant magnetoresistivity (GM) and spin-dependent tunnelling (SDT) effects are very promising for applications in biomedical and bioengineering fields as they allow the elaboration and production of magnetic nanosensors. The elementary concept of sensors in biomedical application is to prepare multifunctionally highly integrated composite provided data on the structural environment to a processing and control computerised system which in turn signals can modify the structural properties. Particularly, core-shell nanocomposites contained soft magnetic Fe-based oxides have captured a dominant position due to their superior chemical and thermal stability, hardness, non-toxicity and biocompatibility [10].

In order to exploit the full potential of such materials a detailed understanding of nanostructure property correlation is needed. Present paper is aimed on the investigation of nanocomposites consisting of magnetic metallic (alloy) nanoparticles (MMNPs) embedded in a dielectric matrix (like SiO₂ or Al₂O₃). Incorporation of oxygen into the nanocomposite structure allows formation of soft ferromagnetic core (alloy)–shell (oxide) structure that is opening wide opportunities for tailoring of magnetic, electric and magnetotransport properties of nanocomposites.

Materials and methods

FIG.1. DC magnetoresistance (A) and magnetisation M at B=400mT (B) of the composite films of series 1 (pure Ar ambient) and 2 (mixed Ar+O ambient) vs composition X.

The studied (Feₓ₈₋ₓCoₓ₄₋ₓZr₀.1₀ₓ(Al₂O₃)₀.₉₀₀₋ₓ(17<x<65 at.%) films with thickness d of 3 to 5µm were manufactured using ion-beam sputtering of the compound target with argon onto the motionless water-cooled substrate. The films were deposited onto glass-ceramic substrates for electrical measurements and on thin aluminium foils. The composites have been investigated by means of Mössbauer spectroscopy, AC/DC measurements and magnetometry.

Incorporation of oxygen into the nanocomposite structure allows formation of soft ferromagnetic core (alloy)–shell (oxide) structure that is opening wide opportunities for tailoring of magnetic, electric and magnetotransport properties of nanocomposites.

Introduction

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Results and discussion

Magnetotransport and magnetic properties

The DC/AC measurements, at room temperature and for the samples of both series, have showed that the relative magnetoresistance (MR) $\Delta R/(R)\cdot B_0$ or low-frequency $\Delta Z/(Z)\cdot B_0$ of the studied nanocomposite films was negative and obeying the relationship of $MR \propto B^2$ as the magnetic induction $B$ increased. Dependences of MR on composition at constant $B$ displayed principally different behavior for the samples deposited in Ar than that in Ar–O mixture (FIG.1A). The negative sign of MR and the exponential factor $k^2$ confirmed the tunnel character of the carrier transport for the studied nanocomposites [11]. Note also that maximal sensitivity of $\rho$ and low-frequency $Z^*$ to magnetic field was very closely to percolation thresholds $X_c$ estimated previously from electrical measurements (45–47 at.% for series 1 and ~ 55 at. % for series 2) [12].

The dependendency of the magnetization $M$ as a function of $X$ (FIG.2B) showed that the tendency of sharp growth of $M$ with the increase of metallic fraction ratio is exhibited only at $X>X_c$ for the samples sputtered in Ar+O mixture at conservation of their low coercivity [13]. At the same time, for the films deposited in a pure argon the $M(X)$ dependence of the films was characterized by a maximum at $X$ close to $X_c$ showing then fast decrease.

Mössbauer spectroscopy

FIG.2 shows Mössbauer spectra for the samples of various $X$ fractions of metallic phase and for both series of samples. As evidenced from the FIG.2A, spectra of the series (A) revealed quite expected transition from nonmagnetic to magnetic state. For $X<45$ at.% $\gamma$ spectra were reasonably fitted with two $\gamma^+$ doublets (D1: IS=0.13–0.14 mm/s, QS=0.88–1.12 mm/s; D2: IS=0.04–0.05 mm/s, QS=0.49–0.52 mm/s) while at $X$ values higher than $47\%$ - with two sextets and the hyperfine magnetic field values close to those of FeCo alloy [14]. Such transformation should be assigned to the structural change from non-interacting superparamagnetic FeCoZr nanoparticles (probably of two different mean sizes) to the ferromagnetic interacting net of these ones.

Contrary to the previous case, spectra of the samples deposited in Ar+O mixture (series 2) showed nonmagnetic state of nanocomposites independently on Co$_{63}$Fe$_{37}$O$_{2.1}$ Zr$_{10}$ MMNs fraction (FIG.2B). The best fitting of spectra at $X=55$ at.% was obtained with two Fe$^{3+}$ doublets and one Fe$^{2+}$ doublet.

The extracted hyperfine parameters assumed that Fe$^{3+}$ doublets should be assigned to residual (non-oxidized) FeCoZr nanoparticles and oxidized FeCoZr nanoparticles (complex FeCo-based oxides) while Fe$^{2+}$ doublet reflected the formation of hercynite phase (FeAl$_2$O$_4$) [13]. For $X=55\%$ only subspectra corresponding to FeAl$_2$O$_4$ and oxidized FeCoZr nanoparticles were detected indicating total oxidation of nanoparticles.

Conclusions

1. The presented work revealed that insertion of oxygen into argon gas in a sputtering chamber at deposition of nanocomposite films with CoFeZr nanoparticles embedded in amorphous alumina matrix have a very strong influences on structure, magnetic behaviour and magnetotransport of the samples.

2. The introduction of oxygen resulted in oxidation of metallic nanoparticles and formation of core (alloy)–shell (oxide) structure inside of dielectric matrix. The last caused doubling of magnetoresistive effect at conservation of low coercivity of the films that potentially allows using them as magneto-sensitive devices working in AC regime.

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References