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ARTICLE

Magneto-Photonic Crystal Micro-Cavities in One Dimensional Photonic Crystals Fabricated by Sol Gel Process

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In this paper, we present a study on the photonic band gap of one-dimensional photonic crystals made by SiO_2/ZrO_2 or SiO_2/TiO_2 doped with magnetic nanoparticles using the sol–gel process. The studied structure consists of a multilayer of SiO_2/ZrO_2 or SiO_2/TiO_2 and air gap with lattice constant $a = 0.70$ μm. The structure is characterized by a background refractive index of 1.51. We started by introducing one defect at different locations, then we followed by two and three defects at different locations. The results obtained show clearly that these magnetic micro-cavities may serve as a fundamental structure in a variety of ultra-compact magneto photonic devices such as optical isolators and modulators in the future.

Keywords: Magneto Photonic, One-Dimensional Magneto-Photonic Crystals (1D MPCs), Photonic Bandgap, Micro-Cavity, Rigorous Coupled Wave Analysis (RCWA).

1. INTRODUCTION

In recent years, there had been a lot of interest magneto-photonic crystals made by sol–gel process and their potential application [1–5]. The integration of magneto-optical devices, such as isolators and circulators, remains a major challenge, due to the difficulties encountered in integrating magneto-optical materials with conventional integrated technologies. Yttrium Iron Garnet (YIG), widely used in bulk optical isolators, requires an annealing temperature of up to 700 °C to be magneto-active.

To overcome this problem, a new approach based on a magneto-optical composite matrix compatible with a glass substrate [6]. The films made by a soft chemical sol–gel process showed promising potentialities illustrated by a specific Faraday rotation of 200°/cm and an index of 1.51 (@1550 nm) [7–12]. In this way, many efforts have been made to obtain such materials compatible with the semiconductor substrate [13, 14], but few concern the glass substrate. Unlike conventional techniques, high temperature is not required to achieve magnetic behavior. The purpose of this study is to provide a framework, is to describe the latest improvements of the approach used to develop magneto-optical structures with a wavelength of the order of (1550 nm). The advantage of this technique is the total compatibility of the sol–gel coating with the conventional integrated treatment technologies and in particular the technology on the ion exchange glass [15–18], it is considered a versatile, flexible and inexpensive technique, useful in the realization of integrated photonic systems [19–24].

In this paper, we study the effect of position and number of defects on the bandgap of 1D MPCs made by SiO_2/ZrO_2 or SiO_2/TiO_2 doped with magnetic nanoparticles using sol–gel process in different geometrical parameter configurations. We started by introducing a defect at different locations, then we followed by two defects and to finish three has variable locations. The results obtained give the designs of magneto photonic crystal devices.

2. STRUCTURE DESIGN

The 1D MPCs structure is very favored for studying the properties of photonic bandgaps, it gives a large opening bandgap and it is a good compromise, especially for high slaughter factors and the incidence angle [25, 26]. The MPCs 1D studied and analyzed in the present work, consists of a multilayer structure in periodic lattice

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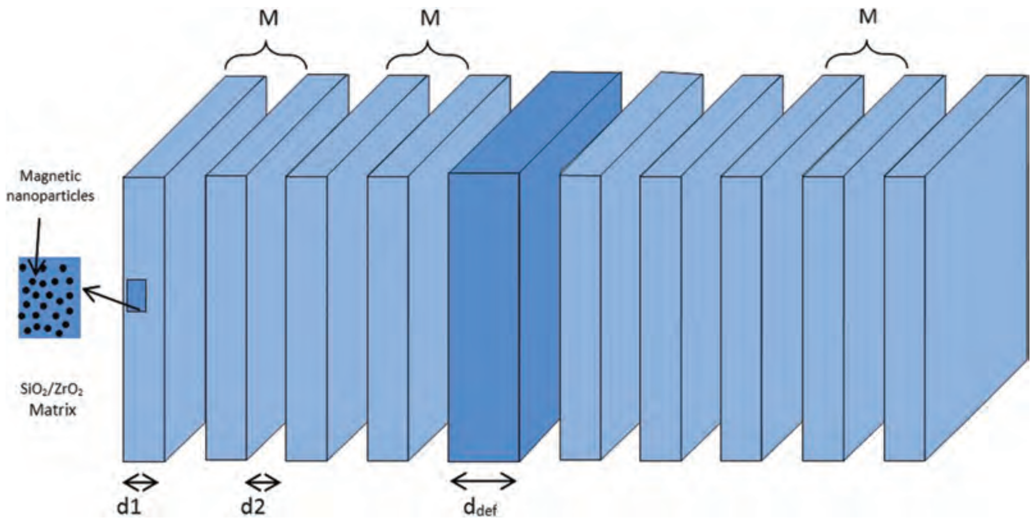

Fig. 1. Structure of 1D photonic crystal made with magneto optic layers with one defect.

