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Exploring Macro-Bending Losses on Photonic Crystal Fiber for Communication Window with Dissimilar Material Composites

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Dimpi Paul[1]* and Sibasish Dutta[2]

[1]*Department of Physics, Patharkandi College-788724, Assam, India*

[2]*Department of Physics, PDUAM Eraligool, Karimganj-788723, Assam, India*

***Corresponding Author:** Dimpi Paul, Department of Physics, Patharkandi College-788724, Assam, India.

Abstract

This paper highlights the losses arising from bending that plays a vital role in long-term communication purposes. To get better transmission it is very essential to control the losses. Losses arising from bending of photonic crystal fiber (PCF) can also be controlled by altering the structural parameter (d/Λ and Λ) that regulates the photonic crystal fiber structure. Different materials (viz. crown and phosphate) based PCF with lower bending losses has been reported by exploring the whole communication band (0.2-2μm) with variable structural parameters and bending radii. During bending of a fiber, evanescent field energy drives light towards cladding and a subsequent attenuation in the guidance of light energy occurs, which generates losses and can be controlled by altering the structural parameters in the PCF. Therefore, failure in total internal reflection is the major contribution towards these losses. In this study, a very low bending loss ~ 0.11 dB/km and ~0.08 dB/km have been observed for crown and phosphate based PCF. Also, an interesting phenomenon has been observed during the study that with increase in Λ for constant d/Λ, losses are found to increase up to the λ ~1.2μm and then started decreasing with increase in Λ which can be useful for the experimentalist during fabrication. Although this work can provide a valuable approach to the engineers to develop a newer kind of PCF model that can lower losses with respective change in material domain.

Keywords: Photonic Crystal fiber (PCF); Macro-bending Loss; Effective index method (EIM)

Abbreviations

Photonic Crystal fiber (PCF), Effective index method (EIM), beam propagation method (BPM).

Introduction

The micro-structured fiber or Photonic crystal fibers (PCFs) is composed of periodic structure made of capillaries, filled with air; laid to form a hexagonal lattice. The design of PCFs is very flexible that composed of few flexible modal parameters that can be controlled for practical uses. The parameters are lattice pitch Λ, air hole shape and diameter d, refractive index of the glass and type of lattice. Freedom of designing PCF allows one to obtain endlessly single mode fibers, which are single mode in all optical range without any cut-off wavelength. Further, unlike conventional optical fiber guiding mechanism of photonic crystal fiber has been divided in two main categories (a) Index guiding and (b) Air guiding. Index guiding mechanism monitored by modified total internal reflection and air guiding mechanism monitored by Photonic band-gap effect [1-5]. The growth in designing of photonic crystal fiber brings numerous practical applications as well. One of the suitable technique for analyzing losses in PCF is effective index method. This method was reported at first by Hongbo Li and Arash Mafi et al [5] in the year of 2007 for designing and analyzing of photonic crystal fiber using effective index method (EIM). To analyze the modal properties of photonic crystal fiber EIM technique can be used by reformulating the effective refractive index of the proposed fiber. The measurable quantities can be studied using this technique by simply altering the refractive index of the compositional element. Further, the modal characteristics can also be studied by changing the refractive index of PCF. Besides, the propagation characteristics of photonic crystal fiber can be studied by simulating and analyzing modal parameter using EIM technique. Even though, several methods are available to design and analysis of modal properties of micro-structured fiber yet there are some method which require high computational skills such as finite element time domain (FDTD) [1-10], FV-FEM [11], beam propagation method (BPM) [12-14] and so on. To analyze modal properties of photonic crystal fiber EIM technique is considered by several researchers owing to flexibility and ease in computation. Thus, the work is motivated to study the losses by observing distinction in involved modal parameters. In addition to that, PCF can also be used in designing sensors to analyze adaptable sensing schemes.

Theory

Photonic crystal fiber or micro-structured fiber is considered to be under extensive study due to their unique features which has some structural parameters that can be modified and controlled to reduce the losses. With bending of a fiber the propagation characteristics get affected and thus, give rise to bending losses which is a very vital parameter to control during communication. Thus, bending losses in the context of dissimilar material parameters has been reported in here and also with modification of few structural parameters. Also the losses with respect to these two materials has compared for different d/Λ value with constant Λ and different Λ with constant d/Λ. Bending loss PCF has been studied by changing compositional materials with respective change in structural parameter (d/Λ and Λ). Besides, the variation in losses has been observed in respective compositions such as crown and phosphate by keeping similar variation of the structural parameter (viz. d/Λ and Λ). Towards this endeavor, PCF has been numerically modeled in communication band from 0.2 to 2 μm. Moreover, empirically evaluated values are compared with respective change in material compositions, pitch and the structural parameters. This paper focused on evaluating macro-bending losses of PCF using equation (1).

