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Optical Parameters Analysis of Photonic Crystal Fiber with Rectangular Lattice Geometry

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Authors' contributions

This work was carried out in collaboration between all authors. Author MBH designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MAK and AAMB managed the analyses of the study. Authors EP and MKH managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This paper investigates effective refractive index, confinement loss and waveguide dispersion for rectangular photonic crystal fiber (PCF) with five layers of air holes.

Methodology: The analysis of these properties is done by changing air hole diameter and lattice pitch. Three different materials namely borosilicate glass, fused quartz glass and sapphire glass are taken as fiber background material. The Finite domain Time-difference method is used for simulation and simulation work is carried on in Opti-FDTD software.

Results: This research work offers with low confinement loss and high negative dispersion for all the three materials for wavelength range from 1200 nm to 1600 nm. Low confinement loss is obtained for the largest air hole diameter from air hole diameter variation and for largest lattice pitch from lattice pitch variation. The lowest confinement loss is found around 0.7×10^{-8} dB/km for fused quartz glass at wavelength 1550 nm for largest pitch (2.3 µm) among all the three materials.

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Again, Large negative dispersion is found for the largest air hole diameter from diameter variation but for the lattice pitch variation, it is achieved from the smallest lattice pitch. Highest negative dispersion is found form sapphire glass when air hole diameter is 0.6 μm and lattice pitch is 1.71 μm. The highest negative dispersion is found approximately -1500 ps/(nm.km) at wavelength 1575 nm.

Conclusion: High negative dispersion is greatly desirable in telecommunication field which has been demonstrated at the simulation output.

Keywords: Rectangular photonic crystal fiber; effective refractive index; large negative dispersion; low confinement loss.

1. INTRODUCTION

Photonics crystal fiber (PCF) has enlarged the communication field with high speed communication. PCF is a newly emerged fiber which gives enhanced design freedom beyond the traditional fiber [1,2,3]. PCF is the greatest successful technology in fiber optic field. It exhibits high power-handling, high nonlinearity as well as controllable dispersion properties [1,4]. A conventional PCF having high-nonlinearity has silica core with numerous air holes arranged periodically in cladding region [5]. In conventional optical fiber, light propagates through it using total internal reflection concept and the core material has larger refractive index than the cladding material to make total internal reflection. But, light propagation mechanism in PCF is far different than conventional fiber. According to light guiding machinery of PCFs, they can be characterized into two types: Index guiding PCF and Photonic band gap (PBG) fiber [6]. Index guiding PCF consists of periodic arrangement of air holes surrounding the core region where these air holes snare light propagation through core region [7,8]. But, in PBG fiber light propagates through PCF in a low index core region for some specific frequency [9-11].

Effective refractive index is an important term for the calculation of diverse parameters of optical communication which change with operating wavelength. Confinement loss, Waveguide dispersion, birefringence, coupling length, effective area etc. can be calculated by using effective refractive index. The effective refractive index gets changed with the change of air hole diameter and lattice pitch. So, by changing air holes, diameter and lattice pitch, effective refractive index can be changed which results in change of dispersion, confinement loss etc. [12,13].

Photonics crystal fibers draw the attention of many researchers in recent years because of their unique and attractive properties such as high non-linearity, better light confinement etc. There are a large number of published papers on PCF where they have tried to achieve low confinement loss, small effective area as well as large negative dispersion [14,15]. With the blessing of PCF, it is possible to design specific application oriented fiber, so there is still scope to design new structure of PCF to get result of optical properties.

The prime aim of this research is to analyze the effects of air hole diameter and lattice pitch variation on the confinement loss as well as waveguide dispersion.

2. METHODS AND MATERIALS

The main objective of our investigation is to study the refractive index, confinement loss, waveguide dispersion of solid core rectangular PCFs by varying air hole diameter and lattice pitch. The structural parameters are given below for the proposed rectangular shape PCFs:

Hole diameter, d = 0.60, 0.65, 0.70, 0.75, 0.80 μm

Lattice Pitch, Λ = 2.30, 2.14, 2.00, 1.81, 1.71 μm

Air-fraction Refractive index = 1.0

Background material Refractive index –

- Fused quartz glass, n=1.46
- Borosilicate glass, n=1.47
- Sapphire glass, n=1.762

When light is sent from one end of fiber to another end of fiber, then the total amount of light is not confined through the fiber. Some amount of light is lost if laser light is not placed in suitable position of fiber. The confinement loss can be calculated by using the following equation [14]:

$$L_c = 8.686 K_0 \operatorname{Im}[n_{eff}]$$

Here, $K_0 = 2\pi/\lambda$ and Im (n_{eff}) is the imaginary part of effective refractive index.

