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Comparative Analysis of Various Types of Photonic Crystal Bends

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Abstract: Photonic crystals are periodically structured electromagnetic media, generally possessing photonic band gaps: ranges of frequency in which light cannot propagate through the structure. The increasing bend losses at longer wavelengths often limit the usable wavelength range of a single-mode fiber. In this paper, the design and analysis of different bending structures has been performed. Three bending structures has been designed with bend angles as: All Crystal, 60 Degree and 90 Degree. In these waveguides, we have seen the propagation of light through them. The observation of the wave when entering this waveguide and when leaving it, has been analyzed. We will analyze which bending structure will provide best results on the basis two parameters: Passband and Ripples. The input wave behaves differently when propagating through different bend angles. To perform these bending techniques, OPTIFDTD software is used.

Keywords: Photonic Crystals, Hollow Core-Photonic Crystal Fiber, Hexagonal Photonic Crystal Fiber, Modified Total Internal Reflection, Polarization Maintaining Photonic Crystal Fiber.

I. INTRODUCTION

A key motivation for using optical signal processing is that optical techniques do not need to “touch” or switch every individual “bit,” as electronic transistors do. Also, the conventional optical fiber is sensitive to bending, which is why the bending has the adverse effect on it. Photonic crystal fibers on the other hand has the Photonic Bandgap Effect, due to which they are insensitive to bending. Because electronic signal processing systems have a bottleneck of low bandwidth, the use of photonic approaches to realize real time signal processing is becoming increasingly popular. The need for electro to optic and back to electro conversion is no longer needed, as it increases the conversion time and the losses. Optical amplifiers, for instance, can amplify Tb/s signals without touching the signal at the bit level. For all optic communication to work we also need photonic bends and other all optic devices. These all optical circuits are miniature devices which includes all components on a very single chip. With help of different types of bends in Photonic Crystal Fiber, we can take the All Optic Signal Processing to a whole new level. Here, photonic crystal waveguide (PCWG) bends with a transmission of up to 77% were realized [1-3]. Photonic crystals (PCs) are periodic dielectric structures that exhibit the unique potential of photonic band gap (PBG), i.e., a frequency region in which the propagation of light is not permitted. This property can be utilized to control the light propagation. Unlike 3D structures, 2D Photonic Crystals can be fabricated easily by integrated circuit technology. PC slabs have vertical confinement using index guiding and confine light in horizontal plane using PBG [4–7]. The first results on PC waveguide bends have been reported by MEKIS et al. [8], where the transmission through a 90° bend in a 2D photonic crystal with a square lattice structure was investigated. High performance bends can be designed if one gives up the circular geometry of the air-holes or dielectric rods [6–9], but the more complicated shapes also increase the difficulty of fabrication. Finally, waveguide bends have also been designed based on changing the lattice structure of the background Photonic crystal [10-11], but they affect a larger area around the bend and are not as suitable for photonic integration. These losses rise very quickly once a certain critical bend radius is reached. Generally, bend losses increase strongly for longer wavelengths. The magnitude of bend losses has some dependence on the polarization [12-13]. Bending not only introduces losses, but can also reduce the effective mode area. This is particularly true for large mode area step-index fibers. Also bending induces birefringence [14-15]. Fibres with large mode area only weakly confine light, and thus they are very sensitive to the bending. Due to the large bending loss, these fibres have to be kept straight when used in lasers. PCFs have remarkable properties, strongly depending on the design details such as low sensitivity to bend losses even for high mode areas, where, low or high mode areas leading to very strong or weak optical nonlinearities. One of the most important issues regarding practical development of PCFs concerns their macro-bending loss properties. Introducing an effective normalized frequency for PCFs, Veff, as presented initially by Birks et al. [16]:

$$V_{eff} = \frac{2\pi\rho_{eq}}{\lambda}\sqrt{n_{co}^2 - n_{cl,eff}^2} \qquad (1)$$