Macro-bending loss:

$$\alpha\left(\frac{dB}{m}\right) = 4.343\left(\frac{\pi}{4a_{eff}R}\right)^{1/2}\left(\frac{1}{W_{eff}}\right)^{3/2}\exp\left(-\frac{4RW_{eff}^{3}\Delta_{eff}}{3a_{eff}V_{eff}^{2}}\right)\left(\frac{U_{eff}}{V_{eff}K_1(W_{eff})}\right)^{2} \quad (1)$$

Where, R is the bending radius of curvature, a_{eff} is the radius of the core and Δ_{eff} implies relative difference between core and cladding index. The modal properties of fiber can be characterized by certain parameters like V_{eff}, W_{eff} and U_{eff} [7].

$$\left.\begin{aligned} V_{eff} &= \frac{2\pi}{\lambda}a_{eff}\sqrt{n_{co}^2 - n_{cl,eff}^2} \\ W_{eff} &= \frac{2\pi}{\lambda}a_{eff}\sqrt{n_{eff}^2 - n_{cl,eff}^2} \\ U_{eff} &= \frac{2\pi}{\lambda}a_{eff}\sqrt{n_{co}^2 - n_{eff}^2} \end{aligned}\right\} \quad (2)$$

Where, n_{co} and ncl are refractive indices of core and cladding respectively and a_{eff} is the radius of core and $V^2 = U^2 + W^2$

Results and Discussion

This paper highlights the macro-bending loss in PCF with respective change in modal parameters. It is known that with change in modal parameter (Λ, d/Λ and λ/ Λ) photonic crystal fiber can control external properties, thus this has been utilized in here. The losses can also be controlled by modifying the refractive index of the proposed fiber. In this case, refractive index of the material has been chosen to be phosphate and crown. The complete study has been performed with respect to crown and phosphate material by changing bending radius R~ 6 cm and 12 cm. The factors that have been changes during the study are d/Λ from 0.25 to 0.35 and Λ from 2 to 3. The complete study has been performed within the communication window 0.2 to 2 µm.

Figure 1 illustrates the change in bending loss with respective change in d/Λ from 0.25, 0.30 and 0.35 for bending radius 6 cm and 12 cm in case of phosphate material. As shown it has been observed that the losses is found to be higher for bending radius 12 cm and increases with increase in communication window and decrease in d/Λ. The loss in each case is found to be steady till 1µm and then increases exponentially with increase in wavelength. The bending losses for crown based PCF in each case of bending radius is found to be more than that of phosphate material. In case of crown it has been observed that the bending loss shows a dip ~0.8µm and than increases exponentially with increase in wavelength and decease in d/Λ in figure 2.

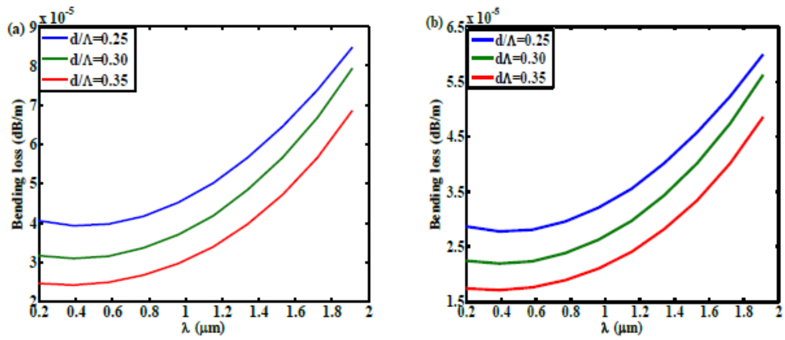

Figure 1: (a) Bending loss bending radius R~6cm and (b) bending radius 12cm in case of Phosphate material with Λ= 3 for d/Λ (0.25, 0.30 and 0.35).

