International Journal of Advance Research In Science And Engineering http://www.ijarse.com
IJARSE, Vol. No.3, Issue No.9, September 2014 ISSN-2319-8354(E)

BENDING WAVEGUIDE WITH HIGH TRANSMISSION SIMULATED IN 2D *Si*- *SiO*$_2$ PHOTONIC CRYSTAL

Shounak Dasgupta[1] **, Chayanika Bose**[2]

[1]*ECE Dept. Heritage Institute of Engg., Kolkata-700107, (India)*
[2]*Dept. of Electronics and Telecommunication Engg, Jadavpur University, Kolkata-700032, (India)*

ABSTRACT

An approach for providing high transmission through a photonic crystal based optical waveguide with sharp bending is made. The bending waveguide is simulated introducing two line defects, perpendicular to each other, within a photonic crystal having 2D array of Si rods embedded SiO_2*. Insertion of additional silicon rods in the output waveguide provides high transmission over 99% at a desired wavelength supported by the proposed waveguide structure. Here, the modeling is based on the couple mode theory.*

Keywords: Photonic Crystal, Bending Waveguide, Couple Mode Theory.

I INTRODUCTION

Optical waveguides are fundamental components in realizing photonic integrated circuits. In high-density integrated light wave circuits, waveguides that allow sudden bends with small curvature are to be used as optical interconnects. A conventional dielectric waveguide mainly suffers from two limitations: some light is reflected, and some light is radiated away from a bend. In general, the sharper the bend is, the greater is the radiation loss. Even in a low-contrast optical fiber, a bend radius of less than a few centimeters will result in almost complete radiation loss. This situation changes in a photonic crystal waveguide as the photonic band gap prohibits radiation losses. Optical waveguides realized through line defects in the crystal are one of the potential candidates for such sharp bends. Photonic crystal based bending waveguides provide strong confinement and flexible control to light waves. However, bending loss, still exists due to reflections at sharp bending corners. Consequently, studies have been focused on optimization of bending at the corner to lessen the such reflection loss. In 1996, A. Mekis *et. al.* proposed a simple 1-D scattering theory based model with a dynamic frequency dependence to describe the transmission properties [1] of a photonic crystal based waveguide bend with line defect. They achieved complete transmission at certain frequencies, and very high transmission (>95%) over wide frequency ranges by increasing the lengths of the bends. T. Baba *el al* also investigated light propagation in 2-D photonic crystal waveguides with bends, which were composed of closely-packed holes formed in a *GaInAsP* thin film, to have higher transmission [2]. High transmission for some frequency ranges, through the sharp bend, in a triangular lattice slab , was also obtained by A. Chutinan and S. Noda [3]. To suppress reflection of light, A. Talneau *et. al.* incorporated a taper structure at the bending corner [4]. J. Smajic *et. al.* also optimized the reflection loss by varying the radius of the dielectric rod at the corner of the bend [5]. In this communication, modulating coupling between the cavity and the output waveguide the high transmission is achieved in a 2-D photonic crystal waveguide of *Si* and SiO_2, which can be precisely realized with the help of matured *Si* technology.

II THEORY AND MODELLING

Couple mode theory can be used to have high transmission [6] in a bending waveguide. The corner of the bend can be considered as a weak resonant cavity. The bend couples this cavity to two waveguides, as represented schematically in Fig. 1 [6].

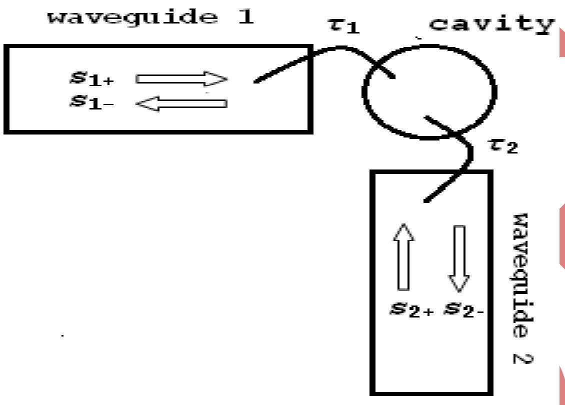

Fig 1: Schematic diagram of a bend as per couple mode theory [6]

