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DESIGN OF PHOTONIC CRYSTAL FIBER FOR MINIMUM CONFINEMENT LOSS BY VARYING THE SIZE OF HOLES

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ABSTRACT

Photonic-crystal fiber (PCF) is a new class of optical fiber based on the properties of photonic crystals. Because of its ability to confine light in hollow cores or with confinement characteristics not possible in conventional optical fiber, PCF is now finding applications in fiber-optic communications, fiber lasers, nonlinear devices, high-power transmission, highly sensitive gas sensors, and other areas. In this paper confinement Loss had been calculated and we know that confinement loss can be calculated on basis of the diameter, pitch and shape of holes. Confinement loss is the loss which should be minimized so that the information to be transmitted is confined in the centre and it should not be dispersed. A 4-layer PCF is designed with different values of diameter of various layers.

KEYWORDS: Confinement, Gas Sensors, Confinement Loss, Dispersion

INTRODUCTION

Optical Fibers have brought a great revolution in the field of Communication as they have provided better quality and good properties of the signal. But they also had limitations with respect to losses, dispersion and non linearity.

The photonic crystal fiber (PCF) is a novel single-material optical waveguide realized by an arrangement of air-holes running along the full length of the fiber. Since the proposal of the PCF in 1996, the technology has developed into being a well-established area of research and commercialization. Due to their wonderful properties PCFs have attracted a great deal of interest. PCF can realize endlessly single-mode operation, flexible Chromatic dispersion over a wide wavelength range, large effective area, controllable nonlinearity, ultralow loss and high group birefringence. PCFs provide confinement and guidance of light in a defect region around the centre as they are single-material fibers with an arrangement of air holes running along the length of the fiber. For the light confinement mechanism, index guiding PCFs rely on total internal reflection to confine light in the region of a missing air hole forming a central core.

Confinement loss (CL), including cladding material losses, is comprehensively evaluated for TE, TM, and hybrid modes of hollow-core Bragg fibers. Small-core holey fibers (HFs) can offer tight mode confinement, and are, therefore, attractive for highly nonlinear fiber applications. However, confinement loss can significantly degrade the performance of devices based on such small core fibers. We also identify a range of fiber designs that result in high fiber nonlinearity and low confinement loss.

In this paper we have tried to study confinement loss by varying the size of the holes and simultaneously we have also tried to study the dispersion characteristics and tried to confine it to nearly zero dispersion. We can see that confinement loss when trying with different sizes of the holes starting from inside. PCFs can have a significantly larger numerical aperture than conventional fiber types because the cladding region can be mostly comprised of air. When this is combined with a wavelength-scale core, PCFs can provide tight mode confinement (i.e., small values of the effective mode area). In such fibers, high light intensities are guided within the core.

The loss in PCFs occurs for a variety of reasons: intrinsic material absorption, additional losses arising during the fabrication process (water contamination, absorption due to impurities, scattering, etc.), and confinement loss [5].The core has the same refractive index as the material beyond the finite holey cladding region, and so every propagating mode is intrinsically leaky, and so experiences confinement loss [5]. Fabrication-related losses can be reduced by careful optimization as we have tried in the proposed designs.

To reduce the impact of confinement loss, we have used the multipole method developed in [5] and [9] to analyze a variety of structures. For this, the cladding region is enclosed within a circular silica jacket with a complex refractive index, which allows the jacket to absorb the portion of the mode that leaks and, thus, the confinement loss to be estimated.