Waveguide dispersion is another important optical property which can be calculated from the following equation [16]:

$$D(\lambda) = -\frac{\lambda}{c}\left(\frac{\partial^2 R_e(n_{eff})}{\partial \lambda^2}\right)$$

Here, λ is the wavelength and c is the speed of light.

The research work is performed in two steps. In the first step, we have used OPTI FDTD software for creating the rectangular photonic crystal fiber for three different materials. The simulation parameters and mesh are set- mesh delta X=0.08 µm, mesh delta Z=0.08 µm, number of mesh cells X=273 and mesh cells Z=316. We create the rectangular PCF for each material with different air hole diameter like 0.60 µm, 0.65 µm, 0.70 µm, 0.75 µm, 0.80 µm and pitch like 2.30 µm, 2.14 µm, 2 µm, 1.81 µm, 1.71 µm. After defining all parameters, the simulation is run. In the second step, we have used MATLAB for driving confinement loss as well as waveguide dispersion with respect to wavelength.

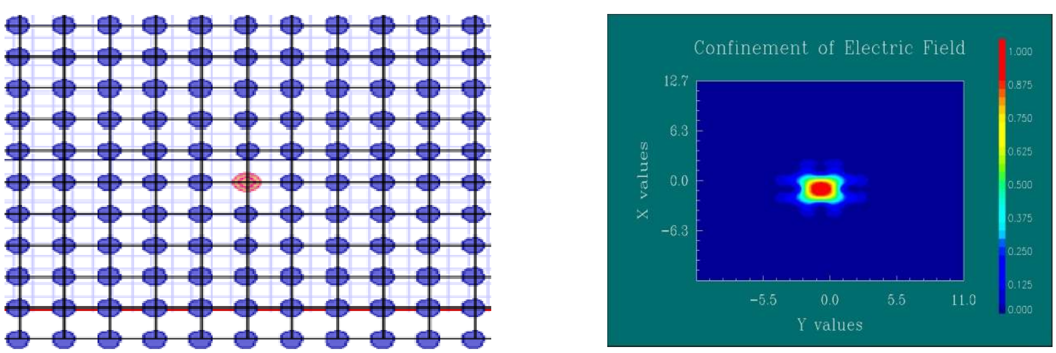
3. RESULTS AND DISCUSSION

Here, we have designed a solid core rectangular PCF geometry with five layers air holes and Fig. 1 shows the cross-section geometry and electric field distribution of the rectangular PCF.

Again, we have performed our simulation in two steps. Firstly, we have run the simulation by keeping lattice pitch constant (2.3 µm) and varying air hole diameter such as 0.60 µm, 0.65 µm, 0.70 µm, 0.75 µm and 0.80 µm. Secondly, we have performed the simulation by keeping air hole diameter constant (0.6 µm) and varying lattice pitch such as 2.30 µm, 2.14 µm, 2.00 µm, 1.81 µm and 1.71 µm. We have run all the simulation for wavelength from 1200 nm to 1600 nm and a point source is used as a laser to propagate light through the fiber.

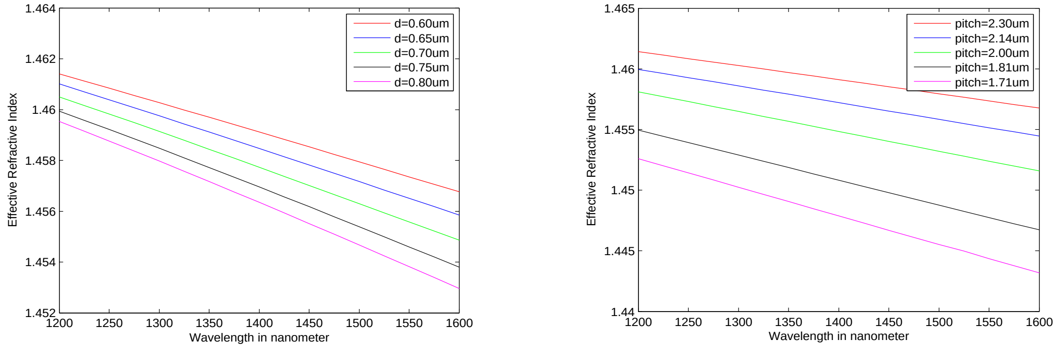
After mode is solved, we have got the effective refractive index with real and imaginary value. Then we have design effective refractive index, confinement loss and waveguide dispersion curve versus wavelength. The confinement loss is plotted in MATLAB by using first equation and Waveguide dispersion is plotted in MATLAB by using second equation. Here, the air hole diameter (d) is varied from 0.6 µm to .8 µm and lattice pitch is varied from 2.3 µm to 1.71 µm to show the effective refractive index profile. Figs. 2-4 show the effective refractive index curve versus wavelength for borosilicate glass, fused quartz glass and sapphire glass respectively at wavelength from 1200 nm to 1600 nm.

