Design and Simulation of Y-shaaped Waveguide Based on Silicon 2D Photonic Crystal for Photonic Integrated Circuits

Trideep Deb[1,*], Puspa Devi Pukhrambam[1], *IEEE Senior Member* and Karthik Nasani[1]

1. Department of Electronics and Communication Engineering, National Institute of Technology Silchar, Assam, India 788010
Email id: trideep23_rs@ece.nits.ac.in

Abstract— **This research proposed Y-shaped waveguide with 17×19 periodic Si rod in rectangular lattice within an air background. PWE, FDTD predicts the band gap and light propagation characteristics. For optimal Si rod radius=0.24µm at T=310 K, maximum sensitivity of 0.128 mW/K and Quality factor of 43.2 are attained.**

***Keywords— photonic crystal waveguide, FDTD, photonic bandgap, amplifier, sensitivity*.**

I. INTRODUCTION

Photonic crystals (PhC) can be described as structures having periodic variations in the refractive index. The foundation of the PhC structure was laid independently by Yablonovitch [1] and John [2] in 1987. PhC structures gained attention owing to its crucial property known as photonic bandgap (PBG), where the propagation of electromagnetic waves of specific frequency range is forbidden. With the introduction of defect in the periodicity, the signal prohibition within the PBG can be lifted as this leads to localized photonic states in the gap. By creating different shapes of defect layer in the PhC structure, numerous novel applications can be envisaged. For example, by introducing point defect, the PhC structure acts as a micro cavity, whereas with the inclusion of line defect and planar defect, the PhC structure behaves as waveguide and perfect mirror respectively. .

A. Rostami et al. [3] designed a Y-shaped defect on a 2D PhC for a 4-channel wavelength division de-multiplexing application, achieving high-quality factor, efficiency, and extremely low crosstalk, ideal for communication applications. Karuna et al. [4] investigated the impact of various geometrical parameters, such as rod radius and lattice constant, on the photonic bandgap (PBG) characteristics. They observed that increasing the rod radius widens the PBG, while a higher lattice constant reduces its width.

In this study, a Y-shaped photonic crystal waveguide structure is proposed, which is analysed for power amplifier and temperature sensing applications. The novelty of this work lies with the investigation of the output power at different radius of the circular rods and at different temperatures.The proposed design bestows improved optical confinement, and high sensitivity, so it can be an apt candidate for applications in photonic integrated circuits.

II. STRUCTURE ANALYSIS AND MATHEMATICAL MODELLING

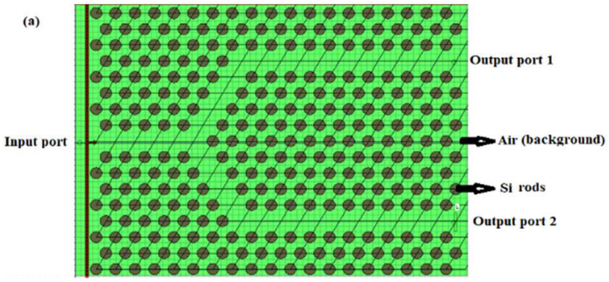

Fig. 1 Schematic of the proposed Y-shaped PhCW

The The proposed PhC-based Y-shaped waveguide (PhCW) is configured on a rectangular slab, illustrated in Fig. 1. It comprises a triangular lattice pattern of 17x19 Si rods embedded in an air background. The waveguide is formed by creating a defect region along the Y-shape, achieved by removing the air holes. We set the radius of the air holes (r) as 0.24 µm and the lattice constant (a) as 1 µm. The slab thickness is 0.144 µm. A light signal with a wavelength of 1.55 µm is directed onto the structure, and field intensities are recorded at the input and output ports of the Y-shaped defect structure.

To investigate the modal characteristics of the proposed structure, we employ the computational techniques like PWE and FDTD. In particular, the band gap characteristic is studied by using PWE technique, whereas the FDTD method is used to study the field components at the input and output ports of the structure.

III. RESULTS AND DISCUSSIONS

The Y-shaped photonic crystal waveguide structure is simulated in optiFDTD software platform, which employs FDTD computational technique to solve the Maxwell equations.Fig.2 illustrates the propagation of electromagnetic signal along the Y-shaped defect area. The signal is applied through the input port, whereas the output field intensity and power are measured at the output ports 1 and 2. From fig. 2, it is perceived that light is confined only in the defect area, which is primarily due to the band gap effect.