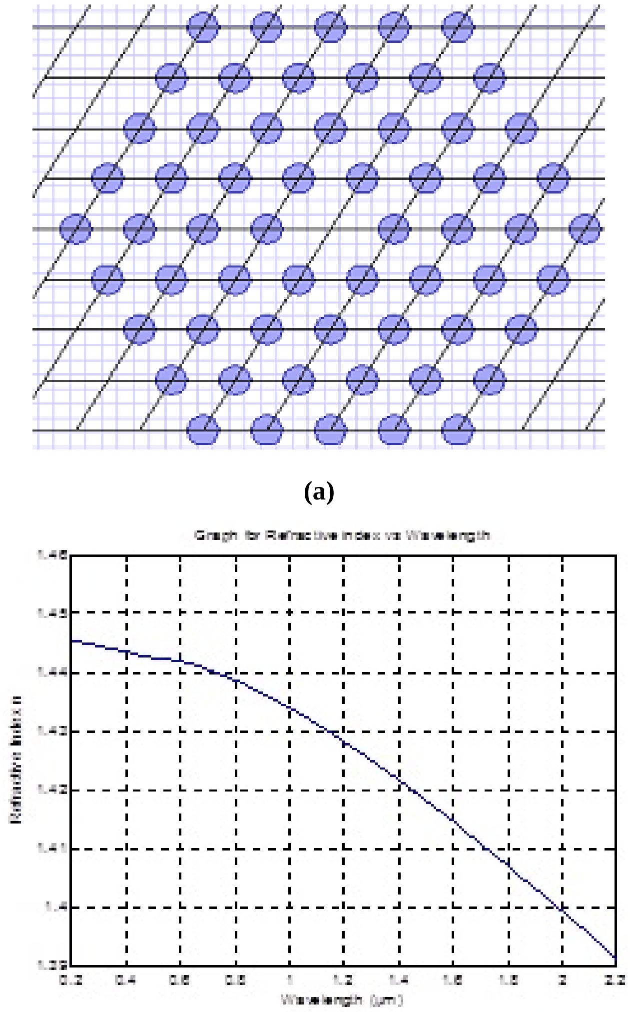
VARIOUS DESIGNS OF PCF TO REDUCE CONFINEMENT LOSS

Study of various types of Photonic Crystal Fibers has been done separately and the comparative study has been done then. In this paper we have used OptiFDTD to analyze various properties like dispersion and confinement loss of variable Photonic Crystal Fibers of different hole sizes.

PCFs or holey fibers guide the light via one of two mechanisms: effective-index guidance and photonic-bandgap (PBG) guidance. In the PCFs with effective- index mechanism, the light is guided based on the total internal reflection between a solid core and a cladding region with multiple air-holes [2]. On the other hand, PCFs based on PBG have the capability to control the guidance of light within a certain frequency band [4]–[6]. In general, PCFs show attractive features, such as a wide wavelength range, essential for transmitting ultra short pulses, bend loss edge at short wavelengths, and unusual dispersion properties at visible and near infrared wavelengths [4], [7], [8]. PCFs fabricated from undoped silica provide low losses, sustain high powers and temperature levels, and can even withstand nuclear radiation. Growing interest is being shown in such PCFs for applications in sensing, signal processing and optical communication systems [7]–[12].

In this we have started with the basic shape that is hexagonal and the shape is being taken circular. Refractive Index is being taken to be n=1.45, pitch (distance between the cells) ^ equal to 2.0μm and wavelength λ =1.55μm.Various designs have been taken into consideration and starting from the first design in which d = 1.0μm and hence r = 0.5μm and when d/^ calculated it comes out to be equal to 0.50. In this case at λ=1.55μm refractive index comes out to be 1.416 while confinement loss is equal to -0.00006404. Then the values of confinement loss and dispersion have been calculated starting from λ=0.2μm to λ=2.2μm.The PCF which had been designed is taken of 4-layers. Then in the second design we have tried to change the variation of Refractive Index and hence the respective confinement loss by varying the hole size of the innermost layer equal to d1=0.6μm and rest three layers having diameter equal to d2= d3= d4=1.0μm and pitch is kept the same i.e. equal to 2.0 μm. We can also design 5-layer fiber which will show some different properties. We can also use various boundary conditions to check the properties like confinement loss and dispersion.

When using the FEM the PCF domain is divided into many sub-domains with triangular shaped elements in such a way that where the step index profiles can be exactly represented. The FEM formulation for modal analysis based on anisotropic perfectly matched layers (PML) is capable of handling as many modes as required and analyse the leaky modes. By using PMLs as boundary condition, propagation characteristics of leaky modes in PCF and both dispersion and loss properties can be accurately evaluated. We can also design dual concentric fibers or fibers with square holes at the same optical wavelength to reduce confinement loss and dispersion.