The refractive index, n = c/v where c is the speed of light in free space and v is the speed of light through fiber. Again, v = frequency × wavelength. As v increases with the increases of wavelength and c remains constant, so the effective refractive index of fiber decreases with the increases of wavelength. Figs. 2-4 show the effective refractive index (n_{eff}) diminishes with the increase of wavelength for both diameter change and lattice pitch change. But, it decreases rapidly for diameter change with constant pitch for all the three materials.



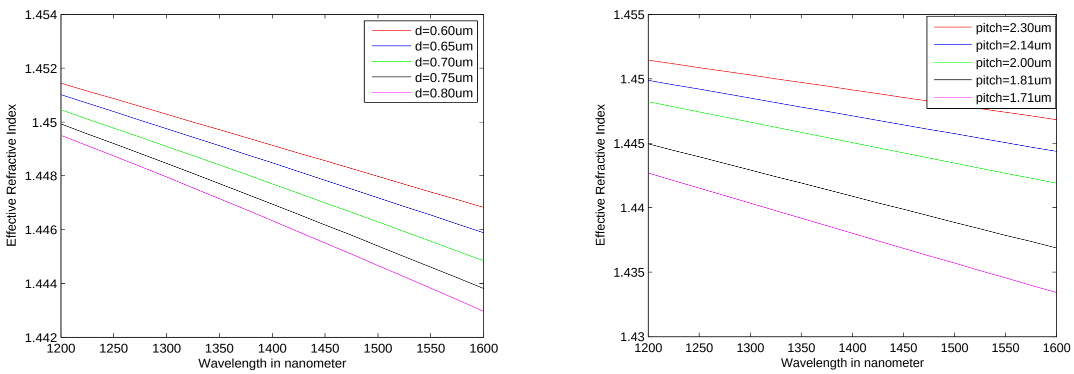
a) b)

Fig. 1. (a) Cross section geometry and (b) Electric field distribution for five rings rectangular PCF



a) b)

Fig. 2. Effective refractive index change of borosilicate glass due to (a) the change of hole diameter with pitch 2.3 µm and (b) the change of lattice pitch with diameter 0.6 µm



a) b)

Fig. 3. Effective refractive index change of fused quartz glass due to (a) the change of hole diameter with pitch 2.3 µm and (b) the change of lattice pitch with diameter 0.6 µm