In this diagram, waveguide 1 is the input waveguide with counter propagating field amplitudes s_{1+}/s_{1-}, and s_{2+}/s_{2-} are those for output waveguide 2. The cavity, with resonant mode of field amplitude *A*, is coupled to waveguides 1 and 2 with lifetime τ_1 and τ_2 respectively. By symmetry, the corner-resonator should decay at equal rates into the input and output waveguides, i.e., $\tau_1 = \tau_2$. Thus it may be expected that the transmission through the waveguide peaks on resonance at certain frequency. However, in this analysis the explanation using couple mode theory has a limitation that, in reality, the bend is not weakly coupled to the waveguides. A more accurate theoretical model of the bend may be constructed considering the fact that light can go only forward or backward at every point, i.e., by exploiting the fact that the problem is essentially one-dimensional. The bend may therefore be mapped onto the classic quantum-mechanical model of scattering from a symmetric 1-D potential well, in which it is known that 100% transmission occurs at resonances.

III DESIGN AND SIMULATION

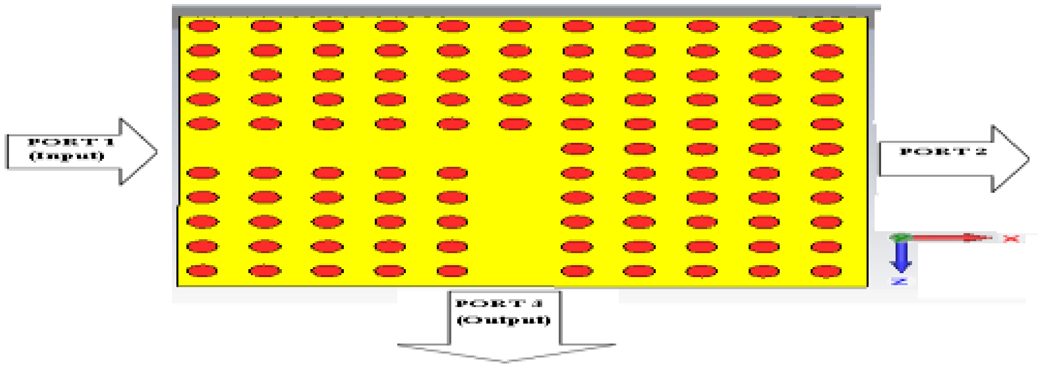

Fig 2: Cross-sectional view of 90^o bend consisting of 11 X 11 Si rods embedded in SiO_2 slab.

In this simulation, the basic 2-D photonic crystal is formed by an 11 x 11 array of silicon rods of radius (*r)* 106.7 *nm* embedded into silicon dioxide slab with 432.4 nm period(*a*) of the square lattice [7]. Two waveguides perpendicular to each other are realized introducing two line defects: defect at the 6th row for the input waveguide and at the 6th column for the output one. These two waveguides result in a bend with bending angle of 90°.

The structure described above is simulated using *CST MW studio* and is presented in Fig 2, indicating all the ports connected to it. Port 1, the input port and port 2, a port to observe unwanted radiation from the opposite wall of the input port in the structure, are connected in yz-plane, while port 3, the port to take the signal out from the waveguide is connected in xy-plane.