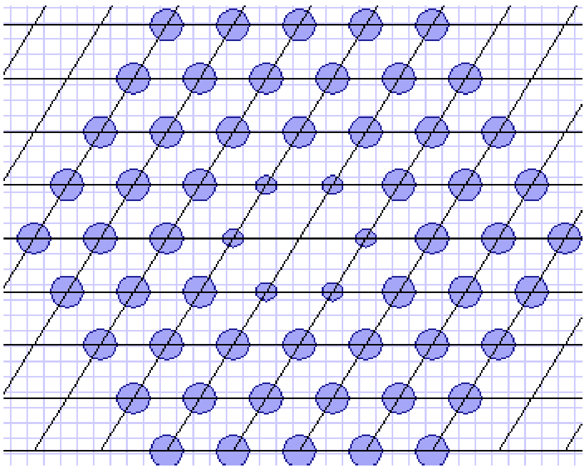


(a)

(b)

Figure 1: a) PCF with d1=d2=d3=d4=1.0μm b) Graph for Refractive Index versus Wavelength

In this paper, we have proposed PCF designs that simultaneously exhibit high birefringence, low confinement losses and ultralow and flattened chromatic dispersion at a wide wavelength. We have employed the full-vectorial finite element method (FEM) to design PCFs. The FEM is a powerful numerical tool able to deal with many complex structures and provide full vector analysis of different photonic waveguide devices [17]–[19].



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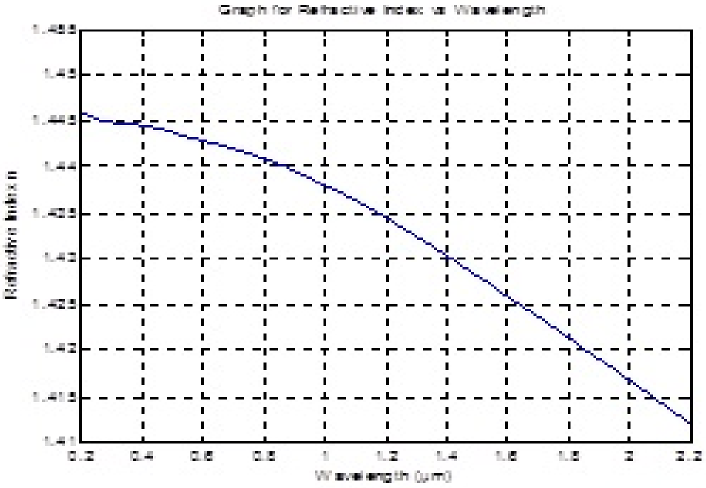

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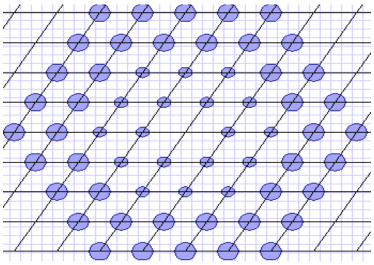
Figure 2: a) PCF with d1=0.6µm and d2=d3=d4=1.0µm b) Graph for Refractive Index versus Wavelength

In Figure 3 a) we have again changed the diameter of the holes in the PCF to observe the change in refractive index profile and trying to improve the confinement loss. We have kept the diameter of the innermost two layers equal to 0.6µm and the outer two rings diameter is equal to 1.0µm. PCFs having good birefringence can be simply realised compared to conventional fibers, since the refractive index contrast between the core and the cladding is higher than the refractive index contrast of conventional fibers. The structural symmetry can be changed either by altering the air hole sizes near the core area, or by distorting the shape of the air holes. The proposed highly birefringent PCFs that simultaneously exhibit low confinement loss, ultralow and ultra flattened chromatic dispersions at wide wavelength band have potential for a number of future applications such as high bit rate communication systems, polarization maintaining devices, and sensing systems.



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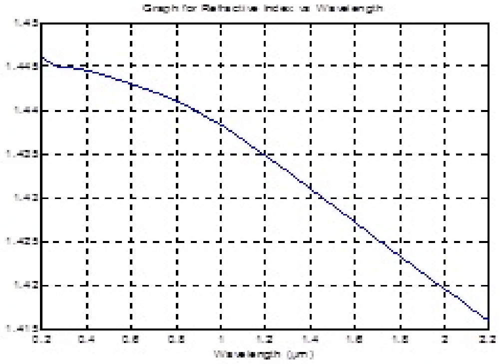

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Figure 3: a) PCF with d1=d2=0.6µm and d3=d4=1.0µm b) Graph for Refractive Index versus Wavelength

In figure 4 we have again changed the diameter of 3rd layer and hence only the outer layer is having the diameter equal to 1.0µm and rest inner three layers are having the diameter 0.6µm .Refractive Index n comes out to be 1.42834 at λ=1.55µm and Confinement loss comes out to be equal to 0.00040379 which has increased a little bit compared to previous designs.