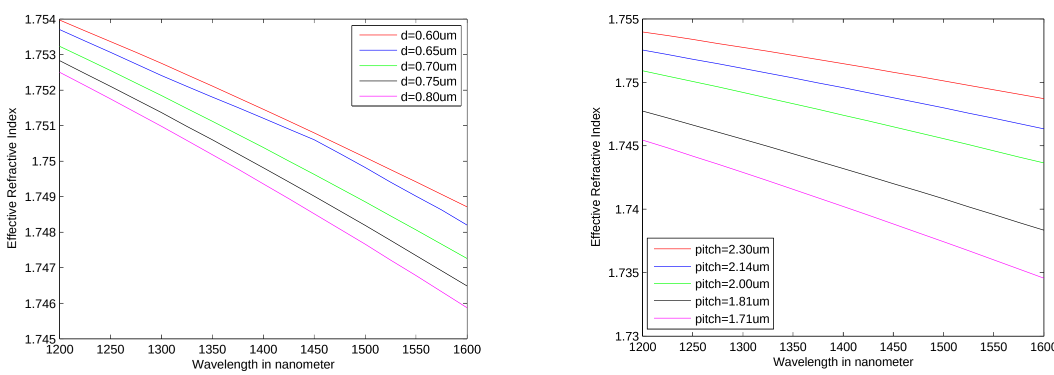
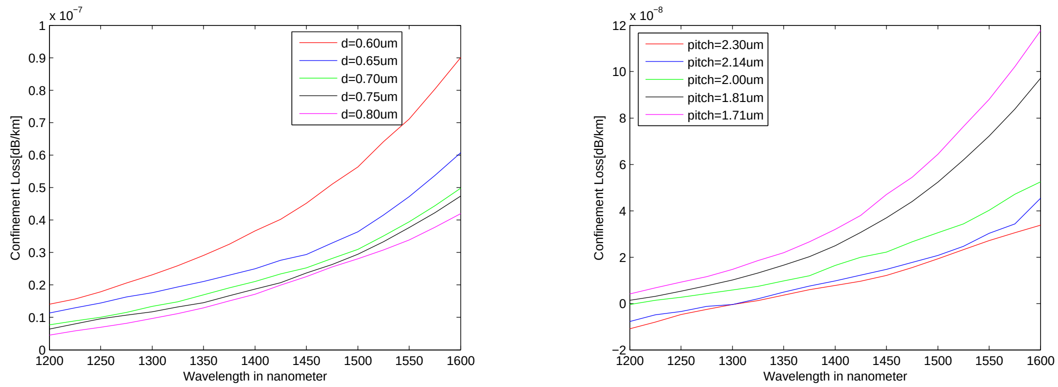


Fig. 4. Effective refractive index change of sapphire glass due to (a) the change of hole diameter with pitch 2.3 µm and (b) the change of lattice pitch with diameter 0.6 µm

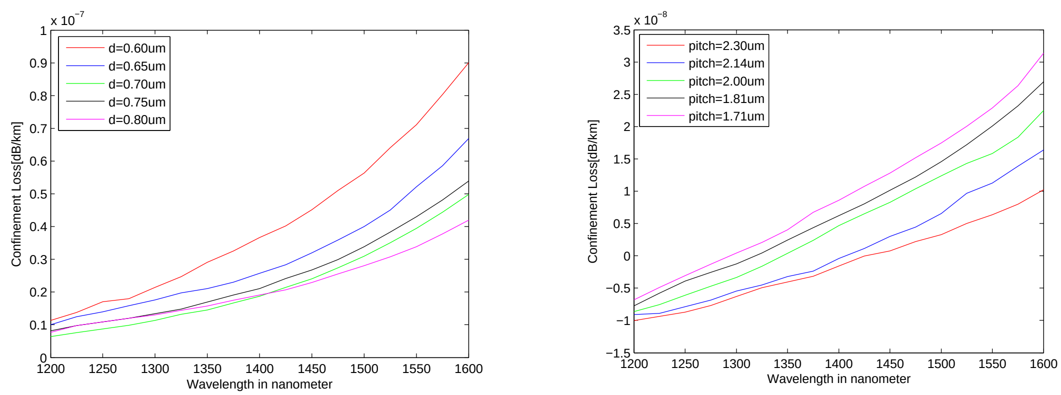
Here, the air hole diameter (d) is varied from 0.6 µm to .8 µm and lattice pitch is varied from 2.3 µm to 1.71 µm for the confinement loss calculation. Figs. 5-7 show the confinement loss curve versus wavelength for borosilicate glass, fused quartz glass and sapphire glass respectively at wavelength from 1200 nm to 1600 nm.

It is observed that, the confinement loss is increasing with the increase of wavelength for both diameter change and lattice pitch change. For the large lattice pitch with constant air hole diameter the light confinement is better than the large diameter with constant lattice pitch. Figs. 5-6 show the low confinement loss is obtained for



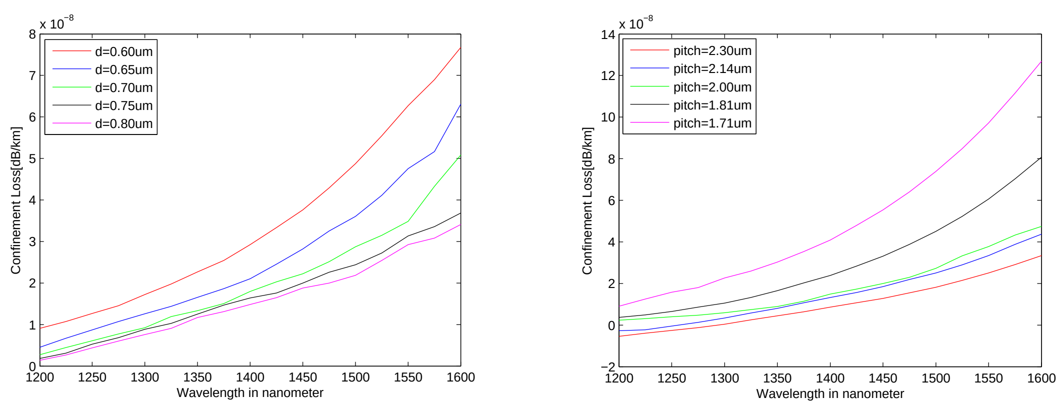
a) b)