SiO_2/ZrO_2 or SiO_2/TiO_2 with air gaps, of period $a = 0.70$ μm. The structure is characterized by a background index of 1.51 to 1.57 and an air-to-air (refractive index $= 1$). The thickness of the layers of material is d_1 and the gap width is d_2 with $(a = d_1 + d_2)$. Figure 1 illustrates the 1D MPCs structure used for the study, it is characterized by the introduction of a defect width $(d_{\text{def}} = 2 * d_1)$ within the structure.

3. RESULTS AND DISCUSSION

In order to study the influence of the material on the photonic bandgap 1D, we introduced a defect to different locations, then two defects and finally three. The simulation is carried out under the Rigorous Coupled Wave Analysis (RCWA) (RSoft Design Group, DiffractMode, Inc. 200 Executive Blvd. Ossining, NY 10562). Firstly, before any simulation, we are fixed geometrical parameters (number of layers 10 and the period of lattice $a = 0.70$ μm, $a = d_1 + d_2$).

In the representation of the spectral transmission curves of Figure 2, we have introduced a defect at different positions and we have observed a resonance of the value of the transmittance in the near infrared region (1500 nm to 1950 nm). The results show that the transmittance

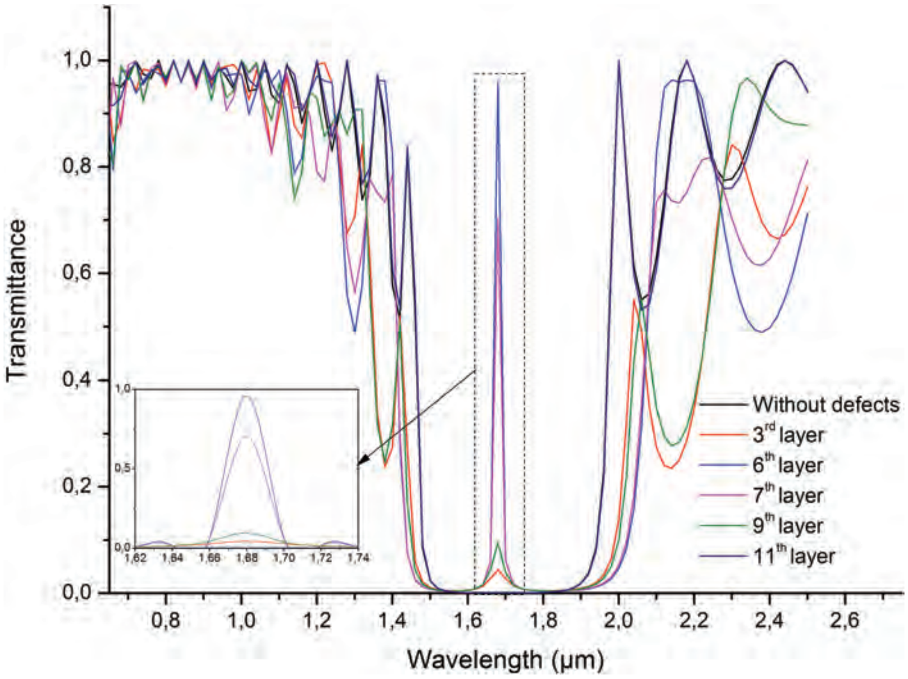

Fig. 2. Transmittance versus wavelength of 1D photonic crystal made with magneto optic layers with one defect.

