Analysis of Effective Area and Splicing Loss Behavior of Square and Hexagonal Phtonic Crystal Fiber

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Abstract- This paper investigates the core and cladding effective area and splicing loss behavior of a square lattice photonic crystal fiber. These behaviors of square lattice photonic crystal fiber are also compared with the hexagonal photonic crystal fiber. Effective index method is applied for the numerical calculation and the plot has been analyzed by using MATLAB. It has been observed that by choosing some sufficient dimensional parameter a square lattice photonic crystal fiber has sufficiently large effective area and nearly zero splice loss of 0.0006dB at 1.55μm.

***Index Terms* -** photonic crystal fiber (PCF), effective index method (EIM), effective area (A_{eff}), Fiber-To-The-Home (FTTH).

I. INTRODUCTION

Photonic crystal fiber is just a new class of optical fiber based on the properties of photonic crystal. It contains an array of holes running along the length of the fiber [1]. PCF contains periodic regions of low and high dielectric. It can guide light not only through the well known total internal reflection but also through the photonic band gap mechanism. PCFs are generally divided into two main categories: index guiding fibers that have a solid core and photonic band gap or air guiding fibers that have periodic micro-structured elements and a core of low index material also called hollow core PCF. Thus due to the crystal like structure of photonic crystal fiber, PCF leads to the number of unusual properties that could not be possible in conventional optical fiber. PCF has ability to be single mode over a broad range of wavelengths [2]. Nowadays, optically-driven data exchange media are playing a central role in many new applications such as defense, security, sensing, transportation, computing and medicine [3]. Today it seems that everyone wants high-speed data, dependable voice service, and high-quality video. Whether these services are delivered by digital subscriber line (DSL), cable modems, or wireless architectures is insignificant as long as the service is fast and dependable. Fiber to the Home or FTTH - enables service providers to offer a variety of communications and entertainment services, including carrier-class telephony, high-speed Internet access etc. Providing all these services together requires increasing bit rate per channel or increasing the power level through the channel. Thus sufficiently large effective area PCF allows high power level without nonlinear effects and material damage. Thus photonic crystal fiber has great potential as communication fiber. Transmission of signal through the fiber optic channel mainly depends upon the loss associated with the fiber. In the field of optical communication there is great development since the introduction of photonic crystal as fiber by Phillip Russel [4][5] in the year 1998.

Applications are emerging in many diverse areas of science including the field of optoelectronics. For example- Ranka et al [6], first shown that an ultra-small core fiber made from solid glass and surrounded by very large air-holes can be arranged to have a nearly zero chromatic dispersion in the 800nm wavelength. In the year 2000, breakthrough losses of 13dB/km were reported in hollow-core photonic band gap fiber by the researchers [7]. Fully characterized hollow core PCF is now commercially available with losses below 0.1 dB/m [8].

Fiber to the home (FTTH), also called "fiber to the premises" (FTTP), is the installation and use of optical fiber from a central point directly to individual buildings such as residences, apartment buildings and businesses to provide unprecedented high-speed Internet access. The splicing loss is a very important parameter of PCF to calculate. It occurs due to misalignment when two optical fibers are joined together. Thus by controlling the splice loss of the fiber, it will be of great use in these telecommunication applications. Based on the current development in the area of optics, it is needed to improve the structure, performance and the cost for the future implementation of crystal fiber everywhere in the field of communication.

In this paper effective index method (EIM) [9][10] is used for the numerical calculation of effective index of cladding (η_{fsm}), effective area (A_{eff}), and splice loss of both square and hexagonal crystal fiber and the plot has been drawn by using MATLAB software.

II. PROPOSED STRUCTURE

The design of photonic crystal fiber is very flexible. There are many parameters like- air hole diameter (d), hole to hole spacing (Λ), number of air hole ring etc. to manipulate. By manipulating all these parameters a number of unusual behaviors of PCF can be seen. The geometrical quantities that describes a PCF can be represented as