Here, ρ_{eq} is the core radius of an equivalent step-index fibre having similar properties as the PCF at wavelength λ. n_{co} is the refractive index of the core, and $n_{cl,eff}$ is the effective refractive index of the PCF cladding region. $n_{cl,eff}$ has a strong wavelength dependency due to the air hole array [17]. To deduce a useful bending loss description, a relation for the power loss coefficient of standard step-index fibres due to macro-bending [18, 19] is applied:

$$\alpha = \frac{\sqrt{\pi}\rho_{eq}A_e^2 \exp\left(\frac{-4\Delta_{eff}W_{eff}^3 R}{3\rho_{eq}V_{eff}^2}\right)}{8PW_{eff}\sqrt{\frac{W_{eff}R}{\rho_{eq}} + \frac{V_{eff}^2}{2\Delta_{eff}W_{eff}}}} \qquad (2)$$

In eqn. 2, Δeff is the relative difference between the core and the effective cladding indices, Veff is the effective normalized frequency, ρeq is the equivalent core radius and Weff is the normalized decay parameter of the cladding. R denotes the radius of curvature in the bend, Ae is the amplitude coefficient of the electric field in the cladding, and, finally, P is the power carried by the fundamental mode multiplied by the vacuum impedance. The wavelength dependencies of Δeff and Veff correctly predict a loss mechanism for shorter wavelengths.

In a hollow-core photonic crystal fiber (HC-PCF), a large central air hole is surrounded by a number of periods of silica/air photonic crystal cladding, formed by a regular array of air holes in a glass matrix [20]. We have designed and compared 3 bending structures of photonic crystal. A frequency range of 200 THz is used.

A. Design of Photonic Crystal Bends

In the simulation, the optical bends of the order of 0 degree, 60 degrees and 90 degrees are designed. The length of the crystal is 21µm and the width is 19µm. The Pitch i.e. the distance between the two capillaries is 3.3µm. The distance d, is the diameter of the air capillary and its value is 1.8µm. The lattice we have used is the type of 2-D Rectangular. The dielectric rods have refractive index of 3.45 with air as surrounding material with refractive index 1.

The performance parameters of the various bending structures are analyzed by these points:

- Passband- the bend giving maximum passband i.e. the spectral distance between the first nulls in frequency range of 1.4 µm to 1.7 µm gives the best performance.
- Ripples- the bend giving us the minimum ripples in the passband has the maximum performance.
- Input to the Bending Structure- The input used into our system is:

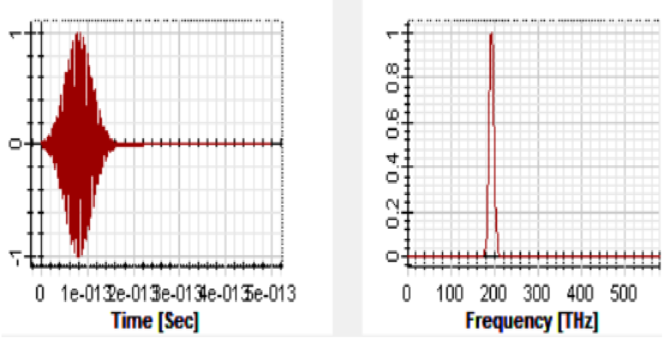

Fig.1: The time offset used for our system is- (8.0267e-014) in seconds and the Half-Width is- (2.9066e-014) in seconds.

In a 0-degree bend, a straight line runs through the centre of the waveguide. This can also be called as a Butt Coupling Taper. Three Observation points are used in the waveguide. The one at the start, second in the centre and third one in the end of the waveguide respectively. They are used to observe the nature of the wave propagating inside the waveguide at that instants. Observation points are the green color markers inside the waveguide.