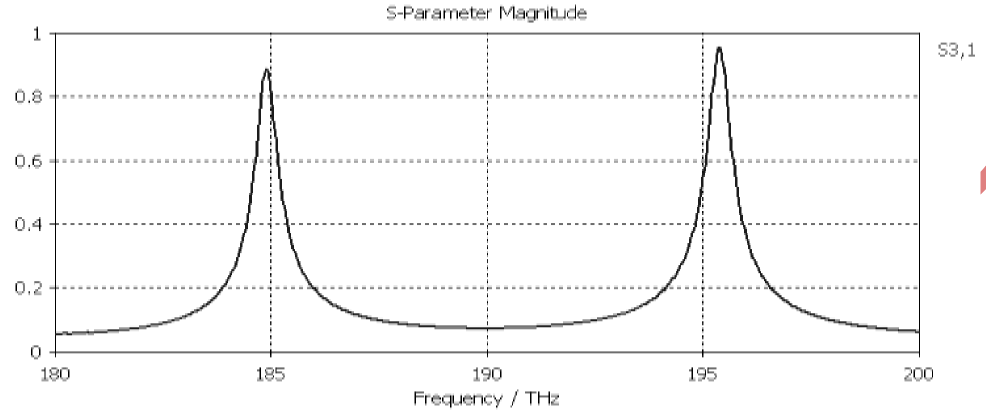

Fig 3: Transmission spectra for the 90° bend.

The transmission characteristics presented in Fig 3 shows that two windows open up around 195 *THz* (1538 *nm*) and 185 *THz* (1620 *nm*) within the stop band of the basic square lattice structure. The structure supports more than 95% and 87% transmission respectively at the above frequencies. Frequencies, at which windows appear, can be tuned by the effective dielectric constant of the structure. An increase in effective dielectric constant is expected to shift the peaks towards left, i.e. towards higher wavelength .

The single mode waveguide and weak coupling at the bend are the key factors for high transmission [8]. In order to have transmission peak at a single frequency, we introduce a dielectric rod just at the bend. The resultant structure is shown in Fig. 4 and corresponding response is presented in Fig. 5.

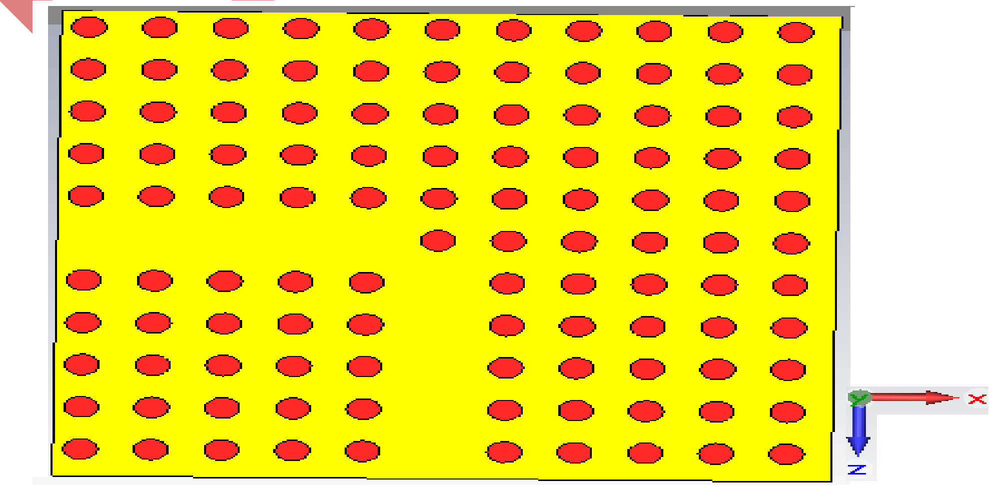

Fig 4: Cross-sectional view of 90° bend with a rod inserted at the bending corner.

Fig.5 reveals that the above structure offers about 90% transmission at about 188 *THz* (1595 *nm*), while the transmission is less than 70% for the other window appearing at 184 *THz* (1630 *nm*). However, introduction of the additional cylinder results shift in transmission peaks.