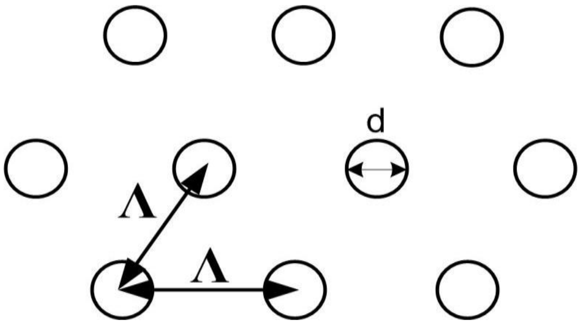

Fig 1: geometrical behaviors describing PCF

The proposed structure of square lattice PCF is

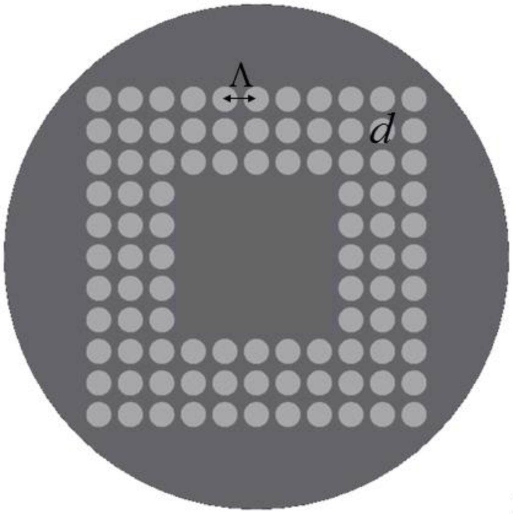

Fig 2: square lattice PCF having three numbers of air hole rings

And the hexagonal PCF can drawn by removing two central air hole rings from the given structure. It also has three number of air hole rings. The dimensional parameter for both the structures are taken same.

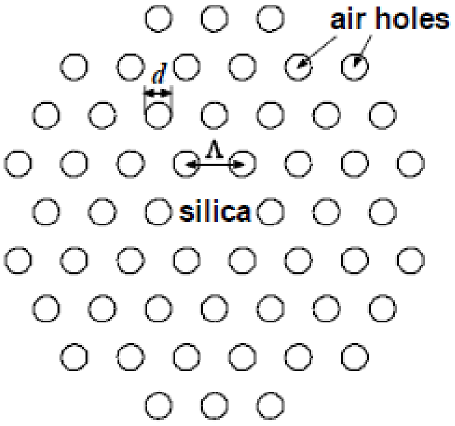

Fig 3: Hexagonal PCF

Both the structure contains three number of air hole rings. The structural parameters of both the given structure is same. In the proposed structures of the PCF, air hole diameter, d= 0.5µm, pitch (Λ) =3µm. The background material for both the structure is taken as S_iO_2 with refractive index 1.445.

III. NUMERICAL ANALYSIS AND SIMULATION RESULTS

Photonic crystals with periodicity in transverse direction supports mode which is referred as space filling mode (SMF) because they are infinitely extends in transverse direction. In the effective index method, the photonic crystal cladding is replaced by a single material with refractive index equal to the modal index of fundamental space filling mode [5]. The modal effective refractive index is calculated by solving the scalar wave equation within a unit cell of photonic crystal, centered on one of the holes. PCF can be well parameterized by V-parameter which is given as-

$$V_{PCF} = \frac{2\pi}{\lambda} \mathrm{a} \sqrt{(\eta_{co}^2 - \eta_{fsm}^2)} \qquad (1)$$

With

$$U = \frac{2\pi}{\lambda} a \sqrt{\eta_{co}^2 - {\eta_{cl}}^2} \qquad (2)$$

$$W = \frac{2\pi}{\lambda} a \sqrt{\eta_{cl}^2 - {\eta_{fsm}}^2} \qquad (3)$$

$$u = \frac{2\pi}{\lambda} b \sqrt{\eta_{fsm}^2 - {\eta_{cl}}^2} \qquad (4)$$

$b = \Lambda\sqrt{\frac{\sqrt{3}}{2\pi}}$ for hexagonal PCF

$b = \Lambda\sqrt{\frac{2}{\pi}}$ for square lattice PCF

Where η_{co} and η_{fsm} are the refractive index of core and the space filling mode respectively. ‘a’ is the effective area of core region and b is the core radius.

