Journal of Magnetics 11(3), 147-150 (2006)

Fabrication of Three-Dimensional Magnetophotonic Crystals: Opal Thin Films Filled with Bi:YIG

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(Received 11 September 2006)

We have fabricated three-dimensional magnetophotonic crystals based on *a*-SiO$_2$ opal films. Opal thin films grown on glass substrates were filled with bismuth substituted iron garnet (Bi:YIG). Scanning electron microscopy data, optical and magnetic properties of the synthesized samples confirm the presence of the Bi:YIG content in the opal lattice. It is shown that the samples exhibit the (111) stop band, and transmissivity of the three-dimensional magnetophotonic crystals is defined by both the film lattice and the Bi:YIG content.

Key words : magnetophotonic crystals, opal films, Bi:YIG

1. Introduction

Photonic crystals (PCs) [1] are one of the most attractive materials for future application in the optoelectronics, since the light flow can be effectively controlled by PCs. The unique applications based on PCs such as acute angle optical waveguides [2, 3], superprism [4], and magnetophotonic crystals [5, 6] allow to control light beam characteristics and could play leading role for realization of optical circuits [7].

Recently, we reported that one dimensional magnetophotonic crystals (1D MPCs) composed of periodic layers of dielectric materials and magnetic materials show large enhancement of Faraday rotation [6]. Experimental studies on fabrication, magnetic and optical properties of 3D MPCs based on bulk artificial opals were reported [8-11]. Note that 3D MPCs are considered as more effective for applications because the enhancement of Faraday rotation is expected to exist for any direction in crystal.

Artificial opal composed of close-packed dielectric *a*-SiO$_2$ spheres with diameters of submicron range is the well known representative of 3D PCs [12, 13]. A number of studies show that fabrication of the opaline structure using different methods (self sedimentation [14, 15], template-directed self-assembly [16, 17], vertical deposition [18-20]) is the effective and practical approach to create highly ordered 3D PCs and more complex structures.

The aim of this paper is to report an approach to fabricate 3D MPCs. The opaline thin films were used as matrixes in which the vacant space between *a*-SiO$_2$ spheres was filled with bismuth substituted iron garnet. We show that the fabricated samples have characteristic properties of both the related magnetic material and photonic crystal.

2. Experimental

Monodisperse colloidal *a*-SiO$_2$ spheres with a diameter of 260 nm were assembled on a glass substrate using the vertical deposition (VD) method to form an opaline film.

The surface of the glass substrate was etched by

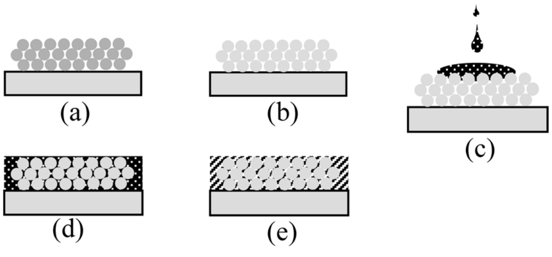

Fig. 1. Schematic outline of the experimental procedure that was used to fabricate 3D-MPCs. (a) Depositing opal film, (b) annealing opal film, (c) coating Bi:YIG precursor liquid, (d) drying, and (e) annealing to crystallize Bi:YIG.

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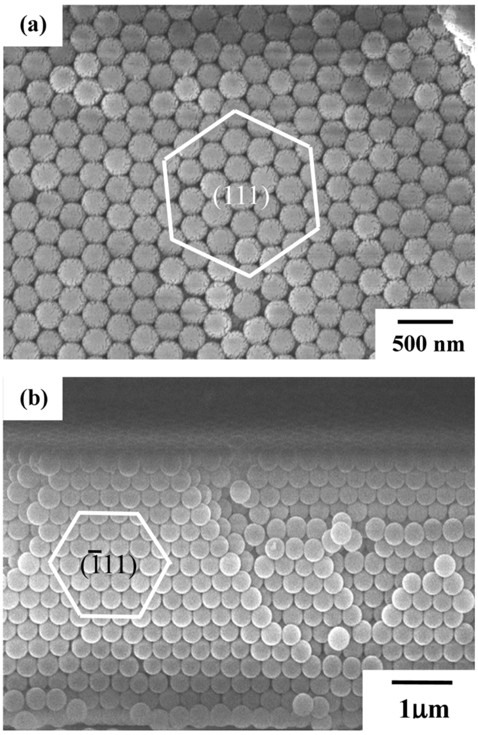

Fig. 2. SEM images of an opaline film: (a) the top view and (b) the cross section.

H_2SO_4:H_2O_2 in a concentration ratio of 3:1. The glass substrate having hydrophilic surface was soaked into the colloidal suspension of dispersed *a*-SiO_2 spheres, whose density was of 0.1 wt%. The colloidal suspension was kept in the atmosphere of 80 °C. After a time, while water is evaporated, spherical particles assembling on the surface of the glass substrate are arranged in the close-packed structure [21].

Figure 1 shows the schematic outline of the experimental procedure that was used to fabricate 3D-MPCs. Thus prepared films by VD method were annealed in the air at 750 °C to harden the film structure [Fig. 1(a) and (b)]. Precursor solution of the $Bi(NO_3)_3$–$5H_2O$, $Y(NO_3)_3$–$6H_2O$, $Fe(NO_3)_3$–$9H_2O$ salts and DMF solvent was infiltrated into the voids in opal lattice and permeated over wide area of the film, when using spin-coater [Fig. 1(c)]. After spin-coating, the infiltrated precursor liquid was dried in the air at 400 °C to evaporate the DMF solvent [Fig. 1(d)].

The process of infiltrating and drying was repeated several times. Finally, the sample was annealed in the air at 750 °C to crystallize the embedded salts.