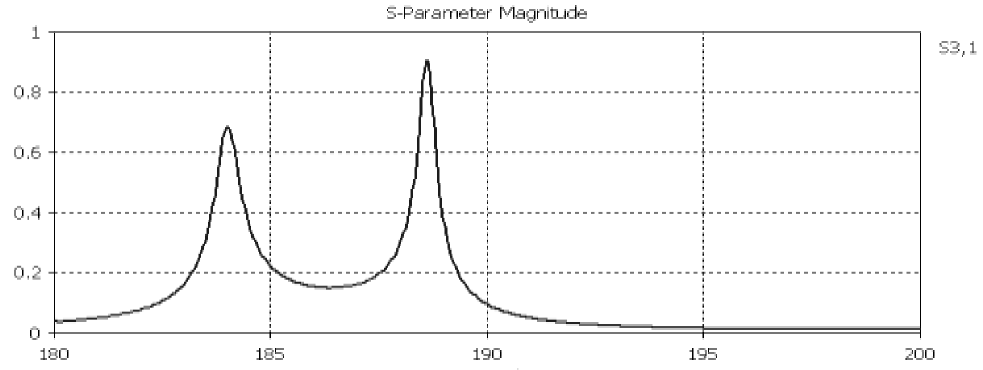

Fig 5: Transmission spectra for the 90^o bend shown in Fig.4.

In order to enhance the transmission through a specific window, another cylinder is placed in the output waveguide (shown in Fig.6).

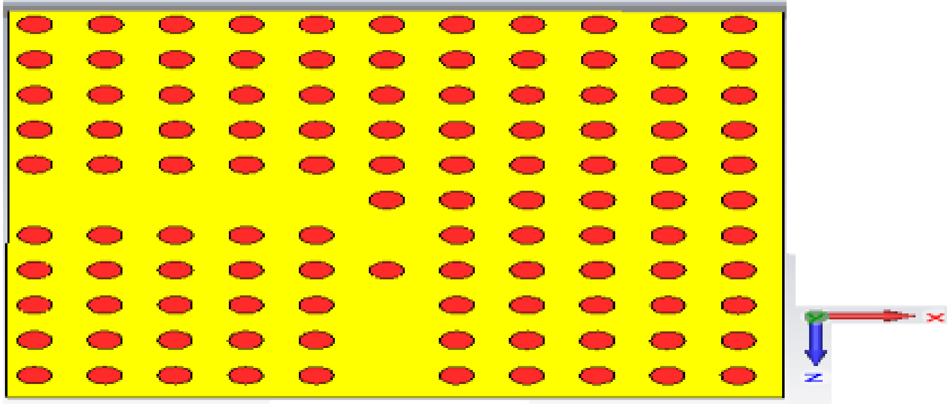

Fig 6: Cross-sectional view of 90^o bend with another rod inserted at the output waveguide.

The transmission spectrum for the above structure, presented in Fig.7, shows almost full transmission (more than 99%) at 188 *THz*.

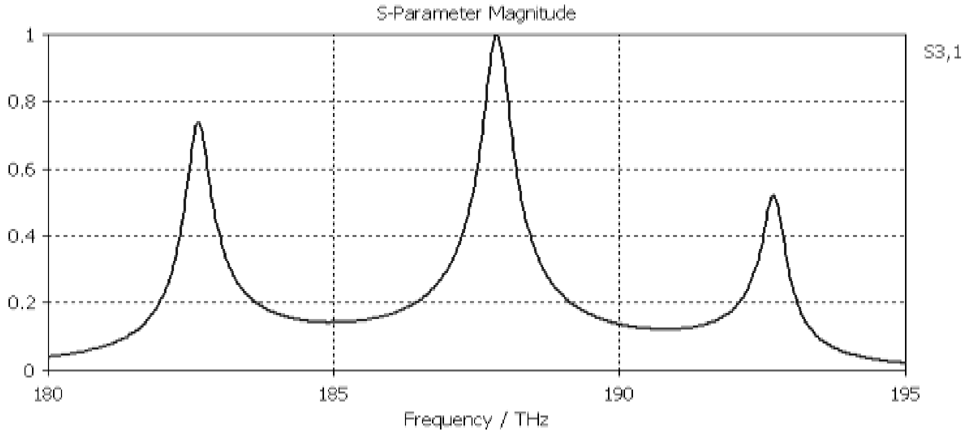

Fig 7: Transmission spectra of the 90^o bend shown in Fig.6.