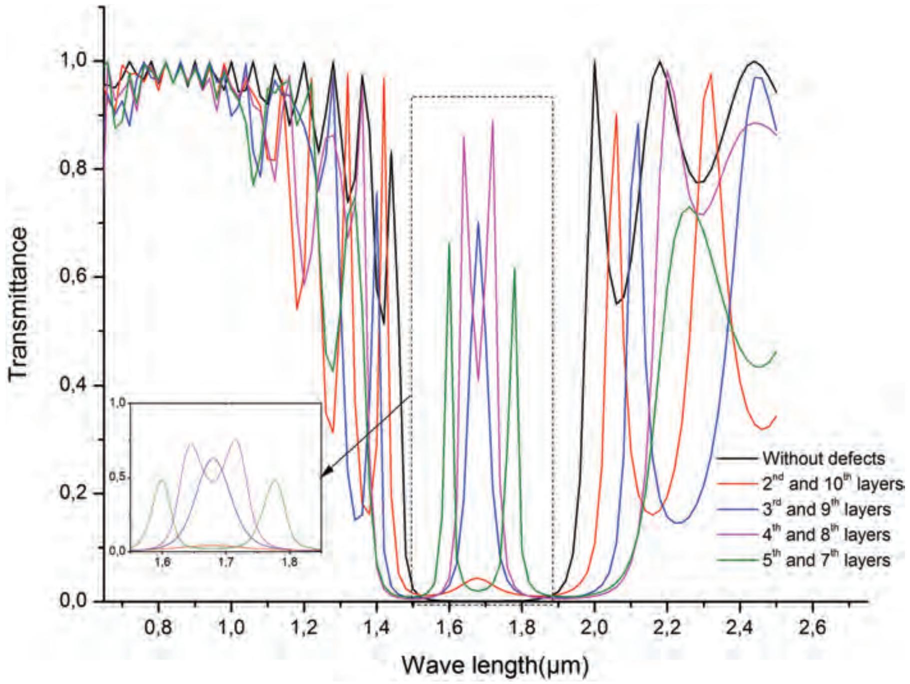

Fig. 3. Transmittance versus wavelength of 1D photonic crystal made with magneto optic layers with two defects.

varies according to the location of the defect from 0 to 0.96 [27].

Figure 2 shows the spectral response of the micro-cavity formed by defecting one layer obtained with the RCWA method of the impulse response for values of refractive index 1.51. The spectrum calculated by TM polarization can be observed one cavity mode for different defects at different positions. From the simulated results, we observe that the best resonance value of the transmittance is obtained for the defect located in the center of the structure, namely at the 6th layer.

The results obtained for this case show us an improved transmittance compared to the results obtained in the different works carried out [28–31].

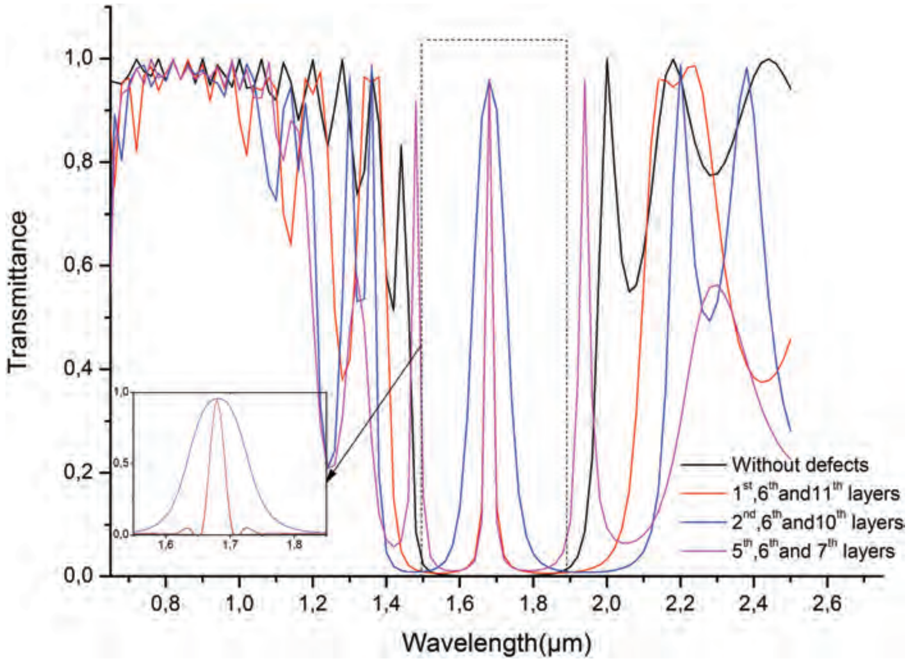

Fig. 4. Transmittance versus wavelength of 1D photonic crystal made with magneto optic layers with three defects.