The PCF cross sections, with a fixed number of air holes are divided into homogeneous subspaces where Maxwell's equations are solved by accounting for the adjacent subspaces. These subspaces are triangles that permit a good approximation of the PCF structures [12], [18]. From Maxwell's curl equations we can obtain the vector wave equations for electric field E and magnetic field H.

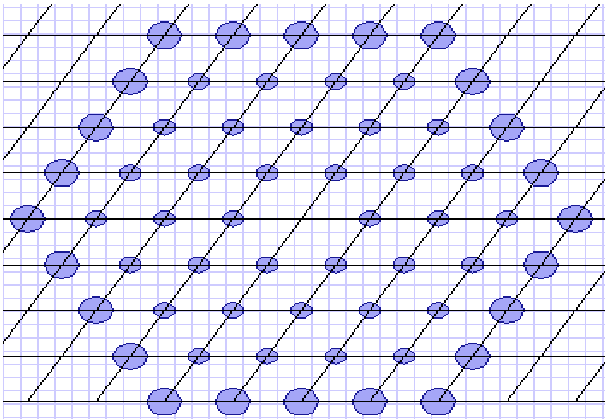
$$\nabla \times E + \frac{i\omega}{c} H = 0 \qquad)$$

$$\nabla \times . \qquad (2)$$

From (1) and (2) the following equation can be obtained:

$$\nabla \times [\nabla \times \qquad (3)$$

where ε_r is the relative permittivity of the medium, c is the velocity of light in vacuum and ω is the angular frequency.



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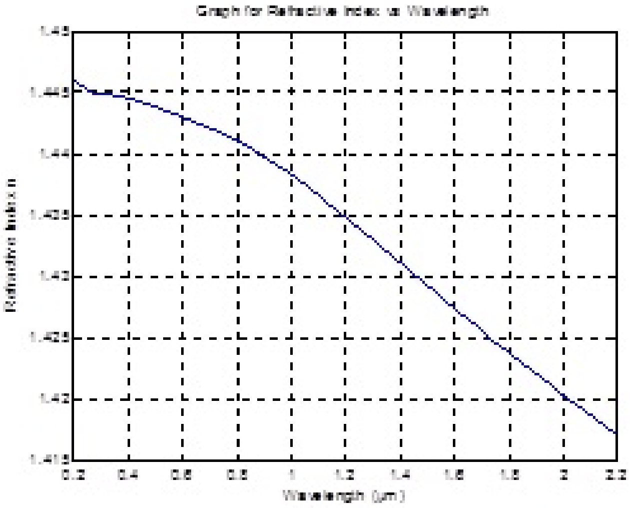
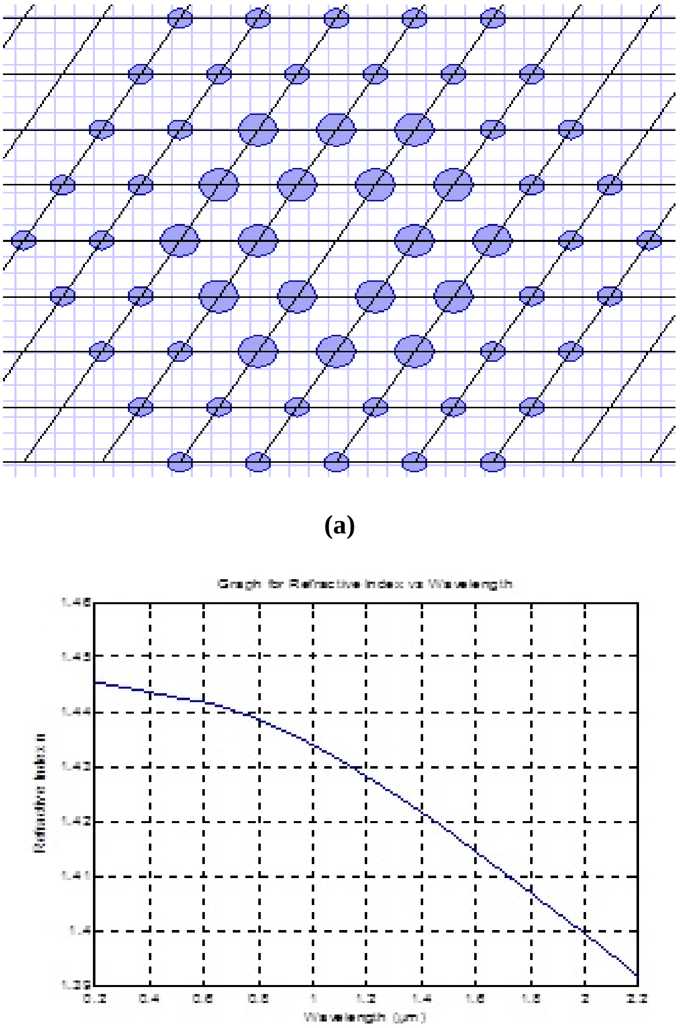


