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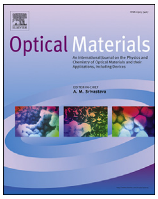

Optimization of one-dimensional photonic crystals with double layer magneto-active defect

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ABSTRACT

Success of practical implementation of one-dimensional photonic crystals with magneto-active layers is evaluated in high values of magneto-optical (MO) quality factor Q and figure of merit F. The article relates to optimization of one-dimensional photonic crystals with double layer magneto-active (MA) defect of composition $Bi_{1.0}Y_{0.5}Gd_{1.5}Fe_{4.2}Al_{0.8}O_{12}/Bi_{2.8}Y_{0.2}Fe_5O_{12}$ located between the nongarnet dielectric Bragg mirrors. The structure design was performed by changing the number of layer pairs in Bragg mirrors m and the optical thickness of MA defect l_M to achieve high values of MO characteristics. Theoretical predictions were confirmed by experimental investigation of eight synthesized configurations with $m = 4$ and $m = 7$. We have demonstrated the maximum $Q = 15.1$ deg and $F = 7.5\%$ at 624 nm for structure with $m = 4$ and $l_M = (2.5 \cdot \lambda_0/2)$, where $\lambda_0 = 690$ nm is the photonic band gap center. Configurations with $m = 3$ can also provide their effectiveness in realization. Maximum MO activity was achieved for configurations with $m = 7$. The structures with $l_M = (0.8 \cdot \lambda_0/2)$ and $l_M = (2.5 \cdot \lambda_0/2)$ showed respectively the specific Faraday rotation −113 deg/μm (that exceeds in 62 times the Faraday rotation of MA double layer film) at 654 nm and absolute Faraday rotation −20.6 deg at 626 nm.

1. Introduction

Microcavity one-dimensional photonic crystals with transparent magneto-active (MA) defect are the first structures of magnetophotonic crystals (MPCs) proposed to control optical response by magneto-optical (MO) effects [1–7]. Special attention is still paid to Faraday and Kerr effects allowing the modulation of intensity, phase and polarization of optical waves by magnetic fields. Moreover, a MPC are a photonic crystal that has photonic band gap (PBG) at a fixed wavelength range and suppressed the propagation of light in one, two or three directions (respectively one-, two- and three-dimensional MPC). Among all possible MA materials [8–12] a bismuth-substituted yttrium iron garnet (Bi:YIG) provides the best relation between the high MO activity and transparency for visible and near infrared range. Microcavity one-dimensional magnetophotonic crystals (MC-1D-MPCs) hold the most promise for optoelectronics applications due to significant enhancement of MO effects in comparison to a single Bi:YIG film for design wavelength. It will be possible to create new devices based on the developed structures for information technology, magnetooptics, photonics, spintronics and microsensors. Magnetic and electric fields are used to control the rotation angle of light polarization of MC-1D-MPCs [13–18]. Spatial light modulators of a high switching speed (several GHz) [14,15], models of individual pixels for MO display with narrow control fields [16] and spatial light phase modulators [17,18], optical insulators [2,19], magnetic field sensors [7,20] etc were created on the basis of 1D-MPCs with Bi:YIG.

Properties of MC-1D-MPCs are defined by the parameters of the constituting layers. The spectral position and width of the photonic band gap are determined by the thickness and optical contrast of nonmagnetic layers of the photonic crystal (Bragg mirrors of microcavity). MA defect layer causes the MO properties of the structure and creates a transmission resonance at the specific wavelength within the PBG. As it was shown in the works [5,21], changing the thickness of magnetic layer controls the defect mode position relative to the PBG center. Moreover, some configurations of structure with one defect layer have two possible resonance

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modes within a PBG.

One of the main problems of designing of 1D-MPCs for various applications is to increase the MO quality factor and determine the optimum between the rotation angle of polarization plane and the intensity of the transmitted or reflected light. Possible ways to solve these problems are to use of dual cavity [7,22,23], conjugated MPC multiple heterojunctions [24] or all-garnet [25,26] structures. However, fabrication of such complex 1D-MPCs is difficult and connected with the application of expensive materials and technologies. Some authors consider the quasi-periodic and disorder one-dimensional photonic crystals in structure design [27].

In our previous works [21,28–31] MC-1D-MPCs $[TiO_2/SiO_2]^m/M/[SiO_2/TiO_2]^m$ were proposed, where M is a double layer ($Bi_{1.0}Y_{0.5}Gd_{1.5}Fe_{4.2}Al_{0.8}O_{12}/Bi_{2.8}Y_{0.2}Fe_5O_{12}$ or $Bi_{1.0}Y_{0.5}Gd_{1.5}Fe_{4.2}Al_{0.8}O_{12}/Bi_{1.5}Gd_{1.5}Fe_{4.5}Al_{0.5}O_{12}$) MA defect and m is the repetition number of layer pairs in Bragg mirrors (BM). The reason for the use of a double MA layer is the technological difficulties of deposition and crystallization of garnet films with a high Bi content on SiO_2 layers. Therefore, the buffer-layer with a lower Bi content (less than 1 at./f.u.) was deposited on SiO_2 and after its crystallization the main MA layer with a higher Bi content (more than 1.5 at./f.u.) was deposited. Due to the proposed method of crystallization new record values of the Faraday rotation (FR) angle of the microcavity structures in the optical wavelength range were achieved. This work focuses on the optimization of these structures depending on the thickness of double layer MA defect and the number of layer pairs in BM. We also present a detailed comparison between experimental and model MO quality factors, optical and FR spectra of MC-1D-MPCs with double layer MA defect of different thickness. New record characteristic values for synthesized structures were obtained.