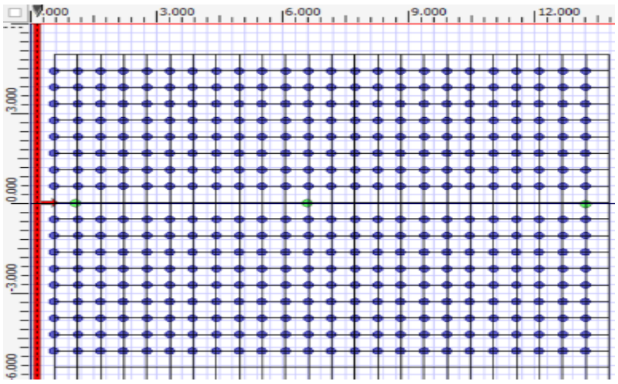

Fig.2: PCF with No Bend

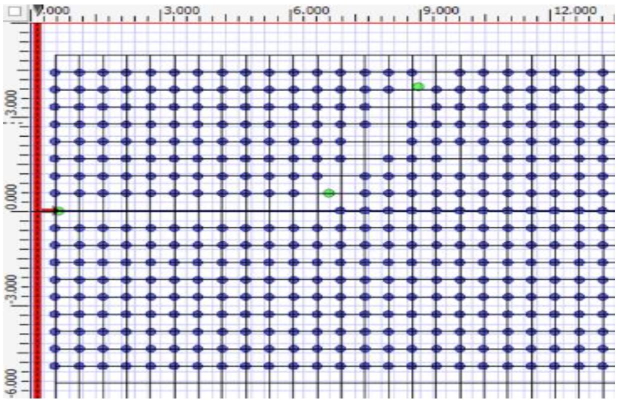

Fig.3: PCF with 60 Degree bend.

Here the positions of observation points are varied due to the bend in the structure.

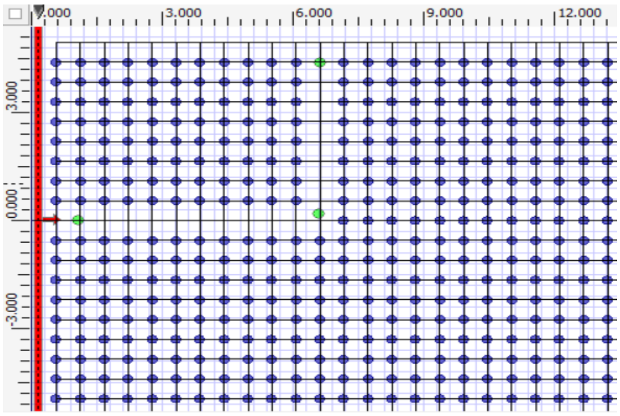

Fig.4: Photonic Crystal Waveguide with 90 Degree bend

From the picture, we can see that a bend of 90 degrees is made. Similar to the above structures, the position of observation points has been varied according to the bend. Input can be viewed at Observation point 1 and output can be viewed at observation point 3.

II. RESULTS

By observing the simulations, we obtain certain results. For 0-degree bend:

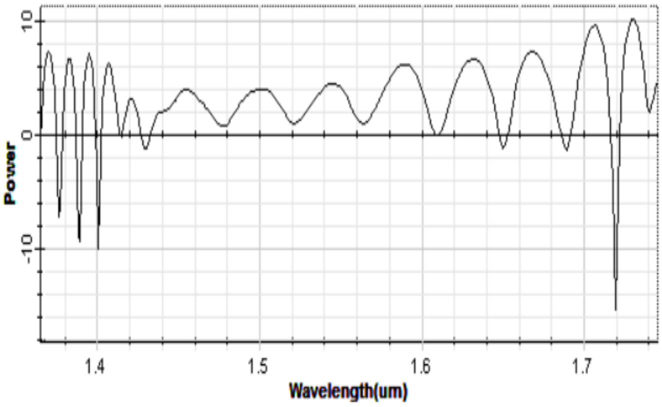

Fig.5: Power observed at Input

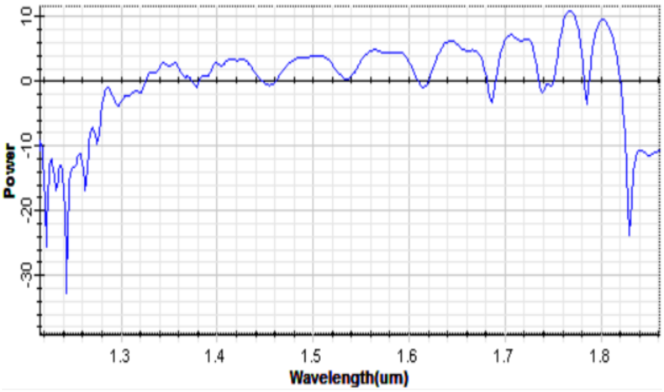

Fig.6: Power Observed at Output

As we can see from the results that there are a greater number of ripples between the nulls. So the system performance is not adequate and not up to the mark.

