A COMPARISION OF VARIOUS TYPES OF PHOTONIC CRYSTAL TAPERS

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***Abstract*:** The various designs of non-uniform shaped photonic crystal tapers are discussed in this paper. These structures are used for coupling modes of broader waveguides with narrow photonic crystal waveguides. In order to achieve adiabatic mode conversion the waveguides are integrated with taper structures. The result includes the power losses in the form of ripples at the output of each taper. The exponential taper of 23 μm length yields the best output amongst the various taper designs. The most appropriate taper model is thus acquired.

***Keywords*:** Photonic crystals (PhCs), photonic band gaps (PBG), Photonic integrated circuit(PIC).

I. INTRODUCTION

Photonic crystal has found immense potential in the field of optical communication. The photonic crystal fiber is new version of optical fibers. The conventional taper designs incorporated electrical to optical and optical to electrical conversions whereas all optical signal processing has been accomplished using PCs. The photonic crystal taper structure constitutes of periodic dielectric rods surrounded by air [1]. This crystal possesses a band gap property which is analogues to the electronic band gap. For certain range of frequencies there is no propagation of light inside the crystal [2-5]. Thus the propagation modes are transmitted through the photonic crystal without being lost [6]. This fascinating property is due to the existence of line defect [7-8]. PhCs have now days become a subject of growing interest for researchers. The serious difficulty that exists with the photonic crystal waveguides is its inefficient coupling due to its extremely smaller width compared to the traditional waveguides. This affects efficient coupling of waves between the waveguides. The losses include back reflection, scattering of incoming light. The coupling of light requires a gradual spot size transformation [9-11]. The photonic crystal taper is an important candidate that can confine light and guide light along the narrow channeled waveguides on the scale of optical wavelength. So focusing the beam of light into waveguide is necessary [12-13]. The tapered structure helps in compressing the mode towards the confined waveguide. Another property of the photonic crystal is the slowing of light which enhances the interaction between light and the matter [14].The Fig. 1 depicts is mode conversion between single mode fiber and micro structured optical fibers. Hence tapering ensures high efficiency coupling. Here larger waveguide mode gets compressed to smaller sized mode and results in higher intensity.

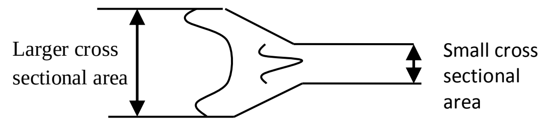
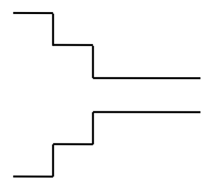


Fig. 1: mode compression in tapered region.

II. DESIGN OF TAPERED STRUCTURE

The need of tapered structure is well elaborated in the above section. The tapered structure designs that will be discussed in this paper are both linear as well as non linear [15]. For the non linear taper we have exponential taper, step taper and concave taper. The two dimensional photonic crystal tapers are designed in this paper because of its easy fabrication.



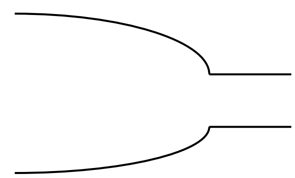


Fig. 2: Step taper. Fig. 3: exponential tapers

III. TESTBED FOR IMPLEMENTATION

The various designs of tapers are implemented using Finite Difference Time Domain Designer i.e Opti FDTD 32 bit. This is a very important and user friendly software. This software has accesses to the passive photonic components. The layout is made in the layout designer window of FDTD. The properties of PCs waveguide needs to be well defined. This is followed by formulation of PBG crystal structure for taper. The taper designed is then simulated followed by OptiFDTD Analyzer. In the analyzer window obtained graphs can be well examined. Similar steps are followed for all the tapers. At last all the obtained curves are compared to achieve the best taper. The basic design of two dimensional photonic crystal is shown in Fig. 6. These are silica rods (blue) with air (red) as its surrounding. Line defect is created for propagation of the light wave by eliminating the central solid rod.

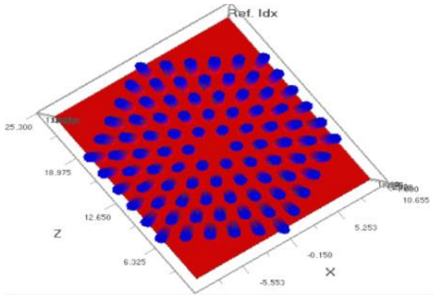


Fig. 4: Two dimensional photonic crystals

IV DESIGN OF PHOTONIC CRYSTAL TAPER

The parameters considered for designing the tapers are illustrated in the table below.