2. Experimental

To consider the MO efficiency of MC-1D-MPCs with double layer MA defect, we have modeled, fabricated and examined the structures with general formula

$$KU-1\ /\ [TiO_2\ /\ SiO_2]^m\ /\ M1\ /\ M2\ /\ [SiO_2\ /\ TiO_2]^m \quad (1)$$

Here KU-1 is a quartz optical glass, m is the repetition number of BM layer pairs, M1 is the buffer MA layer of composition $Bi_{1.0}Y_{0.5}Gd_{1.5}Fe_{4.2}Al_{0.8}O_{12}$ and M2 is the main MA layer of composition $Bi_{2.8}Y_{0.2}Fe_5O_{12}$. According to our previous experiments [21,28–31], this composition of double layer has provided a significant increase of the FR angle and MO quality factor of the cavity structures. To illustrate the structure (1), the two experimentally implemented configurations with four and seven layer pairs in BM are shown in Fig. 1. The parameters of MC-1D-MPCs have been optimized using the transfer matrix method [24,32]. Among all possible configurations these structures have the expected high MO characteristics. We discuss in detail the results of simulation and the experimental achievements in Section 3.

The fabrication process of the whole structure included the following three stages:

i) the synthesis of the bottom BM on the substrate by electron beam evaporation;
ii) the formation of the double layer MA film on the bottom BM by reactive ion beam sputtering and annealing;
iii) the synthesis of the top BM on crystallized double layer MA film by the technique used for the growth of the first BM.

The BMs with the same repetition number of layer pairs were fabricated in one cycle. TiO_2 and SiO_2 layers were deposited using UVN 2000 setup and in situ thickness control. The temperature of the substrate during deposition was 400 °C.

We fabricated the double layer garnet films of each MC-1D-MPC separately. The targets of respective compositions have been prepared by conventional ceramic technique [33–35]. URM 3–279.014 setup with ion-beam Kholodok-1 source was used for reactive ion beam sputtering. It should be noted that all Bi:YIG films in

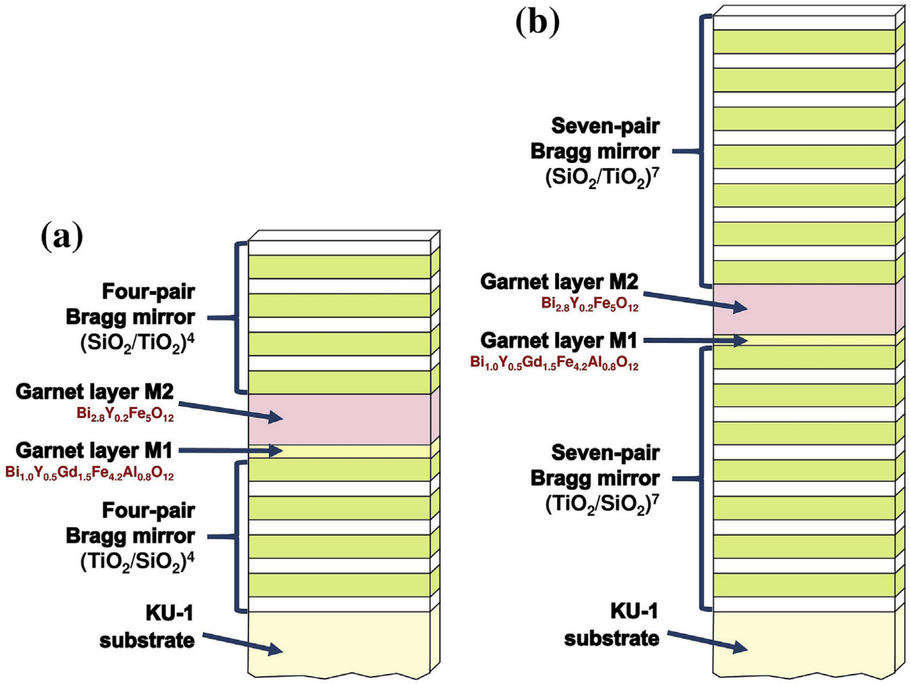

Fig. 1. Schematic diagram of investigated MC-1D-MPCs with double layer MA defect. The two experimentally implemented configurations with four (a) and seven (b) layer pairs in BM are shown. The thickness of double layer MA defect and the repetition number of BM layer pairs have varied in the simulation and experiment.