Materials Research Bulletin 99 (2018) 219–224

Contents lists available at ScienceDirect

Materials Research Bulletin

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

Short communication

Study of magneto-optical characteristics of cerium incorporated yttrium iron garnet films

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ARTICLE INFO

Keywords:
Cerium yttrium iron garnet films
Sol–gel
Magneto-optical properties

ABSTRACT

In the current study, yttrium iron garnet films incorporated with cerium with the general formula of $Ce_xY_{3-x}Fe_5O_{12}$ and values of (x = 0, 0.1, 0.3, 0.5, 0.7) were prepared through sol–gel method using spin coating technique and heating treatment on quartz substrates. Prepared samples were studied to check physical characteristics. X-ray diffraction analysis (XRD), scanning electron microscope (SEM), atomic force microscope (AFM) and vibrating sample magnetometer (VSM) were applied to study the impact of Ce impurities on the structural characteristic, surface morphology of films and magnetic properties, respectively. Faraday rotation values of samples were measured at the wavelength of 632 nm. The image of the atomic force microscope (AFM) of the prepared samples shows that the films have a continuous and smooth surface.

1. Introduction

Rare earth iron garnets (REIGs) are a promising choice to be used in high-performance microwave and electrochemical devices owing to their high resistivity, suitable Curie temperature, chemical stability and unique magneto-optical properties. Many researchers maintain that incorporation of cerium (Ce) in the yttrium iron garnet (YIG) improves magneto-optical effect compared with incorporation of bismuth (Bi). In this regard, several parts of the literature show that these kinds of films are constructed to be used in optical memories and waveguides [1–5]. Therefore, it seems that the Ce incorporated in YIG (Ce:YIG) is an exceptional material with high Faraday rotation (FR) and low optical loss. According to the available literature, controlling incorporation of Ce ions instead of Y^{3+} ions is extremely difficult as Ce intensely desires to become CeO_2 through oxidation, causes restriction on the solubility of Ce in the structure of YIG and creates many problems due to effect of CeO_2 impurities on reducing the magneto-optical and magnetic features of the material.

The mechanism of the effect of incorporation of various elements in YIG structure has been reported in many papers [6–9]. In articles in which preparation of Ce:YIG films has been performed via approaches, including pulsed laser and RF, it is stated that Faraday rotation is increased linearly by enhancing the incorporated Ce concentration, while the amount of impurities in the deposited sample can be one of the main parameters considerably changing the performance of this material as optical memories and waveguides, since it is supposed that these impurities decrease the Faraday rotation [6–8,10]. In addition, formation of capillary cracks in the films produced by these methods is one of their limitations less considered due to the difference between the temperature of the amorphous substrate's surface employed, particularly quartz, and the temperature of the phase formation of the desired material on the surface in these methods. Therefore, other methods such as RF magnetron sputtering technique, liquid phase epitaxy (LPE) and sol–gel have been widely studied for deposition of cerium yttrium iron garnet [11]. In these methods, sol–gel technique is a relatively new synthesis technique with advantages, including low cost, simple processing and the ability of producing thin films. For this reason, we decided to study crystalline, magnetic and magneto-optical features of Ce doped YIG films on quartz substrates using sol–gel method and spin coating techniques. This study aimed to provide relatively cheap films of polycrystalline Ce:YIG on quartz substrates with an acceptable quality, and to study the impacts of the amount of impurities on their physical characteristics.

2. Experimental section

The materials used in synthesizing the YIG films included Fe $(NO_3)_3{\cdot}9H_2O$, $Y(NO_3)_3{\cdot}6H_2O$, $Ce(NO_3)_3{\cdot}6H_2O$ and citric acid monohydrate that were provided by Merck Company, a German, with the purity of 99.9%. Furthermore, quartz was applied as the substrate. YIG and Ce:YIG precursor solutions were prepared through dissolving and mixing the required amounts of metal nitrates in the stoichiometric

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https://doi.org/10.1016/j.materresbull.2017.11.018
Received 18 April 2017; Received in revised form 4 November 2017; Accepted 9 November 2017
Available online 11 November 2017
0025-5408/