The structure, magnetic properties, and transmission spectra of the films were evaluated using the field emission scanning electron microscope (FESEM, Jeol JSM-6700), vibrating sample magnetometer (VSM, Tamakawa) and spectrophotometer (Shimazu UV-3100PC).

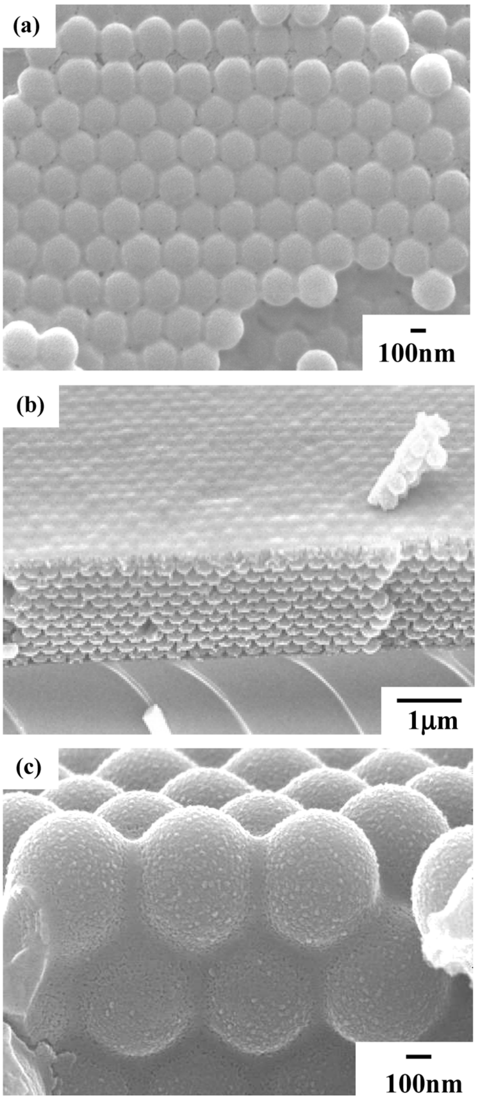

Fig. 3. SEM images of a 3D MPC: (a) the top view, (b) the cross section, and (c) the enlarged edge view showing the Bi:YIG content.

3. Results and Discussion

Figure 2 shows the top view and the cross section of an opal film. One can see a good arrangement of *a*-SiO_2 spheres, which results in close-packed lattice on a scale of several tenths of micrometers. The {111} hexagonal close-packed layers are fairly seen in both images.

FESEM images of the opaline film filled with Bi:YIG are presented in Fig. 3. It is found that all available space between *a*-SiO_2 spheres is occupied by Bi:YIG. It is worth mentioning that synthesis of silicates is possible due to side reactions. And also, some amount of non

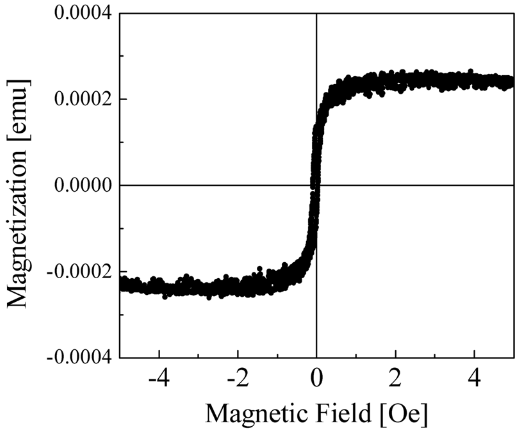

Fig. 4. VSM hysteresis loop of an opaline film filled with Bi:YIG.

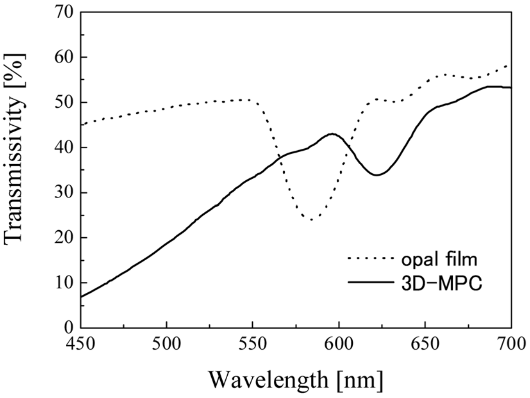

Fig. 5. Transmittance spectra of an opaline film and a film filled with Bi:YIG.

reacted nitrates possibly remains in the synthesized sample.

Magnetization curve of the sample under study (Fig. 4) shows typical behavior that corresponds to polycrystalline Bi:YIG. Transmission spectra of the as-grown initial opaline film and this film filled with Bi:YIG are plotted in Fig. 5. These spectra were taken at normal incidence onto the films. For the initial film, the (111) stop band is seen at about 580 nm. As for the film filled with Bi:YIG, the spectral position of (111) stop band is of 620 nm. It is evident that the shift of the (111) stop band is affected by replacing air in the film interstitial space with Bi:YIG. The transformation of transmission spectrum and its shape correlates well with optical properties of Bi:YIG, which also leads to absorption in short wavelength range.

4. Conclusions

The crystalline structure of synthesized 3D MPCs was studied by FESEM. The samples are planar close-packed crystals of monodisperse a-SiO$_2$ spheres, having high-quality fcc lattice filled with Bi:YIG. VSM data show that the samples exhibit good magnetic properties which are characteristic for Bi:YIG. The (111) stop band is observed in transmission spectra. These results provide convincing evidence that the fabricated samples based on opaline thin films are representatives of 3D MPCs.

Acknowledgements

This study has been financially supported in pat by a Grant-in-Aid for Scientific Research (S) (#17106004) from the Ministry of Education, Culture, Sports, Science and Technology.

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