Highly Sensitive Photonic Crystal Gamma Ray Dosimeter

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Abstract –**Highly sensitive 2D Si photonic crystal (PhC) sensor is proposed and analyzed for the detection of gamma-ray doses in the visible light region. The suggested PhC has a cavity infiltrated by poly-vinyl alcohol (PVA) polymer doped with crystal violet and carbol fuchsine dyes. The optimization of the geometrical parameters results in high gamma ray doses sensitivity of $150\ nm/RIU$ and for the transverse electric (TE) polarized mode. The analysis is carried out using full-vectorial finite-element method and plane wave expansion method.**

Index Terms— Photonic Crystal, Photonic crystal sensor, Gamma ray dosimeter, Polymer based photonic crystal sensor, Photonic dosimetry.

Photonic crystals (PhCs) have attracted great attention nowadays due to their different possible applications including photonic crystal fibers[1-4],sensors[5-10], multiplexers[11-15], logic gates[16-19], and polarization rotator[20-22].In this context, Rozaila *et al.* have studied the thermoluminescence (TL) properties of Ge and B doped collapsed photonic crystal fibers (PCFs) for X-ray low doses measurements[23]. It has been shown that Ge and B doped PCF is sensitive 8 times greater than the traditional thermoluminescence dosimeter.[23] Additionally, Mignani *et al.* have demonstrated an extrinsic optical fiber sensor for gamma-ray detection using Gafchromic film.[24] Further Ghomeishi *et al.* have studied the radiation sensitivity and TL response of three types of Ge-doped optical fibers for radiation dosimetry purposes based on the thermoluminescence technique for doses range from 0.5 to 8 Gy. [25] They concluded that the TL characteristics differ from type to other while all optical fibers have been fabricated from the same Ge-doped preform. Furthermore, Cia *et al.* have investigated the effect of gamma-ray radiation on the radiation-induced attenuation (RIA) of pure silica core PCF at wavelength 1550 nm. The RIA at λ= 1550 nm has effectively declined from 27.7 dB/km to 3.0 dB/km which offers great advantages over conventional fibers.[26]

In this paper, highly sensitive 2D PhC sensor is introduced for radiation dosimetry detection. The 2D PhC has a cavity ifiltrated by Poly Vinyl Alcohol (PVA) doped with crystal violet and carbol fuchsine dyes. The suggested design has one input port for the incident light and one output port for the transmitted light. The sensing technique is based on the radiation-induced refractive index change of the PVA doped dyes for monitoring the high gamma-ray doses in the range of 0 to 70 Gy. The suggested design achieves high sensitivity of 150 nm/RIU for the TE polarized mode. Additionally, high linear performance is obtained for the proposed design.

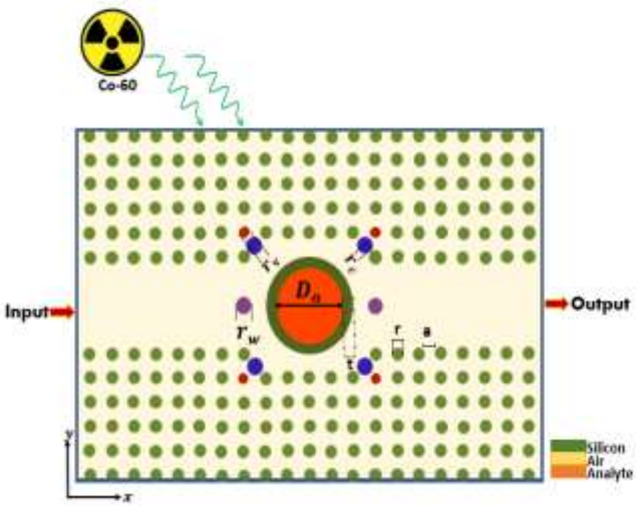

Fig. 1: Top view of the suggested 2D PhC gamma ray dosimeter.