The effective area of the photonic crystal fiber can be calculated from the formula

$$A_{eff} = \frac{\left[\iint_{-\infty}^{\infty} |F(x,y)|^2 dx\, dy\right]^2}{\iint_{-\infty}^{\infty} |F(x,y)|^4 dx\, dy} \qquad (5)$$

Where $F(x, y)$ is the modal field distribution inside the fiber.
The spot size or the mode field diameter W_{pcf} is calculated directly from the Peterman II equation. The equation is given by-

$$W_{pcf} = \sqrt{2}\rho \frac{J_1(U_{eff})}{W_{eff} J_0(U_{eff})} \qquad (6)$$

Where ρ is the core radius of PCF and J is the Bessel function.

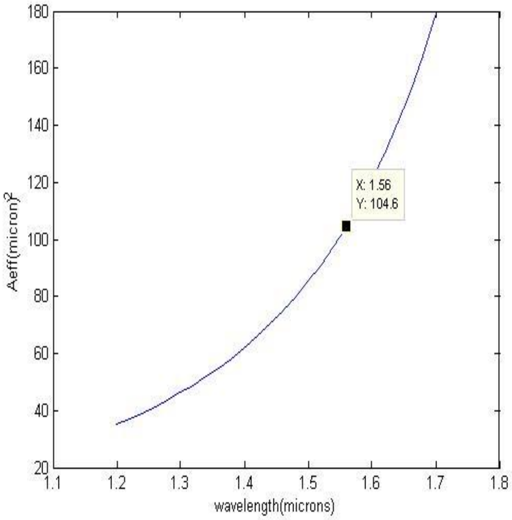

Fig 4: Effective area of square lattice PCF

The Effective area plot of hexagonal PCF is shown below. From the two plots of A_{eff}, it is clear that in the entire telecommunication band, the effective area of square lattice PCF is larger than that of the hexagonal PCF. Specially at 1.56µm of telecommunication band the effective area of square lattice PCF is 104µm^2 and that of the hexagonal PCF it is 45.29µm^2.

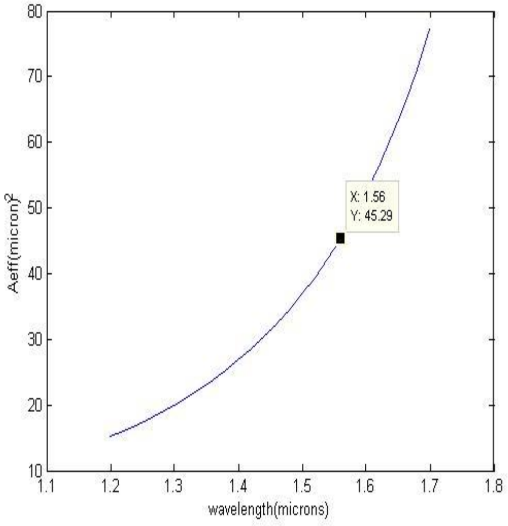

Fig 5: Effective area of Hexagonal PCF

The splice loss occur due to misalignment when two optical fibers are joined together. It is an important parameter to calculate when two PCF are spliced. In this paper splice loss is calculated by using the spot size values. The splice loss in terms of spot size is given as

$$\alpha(dB) = 4.343\left[\frac{u}{W_{pcf}}\right]^2 \qquad (7)$$

Where u is transverse offset between two fibers.

It is clear from the plot that the splice loss of both the fibers are very low i.e.; nearly zero. In case of square lattice PCF the splice loss at 1.56µm of telecommunication band is given as 0.0006115dB for air hole diameter 0.4µm. but it is 0.0008241dB at same frequency in hexagonal PCF with same structural parameter. It is clear from the diagrams that the splicing loss dominates as we go to larger size of air hole diameter.