For 60 Degree bend:

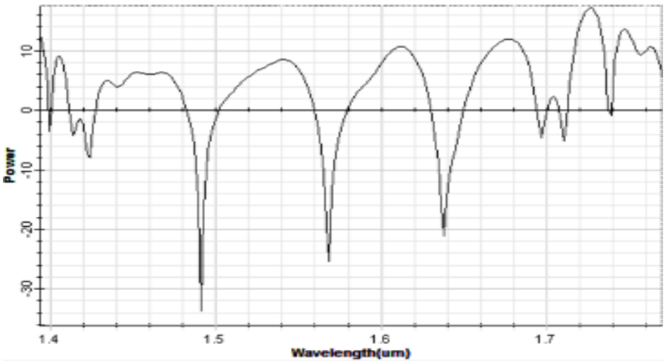

Fig.7: Power Observed at Input

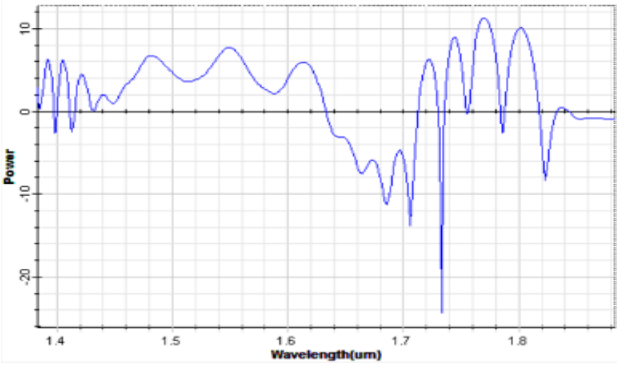

Fig.8: Power Observed at Output

From the above observation we can conclude that the distance between the first null is small. Also the ripples are more.

For 90 Degree Bend:

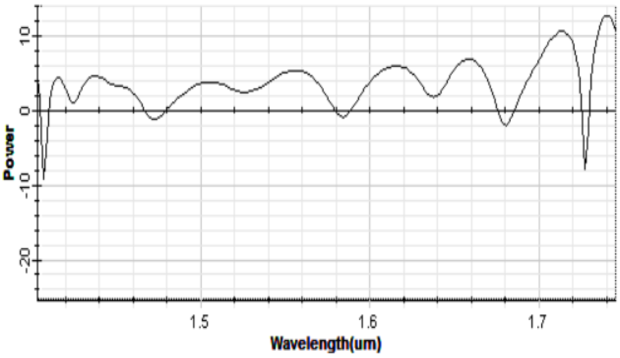

Fig.9: Power Observed at Input

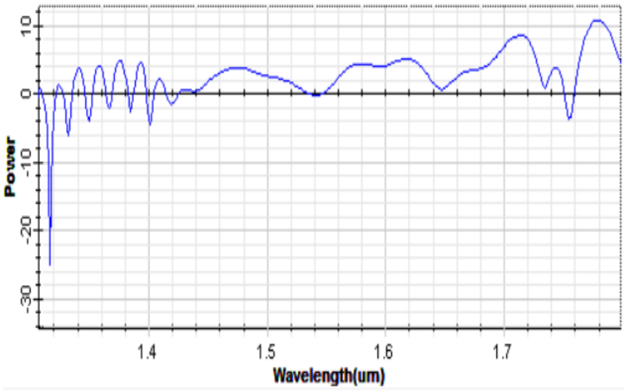

Fig.10: Power Observed at Output

The above graphs are for 90 degree bends. The number of ripples are less and also the distance between the first null is larger.

III. CONCLUSIONS

From the results, we conclude that the 90-degree bend is the most appropriate bend we can use in optical domain. The wave propagates with ease. The number of ripples in the system occurs less and also the distance between the first null isgreat.

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