A cross section of the suggested 2D PhC sensor is shown in Fig.1 with 21×15 silicon (Si) rods immersed in air background. The Si rod has radius $r = 45\ nm$ with lattice constant $a = 200\ nm$. The dielectric constant of Si rods is equal to 3.46. Further, the gamma ray doses dependent refractive indices can be determined using the numerical fitting of the data that reported by Antar.[27]

The numerical study of the proposed biosensor is performed based on full vectorial finite element method (FVFEM). The computational domain is discretized using non-uniform meshing where the maximum element size, minimum element size, growth rate, and curvature factor are equal to 0.03 μm, 1.2× $10^{-4}\ \mu m$, 1.25 and 0.25, respectively. The numerical results are obtained using total number of elements of 133266. The TE mode has a photonic bandgap of (PBG) over the wavelength range from 519 nm –758 nm. However, the TM mode has no complete PBG as shown in Fig .2.

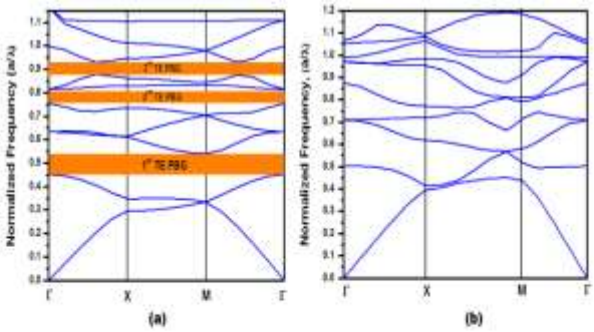

Fig. 2:The band structure of the proposed 2D square lattice PhC, for the (a) TE mode, and (b) TM mode.

The wavelength sensitivity of the proposed design can be calculated according to the following relation:[28]

$$S_{\lambda}(\lambda) = \frac{\partial \lambda_{peak}(D)}{\partial n} \quad (nm/RIU) \qquad (1)$$

where λ_{peak} is the wavelength corresponding to the resonance peak in the transmission spectra.

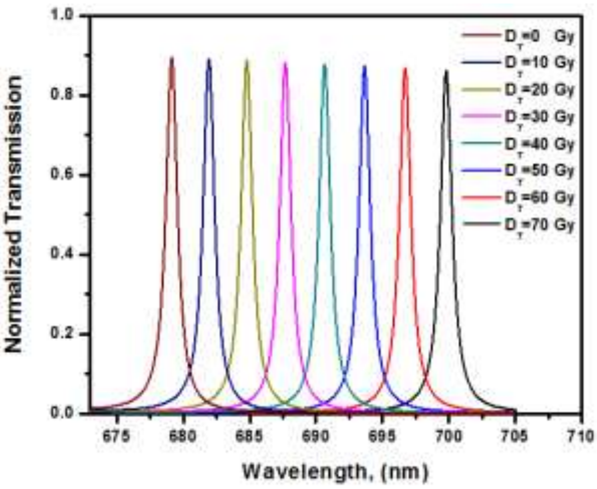

Fig. 3: The shift of the resonant wavelength as a function of gamma ray doses.

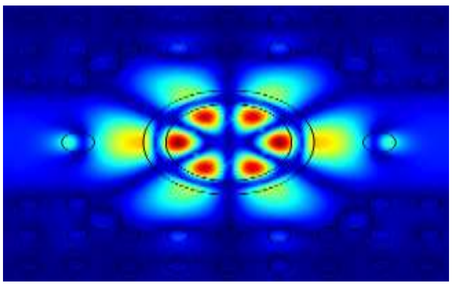

Fig. 4: Steady state electric field distribution through the suggested design at gmma ray dose = 70 Gy.

In order to optimize the suggested sensor sensitivity, the effect of the geometrical parameters on the sensitivity is performed. Figure 3 shows the different normalized transmission as a function of the gamma ray doses. It may be seen that the resonance frequency is sensitive to the gamma ray doses. At the optimized geometrical parameters, high wavelength sensitivity of 150 nm/RIU is achieved for the TE polarized mode. This is due to the well confined of the mode in the cavity under study at the resonance frequency as shown in Fig. 4. The steady state electric field of the resonance wavelength at gamma ray dose of 70 Gy at the optimized parameters is shown in Fig .4. Therefroe, the resonance frequency is sensitive to the gamma ray dose variation which results in high sensor sensitivity.

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