Structure	Photonic crystal
n_{rod}	3.45
n_{medium}	1
Radius of hole	0.11
Lattice constant	3.3
Lattice type	2D-Rectangular

Table1: Common Parameters for all tapers

A. *Basic photonic crystal*

The basic design of photonic crystal is shown below in fig. 5. PhC Tapers are made out of this crystal by eliminating central row of dielectric rod. Here the lattice constants are #A=13, #B=14.

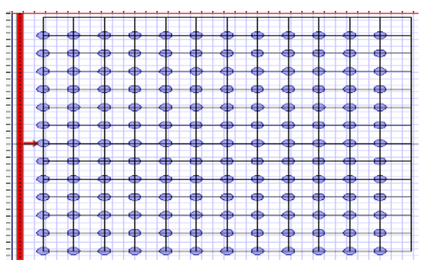


Fig. 5: Photonic crystal structure.

B. *Concave Taper*

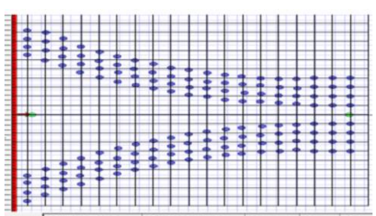


Fig. 7: Photonic crystal concave Taper

For this taper the length of the design is increased so that the sharp change of the width of taper now becomes gradual. This gradual decrease in the shape of the taper is required to have controlled losses.

C. *Step taper*

This taper constitutes of steps from left to right merging in to a photonic waveguide. The Observation points A (1.55, 0) B (8.58, 0)

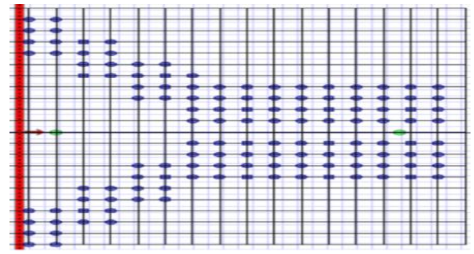


Fig. 7: Photonic crystal Step Taper

D. *Exponential tapers*

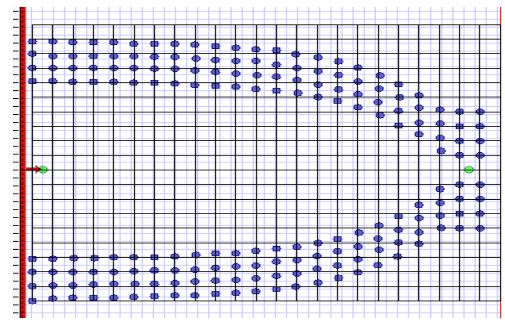


Fig. 8: Photonic crystal Step Taper

The exponentially varying curves form the exponential taper. The width goes on decreasing from input side to the output side. The reduction in the width occurs slowly hence results in the smoother transition. The exaponential taper provides a superior interface. The length for this design is increased to obtain a optimized taper varying exponentialy.The length of the structure is 12.1um. The lattice parameters are #A=21,#B=29.

V. RESULTS AND ANALYSIS

A. *Gaussian input wave*

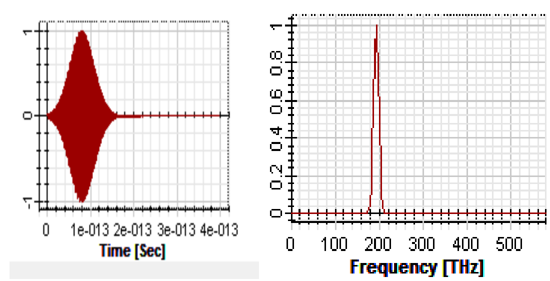


Fig. 9: Gaussian Input Source

A Gaussian input wave of 10 µm is given to the photonic crystal structures. The observation area analysis for the observation points are shown in the following graphs between power and wavelength.

B. Photonic crystal

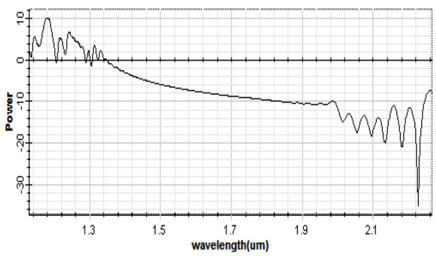


Fig. 10: Power v/s wavelength at observation point

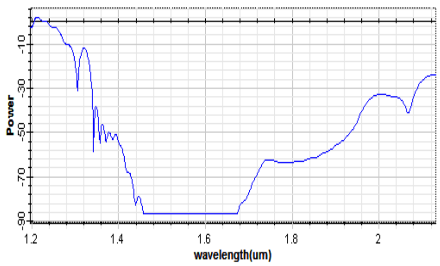


Fig. 11: Power v/s wavelength observation point 2

The graphs obtained after simulation clearly depicts the nature of photonic crystal. The challenge to couple light efficiently into the photonic crystal will be discussed following. The Fig. 11 depicts inability to couple or transmit wave. The photonic crystal is unable to propagate wave through it.

