Investigation of optical amplification action in dielectric photonic crystals cavity based structure

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***Abstract*—In this paper, the 2D Photonic Crystals (PhCs) cavity-based structures are studied for their possible usage in optical amplification action in the near-infrared (NIR) spectral range. The spectral characteristics are investigated by varying the position and the size of the optical cavity in the PhC structure. Moreover, the optical amplification action is studied using two optical signal-based approach, i.e., a data signal and a control signal. The data signal is amplified in presence of a control signal depending on the position and size of the optical cavity. The numerical design and simulations are performed in open-source software based on the Finite Difference Time Domain (FDTD) technique. In the end, the results are concluded and an idea is set for the design of the optical amplification, optical switching, and filters.**

Keywords— Optical amplification, Photonic Crystal Cavity, Guided Mode Resonance, Finite-difference Time-domain.

1. INTRODUCTION

For decades the scientific research has been focused on semiconductor electronics to fulfill the technological needs of the mankind. However, as the modern-day technology is advancing at a fast pace, the semiconductor industry is reaching its breaking point in terms of processing speed, power dissipation and computational capacity. The crucial instrument of the industry *"Transistor"* and its counting is increasing day by day in the devices according to Moore's law: to make it more reliable, fast, and credible. But with the same phase, the cost and losses (in the form of the heat) are increasing at the same rate. Hence, the time will be near, where there could be no alternative but to divert from this technology. Henceforth, a question is enquired, as what will be the arrangement that will overthrow the developed semiconductor technology and outperform it. The answer from many points of view could be *Optical technology*, which in turn is in its initial phases of the research. The alternate to the electron's skill, the exploration of photons is well studied and has seen a peak in the last two decades both from the sight of researchers and commercial silicon industries [1]. The optical structure will be dependent upon the light, its manipulations, and control. Therefore, such devices and themes must be designed to attain the working credibility corresponding to optical amplification. Among such arrangements, the Photonic Crystals (PhCs), are the capable structures of controlling the light at wavelength scale and to perform optical switching [2-3].

2. METHODOLOGY

The design of the proposed structures is investigated using the Finite Difference Time Domain (FDTD) approach using the open-source MIT Electromagnetic Equation Propagation (MEEP) software [4]. The proposed structure shown in Fig. 1 represents the cross-sectional view of the simulation domain with an optical membrane with PhC holes in it. A lattice constant of a = 1 μm is chosen in order to design the PhC structure to operate in NIR range, using user-defined number of frequencies n_f=550. Similarly, to produce smooth, recognizable and best fit results of the structures, the smoothing factor (grid resolution) is used, equal to 1/resolution. Therefore, the resolution taken for this research is 20, equaling the smoothing factor to 0.05, which is smaller than wavelength/30 equaling to 0.052. Moreover, a 2D simulation domain with size of 27a × 0a × 11a (x, y and z-dimension) was used, including the boundary conditions. Similarly, two planewave sources with central wavelength of 1.55 μm were used for generation of data and control signal (guided source) with E_x and E_z polarizations, respectively. The control or pump source is placed inside the waveguide and the data signal is coupled vertically to the PhC structure to create the phenomena of optical amplification as reflected in Fig. 2. The simulation domain is terminated with Perfectly Matched Layer (PML) boundary conditions to absorb the outgoing EM field and avoid back reflections.

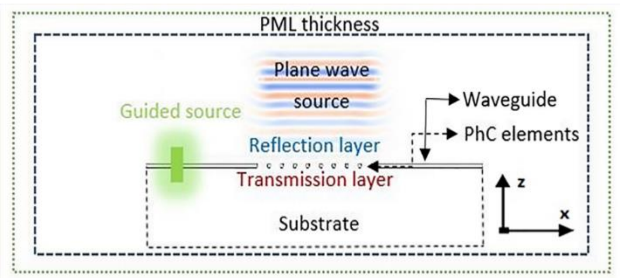

Fig. 1. Cross-sectional view of the simulation doamin depicting the PhC structure, placement of the excitation sources, field monitor layers and the boundary conditions

3. Results

The investigated results of optical amplification are depicted in Fig. 2. The radius of the PhC cavity at the start of the optical membrane is varied from 0.06a to 0.35a to study the optical amplification action and spectral shifting of the resonant modes. The optical amplification is studied in two steps. At first, only the data source is turned on and the resultant reflection peak is measured at the reflection flux monitor layer, reflecting as the radius of the cavity is varied from 0.06a to 0.35a, a blue shift is observed in reflection peak of the guided modes which also indicates a drop in effective refractive index of the waveguide. Moreover, the coupling of energy into the PhC membrane is highest for smaller cavity radii values and lowest for bigger cavity radii.

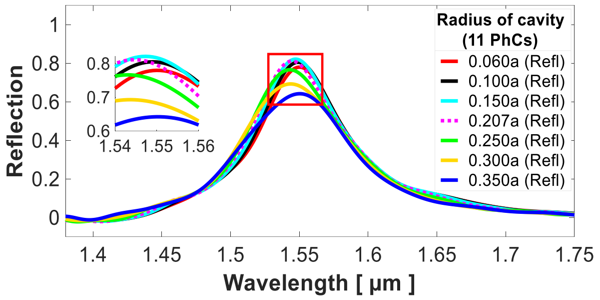

Fig. 2. Spectral response of the proposed structure showing optical amplification of the reflection peaks in a 11 PhC-element structure for variation in the radius of cavity

In the second step, both the data signal and the pump signal are tuned on simultaneously and the resulting field is recorded at the reflection monitor layer as imitated in Fig. 3 and compared for study of the amplification action using the size of the cavity as 0.100a, 0.207a and 0.350a.

The best amplification results are observed at smaller cavity radii values as it can be seen in the inset provided in the Fig. 3. An optimum optical cavity value to get the best amplification is concluded to be 0.15a.

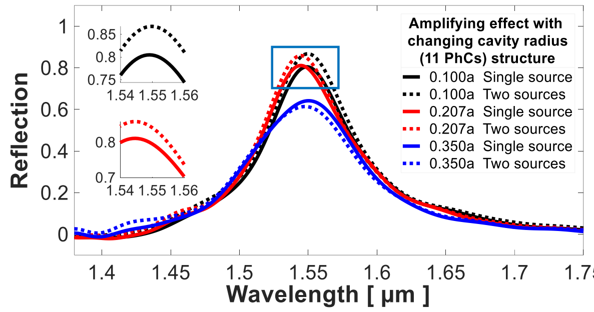

Fig. 3. Optical amplification of data signal for three different values of PhC-cavity radius

4. Conclusion

In this work an optical amplification action is investigated in a dielectric PhC cavity-based structure. The data source is coupled inside the PhC waveguide as per principle of GMR, where the pump source is placed inside the waveguide. It is concluded that a cavity radius of 0.15a gives the best amplification results while keeping the radius of PhC-elements as 0.30a. Further, increasing the radius of the cavity shifts the guided modes from longer wavelength towards shorter wavelengths.

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