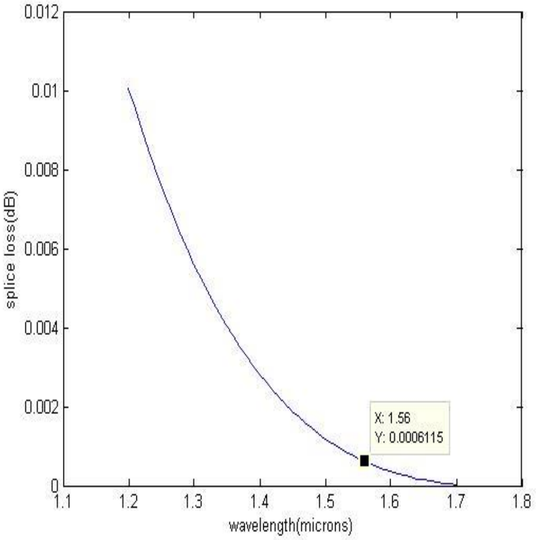

Fig 6: splice loss of square lattice PCF with d=0.4µm, Λ=3µm

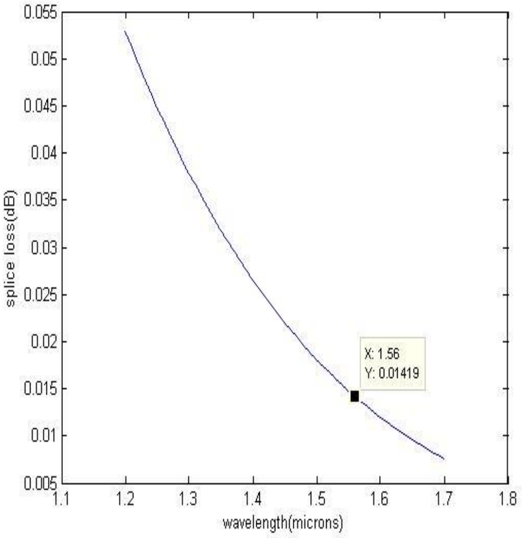

Fig 7: splice loss of square lattice PCF wth d=0.5µm, Λ=3µm

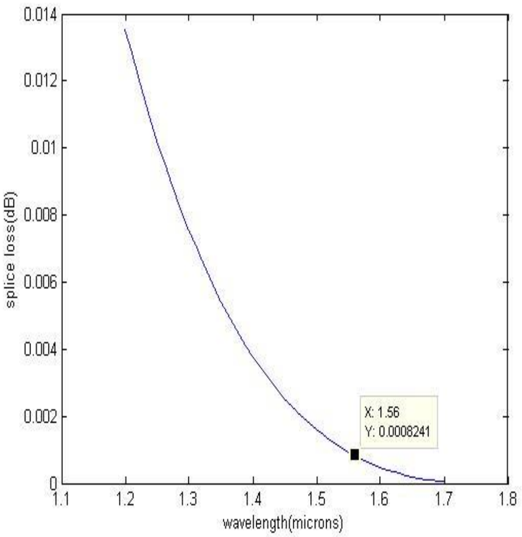

Fig: splice loss of hexagonal PCF with d=0.4μm, Λ=3μm

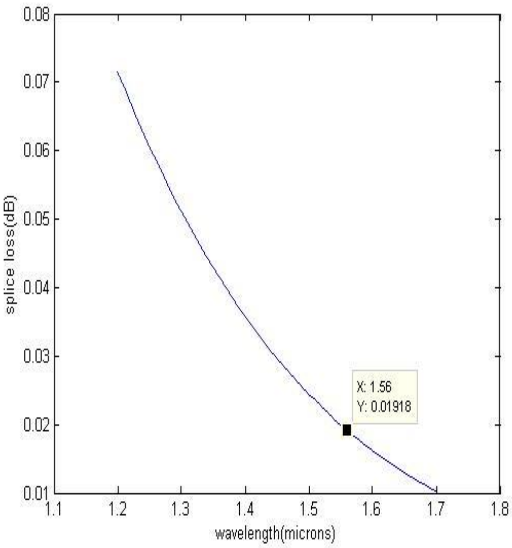

Fig: splice loss of hexagonal PCF with d=0.5μm, Λ=3μm

From the given plots it is clear that with increasing the air hole size of the PCF, the splice loss of the corresponding fiber also increases. We can see from the figure that at d=0.5μm, the splice loss is 0.014dB for square lattice PCF and it is 0.019dB for hexagonal PCF. The lattice constant Λ=3μm is taken same for all the structures. The total number of air hole rings in the structure used is three.

IV. CONCLUSIONS

Studying the result of two photonic crystal structure i.e. square and hexagonal PCF, shows that the by using sufficient number of dimensional parameter, the effective area of the square lattice is larger than that of hexagonal lattice. Thus allows more power level in the fiber which will be very useful in modern triple-play delivery of voice, data and tele-services for the telecommunication purpose. The splice loss is also comparatively less for square lattice PCF. Hence it will also be suitable for FTTH communication application.

ACKNOWLEDGEMENTS

This work is well supported by the electronics department of National Institute of Technology, Patna (BIHAR) for the partial fulfillment for the award of degree of M Tech in Communication System.

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