Nuclear Instruments and Methods in Physics Research B 272 (2012) 104–107

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Structural and magnetic studies of Co and Fe implanted $BaTiO_3$ crystals

N.I. Khalitov [a,b], R.I. Khaibullin [a,b,*], V.F. Valeev [a], E.N. Dulov [b], N.G. Ivoilov [b], L.R. Tagirov [a,b], S. Kazan [c], A.G. Şale [c], F.A. Mikailzade [c]

[a] Kazan Physical–Technical Institute of RAS, Sibirsky Trakt 10/7, 420029 Kazan, Russia
[b] Kazan Federal University, Kremlevskaya 18, 420008 Kazan, Russia
[c] Department of Physics, Gebze Institute of Technology, 41400 Gebze-Kocaeli, Turkey

ARTICLE INFO

Article history:
Available online 2 February 2011

Keywords:
Ion implantation
Magnetic nanoparticles
Multiferroics
Magnetoelectric effect

ABSTRACT

Singly-charged Co or Fe ions with energy 40 keV were implanted into single-domain ferroelectric plates of barium titanate ($BaTiO_3$) with high fluences in the range of $(0.5–1.5) \times 10^{17}$ ion/cm^2 to create new magnetoelectric materials. Scanning electron microscopy (SEM) and conversion electron Mössbauer spectroscopy (CEMS) studies have shown that high-fluence implantation with 3d-ions results in formation of cobalt or iron nanoparticles in the near-surface irradiated region of perovskite-type crystal. With increasing the fluence, the both Co- and Fe-implanted $BaTiO_3$ samples reveal at first superparamagnetic, and then ferromagnetic properties at room temperature. Analysis of magnetic hysteresis loops measured in the in-plane and out-of-plane geometries have shown that ferromagnetic $BaTiO_3$:Co(Fe) nanocomposite layers display the "easy plane" magnetic anisotropy similar to that found for thin granular magnetic films. Together with our previous observation of the magnetoelectric effect in these samples, our structural and magnetic investigations show that the ion implantation is suitable to synthesize the desired magnetoelectric nanocomposite materials.

1. Introduction

Multiferroic materials attract considerable attention due to wide applications in fields of sensors, data storage, spintronics, etc. [1]. In these materials, the interaction between ferroelectric and ferromagnetic substances may produce a magnetoelectric effect (MEE), in which change in magnetization can be induced by an electric field or vice versa. Magnetoelectric coupling in natural multiferroic single-phase compounds is weak or occurs at temperatures too low for practical applications [1]. In contrast, multiferroic composites based on the dispersion of magnetic nanoparticles in ferroelectric or piezoelectric matrices typically reveal giant MEE above room temperature that makes them suitable for technological applications [1]. Hence, the synthesis and characterization of new multiferroic nanocomposite materials are of great interest. In the given context, we implanted ferroelectric perovskite-type oxide, $BaTiO_3$, with high fluences of cobalt or iron ions to form magnetic nanoparticles in the near-surface region of the irradiated substrate. In our previous paper [2] we reported on the observation of the magnetoelectric effects in the Co-implanted $BaTiO_3$. In particular, the line shift was observed in the ferromagnetic resonance signal upon applying the external electric field to the samples. This was an indication of a change in magnetization in the electric field. In addition, the magnetocapacitance and magnetodielectric effects were observed, they point to changing the ferroelectric polarization when applying the magnetic field. In this paper we investigate fluence dependence of the structural and magnetic properties of ferroelectric crystals of barium titanate implanted with cobalt and iron ions.

2. Experimental

The $10 \times 10 \times 0.5$ mm^3 single-crystalline (0 0 1)-face oriented single-domain plates of $BaTiO_3$ (*CrysTec GmbH*, Germany) were implanted with 40 keV Co^+ and Fe^+ ions at the ion current density of 8 μA/cm^2 to fluences in the range of $(0.5–1.5) \times 10^{17}$ ion/cm^2. Implantation was carried out at room temperature by using ion-beam accelerator *ILU-3* kept at residual vacuum of 10^{-5} Torr. Small pieces of the implanted samples were annealed subsequently in air at temperatures from 450 to 1200 K for 30 min.

Depth profiles of cobalt and iron concentration were calculated using the simulation-code *SRIM-2008* [3]. Element composition and surface morphology of the samples were investigated using commercial scanning electron microscope *«Zeiss» EVO-50XVP* with energy-dispersive X-ray (EDX) spectrometer *Oxford INCA Energy 330*. In addition, the conversion electron Mössbauer spectroscopy (CEMS) was used to determine iron-based phases in Fe-implanted samples. CEMS spectra were recorded at room temperature on the

* Corresponding author at: Kazan Physical–Technical Institute of RAS, Sibirsky Trakt 10/7, 420029 Kazan, Russia. Tel.: +7 843 231 91 09; fax: +7 843 272 50 75.
E-mail address: rik@kfti.knc.ru (R.I. Khaibullin).

0168-583X/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.nimb.2011.01.042