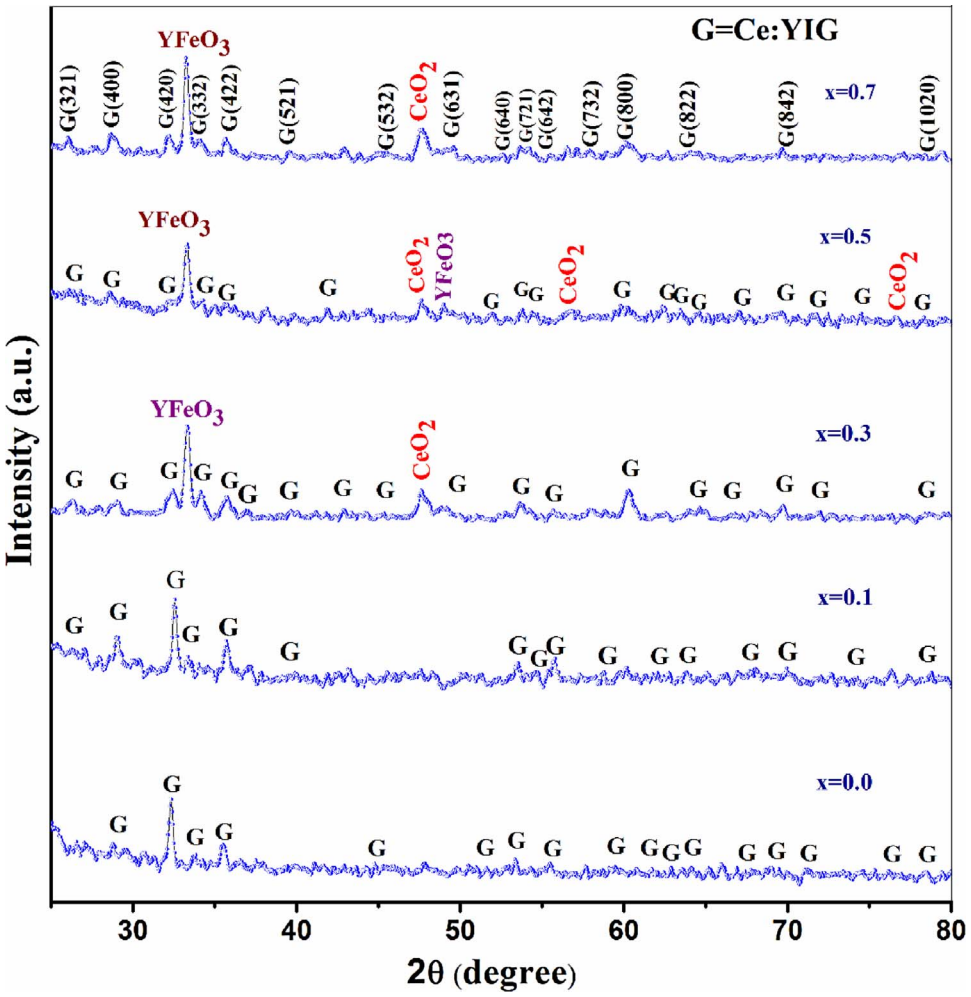

Fig. 1. XRD patterns of $Y_{3-x}Ce_xFe_5O_{12}$ thin films with Ce concentration (x) at 800 °C for 3 h.

Table 1
Crystallite sizes of samples with Ce concentration (x) from 0 to 0.7 treated at 800 °C.

Crystallite size (nm)	Concentration (x)
36	0.0
35	0.1
23	0.3
26	0.5
30	0.7

Table 2
Lattice parameter of samples with Ce concentration (x) from 0 to 0.7 treated at 800 °C.

Lattice parameter of YIG (Å)	Concentration (x)
12.26	0.0
12.28	0.1
12.29	0.3
12.38	0.5
12.44	0.7

ratio of $Y_{3-x}Ce_xFe_5O_{12}$ (where x = 0, 0.1, 0.3, 0.5, 0.7) in deionized water. Citric acid was then added to the prepared aqueous solution to chelate Y^{3+} and Fe^{3+} in the solution that was added to both solutions as the equal concentration of PVA. Afterward, NH_4OH was added in droplets to set pH to 2, and the resulting solution was heated at 80 °C for 2 h to prepare YIG and Ce:YIG gel. The YIG and Ce:YIG gel films were spin coated on the substrate with 3000 rpm at room temperature. The procedure continued with two-step pre-heating at 300 °C for 1 h and 500 °C for 5 min in the air. The as-deposited films were annealed at 800 °C in the air for 3 h. These processes, including spin coating, drying and pre-heating were repeated to obtain an appropriate thickness. The annealed films phase was identified using X-ray diffraction (XRD, D8 Advance X-ray diffractometer, Germany) using Cu k_α radiation (λ = 1.5405 Å). The films morphology was studied using atomic force microscopy (AFM, Multi-Mode Advanced, Ara Research Co., Iran) and scanning electron microscopy (SEM, VEGA\\TESCAN-LMU, Czech Republic). Finally, to measure the magneto-optical properties of the films, the samples were placed in a magnetic field, and the Faraday rotation hysteresis loops were then recorded (Chromex spectrometer and a halogen lamp as the light source). The magnetic properties of YIG and Ce:YIG nanoparticles were measured at room temperature with VSM (AGFM systems, Meghnatis Daghigh Kavir Co., Kashan, Iran).

3. Results and discussion

3.1. Structural study

Fig. 1 shows X-ray diffraction pattern of the films of $Y_{3-x}Ce_xFe_5O_{12}$ with different values of x (x = 0, 0.1, 0.3, 0.5, 0.7). All the samples were crystallized and conformed to the garnet phase with cubic crystal system (JCPDS Card No. 00-043-0507). In addition, the orthoferrite ($YFeO_3$) with orthorhombic crystal system (JSPDS card No. 00-039-1489) and CeO_2 with cubic crystal system (JSPDS card No. 00-034-0394) were identified in doped samples (x = 0.3, x = 0.5, 0.7). All samples were prepared after several spin coating and heating