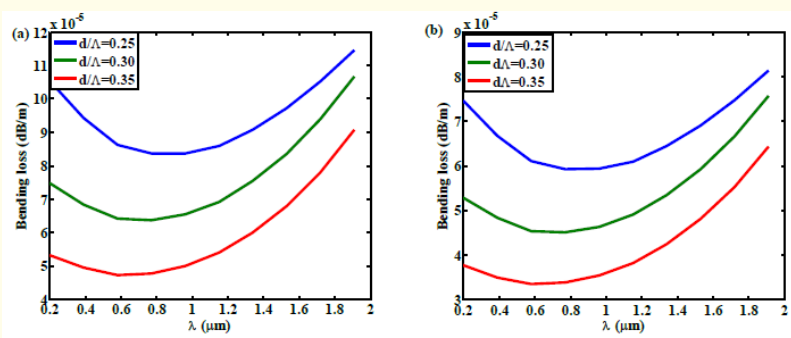

Figure 2: (a) Bending loss bending radius R~6cm and (b) bending radius 12cm in case of crown material with Λ= 3 for d/Λ (0.25, 0.30 and 0.35).

The change in bending losses can also be observed with change in Λ. As illustrated in figure 3, the bending loss in case of phosphate is found to decrease till ~1μm than increases with increase in wavelength, bending radius and decrease in Λ. In case of crown based PCF a dip in bending loss has been observed at wavelength ~1.1μm and than the loss is found to increase with wavelength and decrease in Λ. It has been observed that bending loss is higher in case of crown based fiber than that of phosphate with respective change in modal parameter.

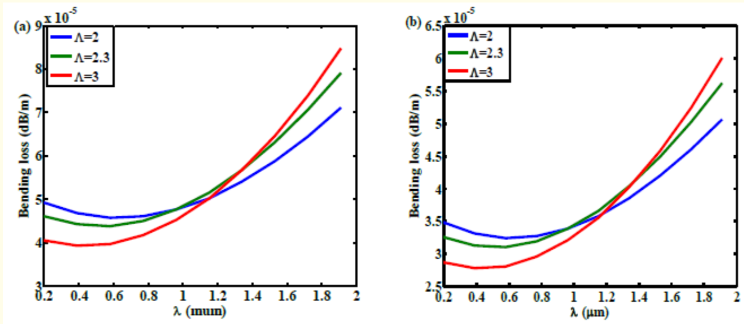

Figure 3: (a) Bending loss for bending radius R~6cm and (b) bending radius R~12cm in case of phosphate material with Λ=2, 2.3 and 3.

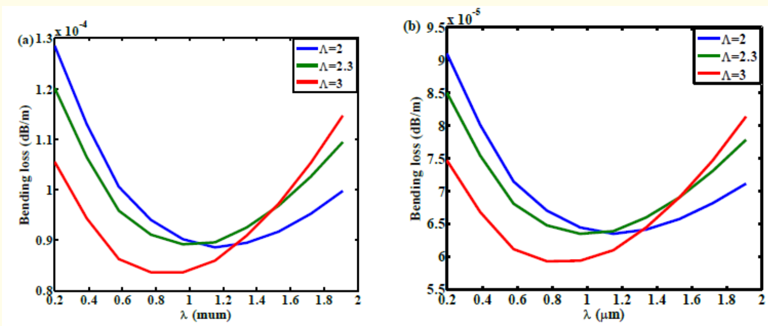

Figure 4: (a) Bending loss for bending radius R~6cm and (b) bending radius R~12cm in case of crown material with Λ=2, 2.3 and 3.

During the complete study it has been observed that bending loss increases with wavelength as well as with bending radius and also losses is found to be higher in case of crown. Further, it shows that for higher pitch and d/Λ losses are less. These are the factors in which the bending losses depends in case of different material based photonic crystal fiber.

Conclusion

A detail and comprehensive analysis has been carried out to estimate losses in PCF Using EIM technique one can easily incorporated different material core PCF which can be used for communication purposes. Here, the study highlights issues related to bending as well as splice loss with good tuning control of structural parameters. Bending of a fiber, evanescent field energy drives light towards cladding and a subsequent attenuation in the guidance of light energy occurs, which generates losses and can be controlled by altering the structural parameters in the PCF. With increase in structural parameter such as Λ and d/Λ losses in each set of material compositional PCF is found to decrease. In addition to that with increase in bending radius the losses is found to diminish. Low bending loss ~ 0.11 dB/km and 0.08 dB/km have been observed for crown and phosphate based PCF. Also, an interesting phenomenon has been observed during the study that with increase in Λ for constant d/Λ, losses are found to increase up to the λ ~1.2 μm and then started decreasing with increase in Λ.

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