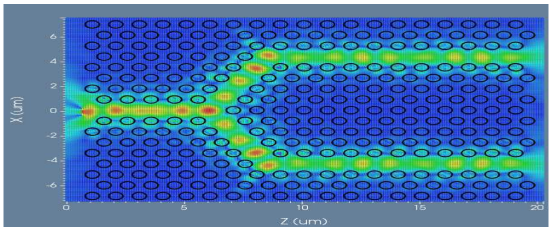

Fig. 2 Propagation of electromagnetic waves along the Y-shaped PhCW

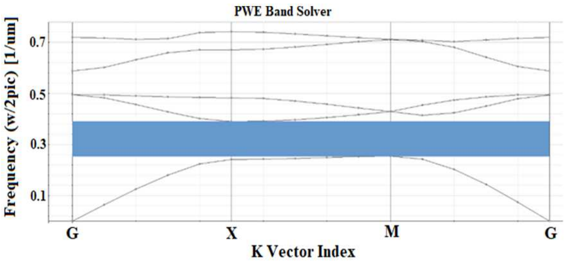

Fig. 3 Analysis of band gap in the proposed structure

Fig. 3 demonstrates the band diagram of the designed structure, which is obtained through PWE technique. The range of band gap (i.e. reflected wavelength) is highlighted with blue colour in the figure. It is calculated that the wavelength range from 0.6129 µm to 0.9382 µm is completely reflected by the structure for the TE mode.

We studied the proposed Y-shaped PhCW for two notable applications i.e. power amplifier and temperature sensor. We varied the radius of the Si rods from 0.24 µm to 0.29 µm, and the temperature in the range 300 K to 330 K. We observed that the proposed structure bestows maximum power efficiency of 3.32%, 5.44%, 5.49%, 2.36%, 5.66%, and 2.95% for r=0.24 µm, r=0.25 µm, r=0.26 µm, r=0.27 µm, r=0.28 µm, and r=0.29 µm respectively. So, it is clear that with the above specified power efficiency, the proposed structure can be a suitable candidate as a power amplifier in light wave circuits.

Fig. 5 demonstrates the normalized transmission spectrum of the proposed structure for different temperature values at r=0.24 µm. The definite shift in the spectrum with respect to temperature makes the structure suitable for temperature sensing applications. We evaluated the temperature sensitivity at different temperatures by taking T=300K as the reference. Basically, sensitivity is computed as the ratio of change in the output power to the change in temperature. Sensitivity is analysed at different radius of the circular air holes, which is shown in fig. 6. Apart from this, we calculated the quality factor (Q), Quality factor is the measure of the accuracy with which the change in temperature can be accurately detected. It is noticed that the maximum Q of 43.2 is obtained at r=0.24 µm and T=310 K.

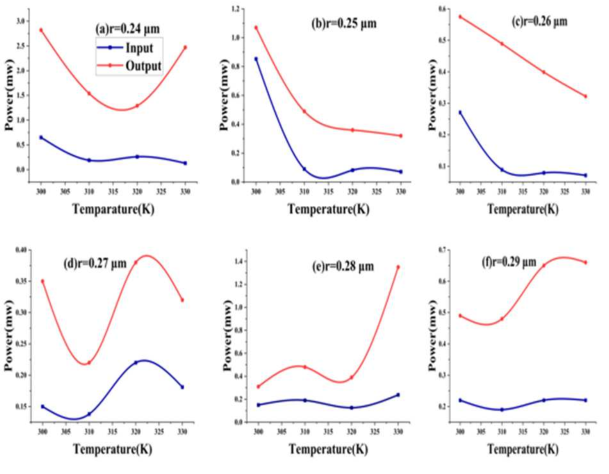

Fig. 4. Input and output power of the waveguide at different temperatures

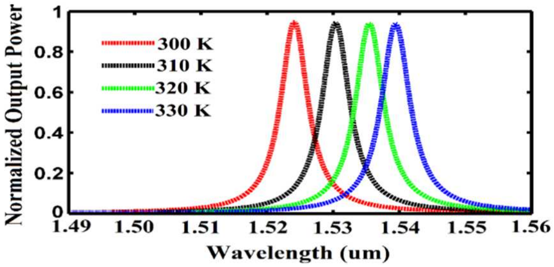

Fig. 5. Normalized transmission spectra for different temperatures

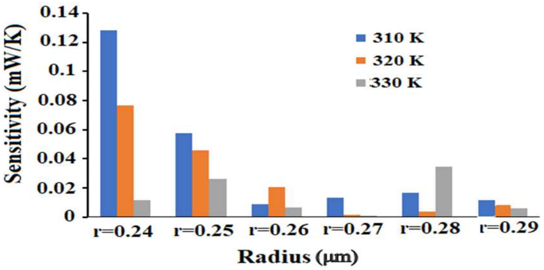

Fig. 6: Analysis of sensitivity at different values of 'r'

IV. CONCLUSIONS

In conclusion, a Y-shaped PhCW is designed and evaluated using numerical modelling in OptiFDTD. Computational techniques like PWE and FDTD are employed to envision key characteristics like photonic band gap and transmission spectrum. We observed the power efficiency at different Si rods radius. The structure offers noteworthy sensitivity of 0.128 mW/K, high Q factor of 43.2, high transmission efficiency of over 90%, and compactness.

ACKNOWLEDGEMENTS

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