C. Concave Taper

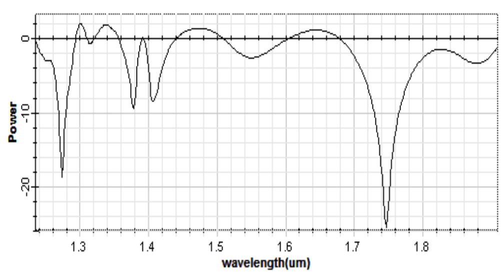


Fig. 12: Power v/s wavelength at observation point 1

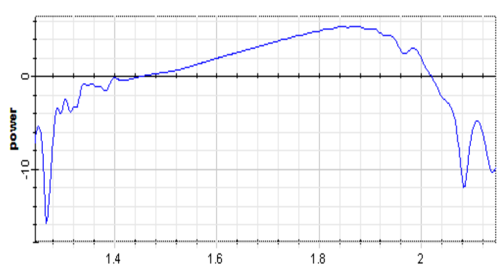


Fig. 13: Power v/s wavelength at observation point

The line defect is necessary to realize propagation through photonic crystal. The transmission occurs in the band gap where previously no transmissions were possible. The output from the concave taper is relatively better for a wavelength range of 1.5 µm to 1.8 µm.

D. Step taper with unit step size

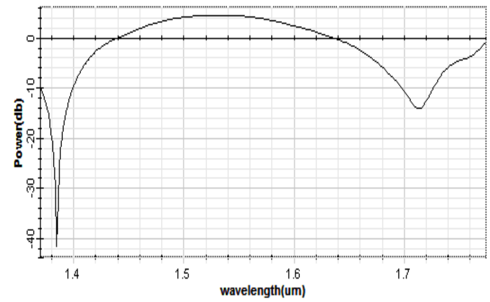


Fig. 14: Power v/s wavelength observation point 1

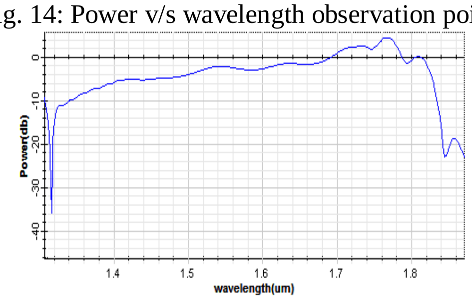


Fig. 15: Power v/s wavelength observation point 2

The output is possessing less ripples in comparision to concave taper and observed a bend at 1.55µm. The output is many fold smoother than the previous output.

E. Exponential taper

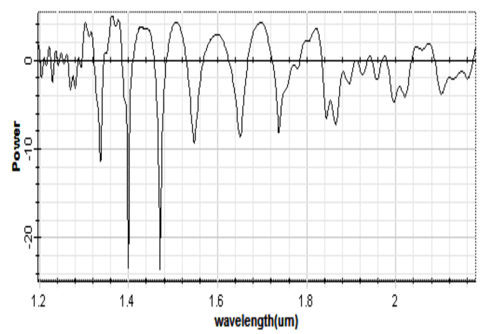


Fig. 16: Power v/s wavelength observation point 1

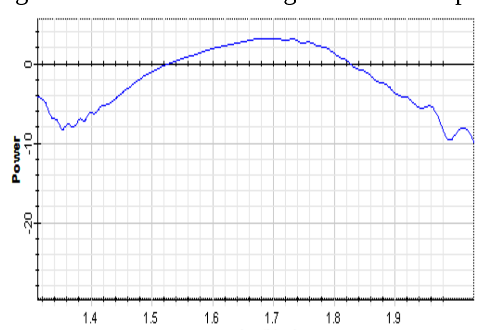


Fig. 17: Power v/s wavelength observation point 2

This possesses far less ripples in the output curve than all the other tapers. Since exponential taper has broader input area which narrows gradually while moving away from input end. Hence lesser losses are experienced in this taper.

VI. CONCLUSION

Hence it can be concluded that tapers are indispensible part of photonic crystal waveguides. PIC is made possible by integrating various optical devices but the cross sectional differences hinder it. So tapers are required to reduce the losses such as the back reflection scattering etc. The area analysis curve confirmed the superiority of the exponential taper in comparison to all other tapers. Due to the broader input area the losses are minimum hence ripples incurred are least where as for the output of concave taper more ripples exist than the exponential taper. Despite of the losses, coupling and tapering is possible for all the tapers discussed in the paper

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