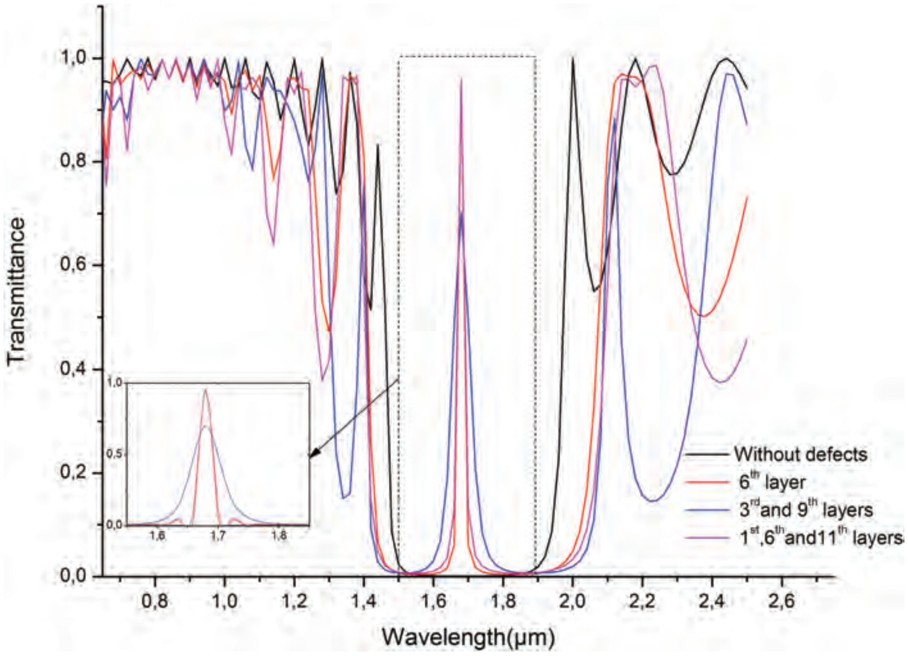

Fig. 5. Comparisons of the three structures configurations.

In the following, we study the optical properties of the behavior of one dimensional photonic bandgap when two or three defects are inserted at different locations in the structure.

A resonance of the value of the transmittance is observed in the bandgap which obtained without defects. The value of transmittance is strongly influenced by the presence of the defects and their locations. From the results obtained, we observe that the most regular value is obtained for the defects located in the third layer and ninth layer.

As seen, the structures have not only a high transmittance, but also provide the flat top resonance peaks. Therefore, these matrices doped with MPCs magnetic nanoparticles based on be used in integrated MOs, since the operating bandwidth is one of the most important functional characteristics of MPC-based devices [28–31]. Devices built on narrowband CPM would face instability due to frequency fluctuations; a flat-topped resonance is necessary in practice.

For different positions of three defects, we show in Figure 4 the simulation results of the resonant wavelength which hardly changes dependence on position of defects.

For a multi-cavity structure a significant improvement of the transmittance is obtained for a variable localization of the defects which is in adequacy with the work previously carried out [30, 31].

Now, we make a comparison of the three structures configurations used with the best values of the transmittance resonance obtained.

For a single defect, the best value corresponds to the 6th layer, then for two defects the best value is obtained for the 3rd and the 9th layer. For three defects, the best value is obtained for the 1st, the 6th and the 11th layer like us mentioned in Figure 5. It is clear that the three configurations give good results however the first configuration (one defect at the 6th layer) remains the one that gives the best value of the resonance. Therefore, these SiO_2/ZrO_2 matrix doped with $CoFe_2O_4$ magnetic nanoparticles-based MPCs can be used in integrated MO devices such as filters and isolators.

4. CONCLUSION

This work presents a new design for magneto-photonic crystal platform cavity. We have utilized a new kind of artificial magneto optical materials (SiO_2/ZrO_2 or SiO_2/TiO_2 matrix doped with magnetic nanoparticles) in magneto-photonic crystals as a magnetic defect layer, characterized by low refractive index material 1.51. In addition, we have studied the effect of the defects at different locations on the resonance of the value of the transmittance of micro-cavities in a one dimensional magneto-photonic crystal. The resonance of the value of the transmittance in the bandgap is sensitive to the locations and number of photonic crystal cavity. Hence, we have also investigated the influence of defects at different locations on the optical response of transmission-type one-dimensional MPCs.

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