Fig. 5. Confinement loss change of borosilicate glass due to (a) the change of hole diameter with pitch 2.3 µm and (b) the change of lattice pitch with diameter 0.6 µm



a) b)

Fig. 6. Confinement loss change of fused quartz glass due to (a) the change of hole diameter with pitch 2.3 µm and (b) the change of lattice pitch with diameter 0.6 µm



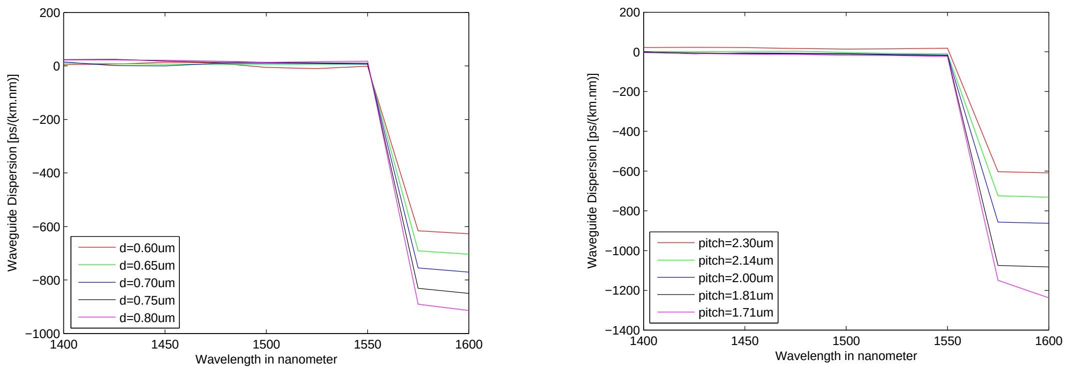
a) b)

Fig. 7. Confinement loss change of sapphire glass due to (a) the change of hole diameter with pitch 2.3 µm and (b) the change of lattice pitch with diameter 0.6 µm

largest diameter when pitch is constant as well as for largest pitch when diameter is constant. But better result is seen for largest pitch (2.3 µm) with constant diameter (0.6 µm) for all the three materials.

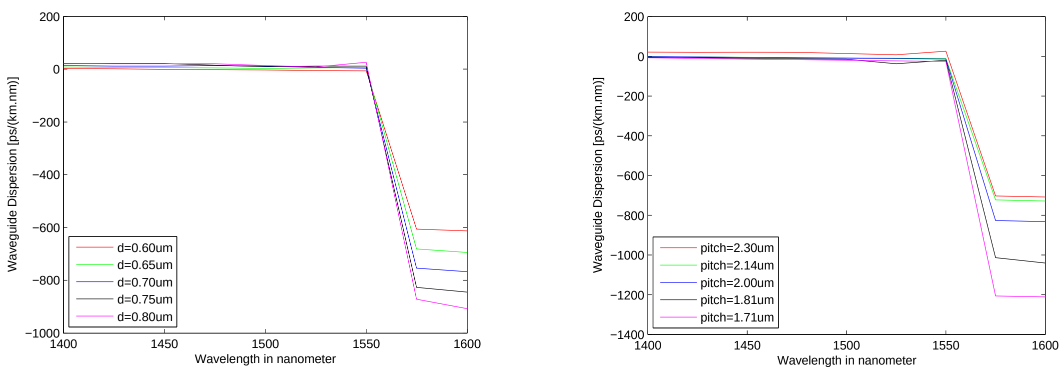
Confinement loss is found approximately 0.35×10^{-7} dB/km, 2.5×10^{-8} dB/km for borosilicate glass, 0.33×10^{-7} dB/km, 0.7×10^{-8} dB/km for fused quartz glass, 2.98×10^{-8} dB/km, 2.3×10^{-8} dB/km for sapphire glass from large diameter with constant lattice pitch and large pitch with constant diameter respectively at wavelength 1550 nm.