(b)

Figure 4: a) PCF with d1=d2=d3=0.6µm and d4=1.0µm b) Graph for Refractive Index versus Wavelength

Lastly we have designed another 4-layer fiber in which the four layers are equally divided in two and both the layers are having equal diameters. Innermost two layers are having diameter d1 = d2 = 1.0 µm and outermost layers are having diameter d3 = d4 = 0.6µm and the pitch is still the same i.e.2µm. By comparing the confinement losses in all the graphs we can see that this is the best design in which we are getting the lowest confinement loss.

The design of PCF structures with small mode areas that lead to a high nonlinear coefficient is an ongoing challenge. By varying the size of the air holes in the cladding region and the hole-to-hole spacing, desired effective mode areas can be obtained [7], [8], [16]. A small core diameter that leads to low effective mode area can be reduced by having a relatively small hole-to-hole spacing. In recent years, highly birefringent PCFs with nonlinear properties have received growing attention in telecommunication and super continuum applications.



(a)

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Figure 5: a) PCF with d1=d2=1.0µm and d3=d4=0.6µm b) Graph for Refractive Index versus Wavelength

CONFINEMENT LOSS

The jacket of the fiber is far from cladding and core area, propagation of the light in the core area is due to a finite number of layers of air holes in bulk silica extending to infinity. Due to the fixed number of layers of air holes, leaking of the light from the core to the exterior matrix material takes place through the bridges between air holes, resulting in confinement loss [9]. The field confinement and its decay rate have a fundamental role in the leakage properties. The confinement loss is calculated from the imaginary part (Im) of the complex effective index, using the following equation:

$$\text{Conf. Loss} = \frac{40\pi}{\ln(10)\lambda} Im\left(n_{eff}\right) = 8.686 k_o Im$$

When calculated confinement loss for the above designs we observed that the best and lowest confinement loss came out to be for the 4-layer PCF having d1=d2=1.0µm and d3=d4=0.6µm.The wavelength range is taken to be between 0.2µm and 2.2µm.Confinement loss came out to be near about -0.09 dB/m which is the lowest value among the above designs. The precision of method depends on the accuracy of the imaginary part of the effective index.