The same spectrum, plotted in *dB* in Fig.8 indicates that adjacent peaks are lower by 2.6 *dB* and 6 *dB* than the strongest one appearing at frequency 188 *THz.*

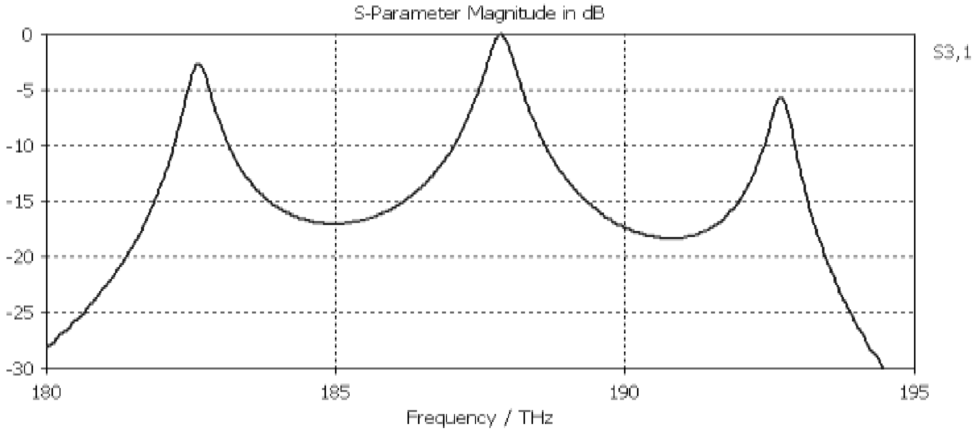

Fig 8: Transmission spectra of the bend in terms of dB.

IV CONCLUSION

In this communication, the transmission through a photonic crystal based bending waveguide is maximized. A bend with bending angle of 90° is realized in a 2-D photonic crystal composed of an array of silicon rods embedded into silicon dioxide slab. The bending waveguide provides almost 100% transmission at 188 THz with adjacent peaks separated by at least 5 THz on either side of it and of strength lower than 2.6 dB and 6 dB. Such 90° bent waveguides can be employed to design a multiplexer/demultiplexer which posses low insertion loss and can be implemented efficiently in integrated form.

REFERENCES

[1] A. Mekis, J. C. Chen, I. Kurland, P. R. Villeneuve and J. D. Joannopoulos. “High transmission through sharp bends in photonic crystals waveguides”. Physical Review Letters. 1996, Vol. 77, No. 8, pp. 3787 -3790.

[2] T. Baba, N. Fukaya and J. Yonekura. “Observation of light propagation in photonic crystal optical waveguides with bends”.Electronics Letters 1999, Vol. 35, No. 8, pp. 654-655.

[3] S. Noda and A. Chutinan. “Waveguides and waveguide bends in two- dimensional photonic crystal slabs”. Physical Review B. 2000, Vol. 62, No. 7, pp. 4488 -4492.

[4] A. Talneau, P. Lalanne, M. Agio and C. M. Soukoulis. “Low-reflection photonic-crystal taper for efficient coupling”. Optics Letters. 2002, Vol. 27, No. 25, pp. 1522-1524.

[5] J. Smajic, C. Hafner and D. Erni. “Design and optimization of an achromatic photonic crystal bend”. Optics Express. . 2003, Vol. 11, No. 10, pp. 1378-1384.

[6] J.D. Joannopoulos. “ Photonic Crystal : Molding the flow of light”. Princeton University press, 2008.

[7] S. Dasgupta, S. Saha and C. Bose, “Design and simulation of various 2-D photonic crystal structures: a comparative study” CALCON 11, Kolkata, 2011.

[8] Fan, Shanhui, Steven G. Johnson, J. D. Joannopoulos, C. Manolatou and H. A. Haus. “Waveguide branches in photonic crystals”. Journal of Optical Society America B. 2001, Vol. 18, No. 2, pp. 162–165.