Here, the air hole diameter (d) is varied from 0.6 µm to .8 µm and lattice pitch is varied from 2.3 µm to 1.71 µm for the waveguide dispersion calculation. Figs. 8-10 show the waveguide dispersion curve versus wavelength for borosilicate glass, fused quartz glass and sapphire glass respectively at wavelength from 1200 nm to 1600 nm.



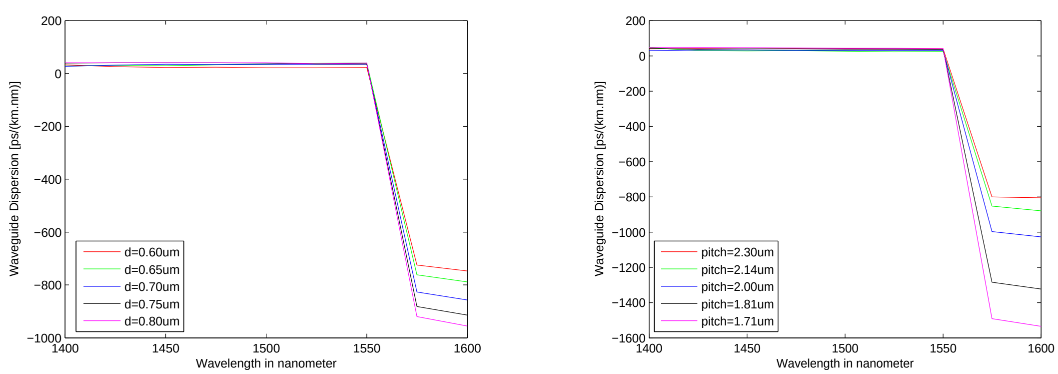
a) **b)**

Fig. 8. Waveguide dispersion change of borosilicate glass due to (a) the change of hole diameter with pitch 2.3 µm and (b) the change of lattice pitch with diameter 0.6 µm



a) **b)**

Fig. 9. Waveguide dispersion change of fused quartz glass due to (a) the change of hole diameter with pitch 2.3 µm and (b) the change of lattice pitch with diameter 0.6 µm



a) **b)**

Fig. 10. Waveguide dispersion change of sapphire glass due to (a) the change of hole diameter with pitch 2.3 µm and (b) the change of lattice pitch with diameter 0.6 µm

Approximately zero dispersion is obtained till wavelength of 1550 nm and after that dispersion curve starts to decrease for all three materials. For each material large negative dispersion is obtained for diminishing lattice pitch with constant air hole diameter rather than increasing diameter of air holes with constant lattice pitch. Large negative dispersion is found approximately -700 ps/(nm.km), -1150 ps/(nm.km) for borosilicate, -650 ps/(nm.km), -1200 ps/(nm.km) for fused quartz glass, -920 ps/(nm.km), -1500 ps/(nm.km) for sapphire glass from largest diameter with constant pitch and largest lattice pitch with constant diameter respectively at wavelength 1575 nm. For the proposed geometry, among the three background materials, the highest negative dispersion is found from sapphire glass approximately -1500 ps/(nm.km) at 1575 nm when air hole diameter is constant (0.6 µm) and lattice pitch is diminished to 1.71 µm where the height negative dispersion is approximately -920 ps/(nm.km) at 1575 nm wavelength when air hole diameter is increased to 0.80 µm and lattice pitch is constant (2.3 µm).

4. CONCLUSION

Here, we have designed a rectangular PCF with air holes of five layers. We have analyzed the confinement loss and wave guide dispersion for borosilicate glass, fused quartz, sapphire glass by changing air hole diameter and lattice pitch at wavelength range from 1200 nm to1600 nm. Low confinement loss is achieved for the largest air hole diameter from air hole variation and for largest lattice pitch from lattice pitch variation. The lowest confinement loss is found around 0.7×10^{-8} dB/km at wavelength 1550 nm for fused quartz glass for largest pitch (2.3 µm) among all the three materials. Moreover, the large negative dispersion is found from the largest air hole diameter for diameter variation as well as from the smallest lattice pitch for the pitch variation. Highest negative dispersion is found from sapphire glass when air hole diameter is constant (0.6 µm) and lattice pitch is diminished to 1.71 µm and it is found approximately -1500 ps/(nm.km) at wavelength 1575 nm.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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