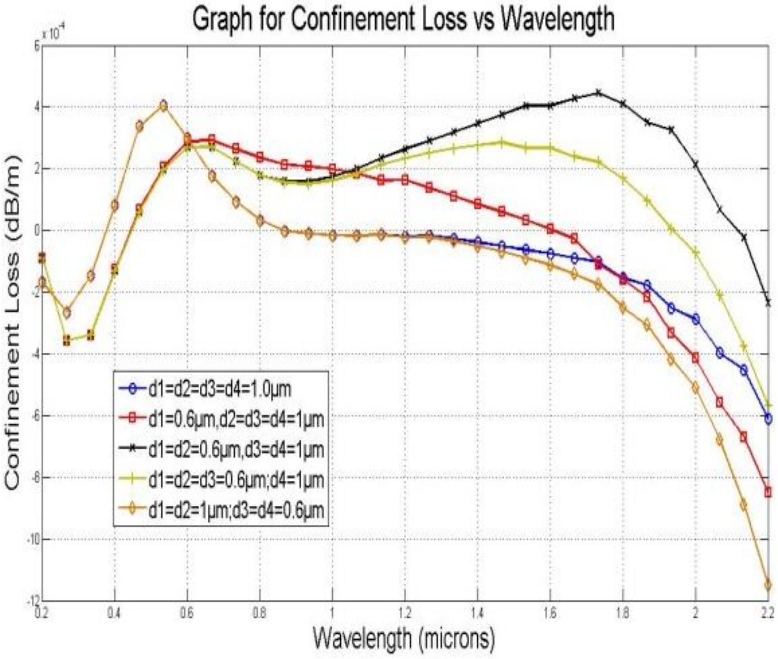

Figure 6: Comparative Graph for Various PCFs of Varying Diameters for Wavelength versus Confinement Loss

DISPERSIONS

In optics, dispersion is the phenomenon in which the phase velocity of a wave depends on its frequency,[1] or alternatively when the group velocitydepends on the frequency. Media having such a property are termed *dispersive media*. Dispersion is sometimes called *chromatic* dispersion to emphasize its wavelength-dependent nature, or group-velocity dispersion (GVD) to emphasize the role of the group velocity. Dispersion is most often described for light waves, but it may occur for any kind of wave that interacts with a medium or passes through an inhomogeneous geometry (e.g., awaveguide), such as sound waves. Total Dispersion is the combination of material and waveguide dispersion. Chromatic Dispersion is the main contribute to the optical pulse broadening.

We have seen that from the above designs the best design which is having lowest confinement loss is the design having d1=d2=1.0µm and d3=d4=0.6µm. So for this type of PCF we have calculated dispersion and we have noted that the dispersion is flattened and comes out to be near about equal to zero as the wavelength is increasing.

Control of the chromatic dispersion in PCFs is essential for practical applications in optical communication systems, dispersion compensation and linear/nonlinear optics. In the short wavelength range, the guided mode is well confined into the PCF core region and the dispersion property is affected by the inner air-hole rings. In the long wavelength range, the PCF effective core area is increased and the dispersion is affected not only by inner rings but also by the outer rings, particularly when the hole-to-hole spacing is small.

Dispersion starting from higher value in the proposed design decreases to a lower value moves towards a lower level and then to a higher level with a slight increase and then finally reduces to zero value.

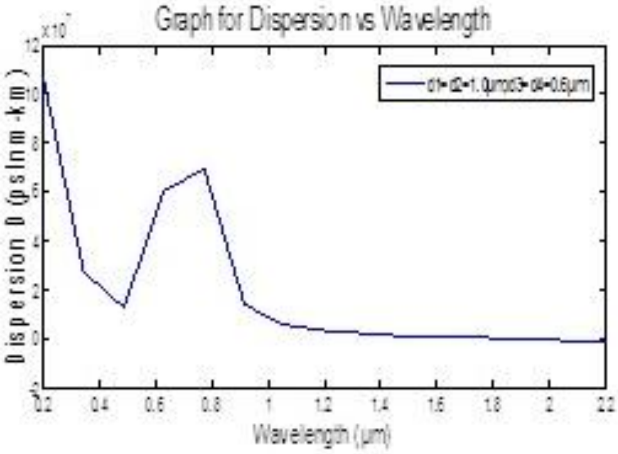

Figure 7: Dispersion Curve for the Design Having Lowest Confinement Loss

CONCLUSIONS

Photonic crystal fibers can be divided into two modes of operation, according to their mechanism for confinement. Those with a solid core, or a core with a higher average index than the microstructured cladding, can operate on the same index-guiding principle as conventional optical fiber — however, they can have a much higher effective-refractive index contrast between core and cladding, and therefore can have much stronger confinement for applications in nonlinear optical devices, polarization-maintaining fibers. In this paper we have designed various types of fibers and among these fibers the last fiber having equal number of layers having same diameter is showing the lowest confinement loss and hence the best design proposed is this one. However, at higher wavelengths we can see that the design having diameter of innermost layer the least is having very less confinement loss. We can also propose in future a design having less confinement loss by changing the shape of the holes like square or elliptical. Fabrication of the proposed PCFs is believed to be possible with a high feasibility and is not beyond the realm of today's existing PCF technology.

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