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Analysis of Borosilicate Crown Glass PCF for Near Zero or Flat Dispersion and Minimum Confinement Loss at 1.55µm

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Abstract: The dispersion in PCFs likewise other conventional optical fibers determines performance of optical systems. In this paper we investigate the method for chromatic dispersion and confinement loss of Borosilicate crown glass from the scalar effective index method using transparent boundary condition with combination of linear and elliptic waveguide. It has been demonstrated that it is possible to obtain zero dispersion in a wavelength range of 1.5 to 2.0 µm from a eight ring into which inner five ring are designed with circular air holes and the outer three ring are designed by using square air holes for the calculation of Flat and near zero dispersion and minimum confinement loss in PCF within range of 0.5 to 2.0 µm wavelength. Finite-difference time domain (FDTD) method has been used for investigation.

Keywords: Photonic crystal fibers (PCFs), Chromatic dispersion, Confinement losses, SVEI Method. Linear waveguide.

1. INTRODUCTION

Many research teams are investigating materials and a few researchers are using them to form new types of optical fibers. Such fibers are known as photonic crystal fibers (PCFs). PCF, known as holey fiber, is a microstructure fiber consisting of air hole array that run along the waveguide length of the fiber.

Photonic crystals [2] usually consist of dielectric materials that serve as electrical insulators or in which an electromagnetic field can be propagated with low loss. Holes are arranged in a lattice-like structure in the dielectric and repeated identically and at regular intervals, the resulting crystal will have what is known as a photonic band gap, a range of frequencies within which a specific wavelength of light is blocked. The holes used in the lattice structure could be of different diameter or different shape. Elliptic waveguide [5] properties are used to fabricate the circular air holes by varying the value of major axis and minor axis and Linear waveguide is used to design the squared shape holes by varying the starting and ending point of the holes in horizontal and vertical axis. From the investigation I observed that square air holes in the outer rings provide flattened dispersion at the wavelength range from 1.0 µm to 2.0 µm. In this paper we used both elliptic and Linear waveguide to design the air holes.

The most important factor for any optical fiber technology is losses of signal. Here we try to find out the flattened dispersion and to reduce confinement losses by using borosilicate crown glass as core material. Most BK7 is colorless 70% silica, 10% boron oxide, 8% sodium oxide, 8% potassium oxide and 1% calcium oxide [3] are used in the manufacture of borosilicate glass.

TABLE 1: COMPARISON OF BOROSILICATE AND SILICA GLASS

Properties	Silica Glass	BK7 Glass
Density(g/cm^3)	2.2	2.51
Refractive Index(µm)	1.458	1.516
Light Transmission Wavelength(µm)	0.18 to 2.5	0.35 to 2.5
Maximum Temperature (degree C)	1120	560

BK7 glass is lighter and stronger than silica glass which has a higher melting point and much lower thermal expansion coefficient. BK7 is used for scientific glass apparatus and art projects.

In this paper, we have designed PCF by using three sets of layer cladding which is characterized by a different air holes, pitch with different diameters in which the first five rings of circular air holes and the outer three rings are of square air holes which is intimated in the proposed structure. The structure can ensure flat dispersion and minimum confinement loss in a wide wavelength range and simple than the existing designs.

2. PROPOSED STRUCTURE

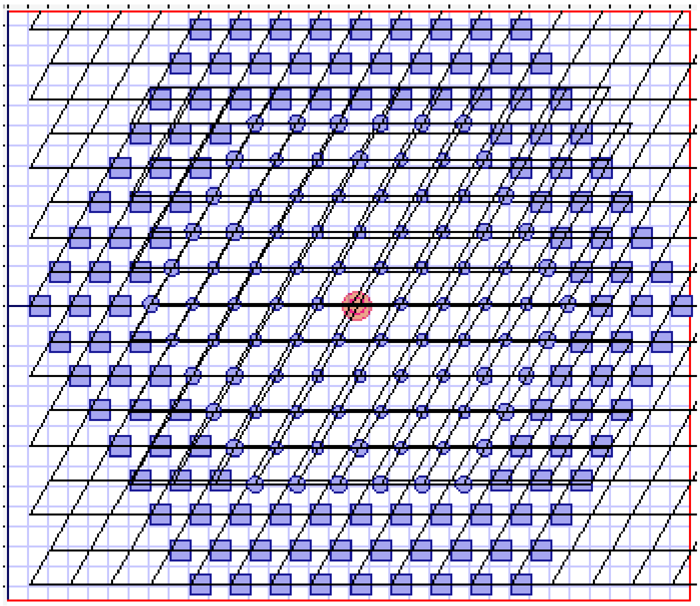

Figure 1: Proposed PCF Structure

Fig. 1 shows the proposed PCF. The inner five layers of cladding is composed of circular air holes with elliptic waveguide of a common air hole pitch Λ and diameter d_1, d_2 and outer three layer of cladding is composed with linear waveguide with parameter length L and width w. For achieving the flattened dispersion and minimum confinement loss. We proposed the inner rings air holes of smaller area. We have investigated the dispersion and confinement loss for different air hole parameter of inner by keeping the outer three rings parameter constant.

3. STRUCTURE PARAMETER

Cladding Layers

1. d_1 = 0.6 µm, d_2=0.8µm, L=1µm, w=1µm, $\wedge_1$ = 2.0 µm, $\wedge_2$=2.0
2. d_1=0.6 µm, d_2=0.8µm, L=1µm, w=1µm, $\wedge_1$ = 2.05 µm, $\wedge_2$=2.0
3. d_1=0.6 µm, d_2=0.8µm, L=1µm, w=1µm, $\wedge_1$ = 2.08 µm, $\wedge_2$=2.0
4. d_1=0.6 µm, d_2=0.8µm, L=1µm, w=1µm, $\wedge_1$ = 2.10 µm, $\wedge_2$=2.0.

Where d_1 denotes the diameter of inner three ring holes, d_2 denotes the diameter of the fifth ring, L and w denotes the Length and width of the outer three square holes. $\wedge_1$ denotes the inner five rings air holes gap and $\wedge_2$ denotes the air holes gap of outer three rings.

The fourth ring designed with the combination of d_1, and d_2. The wafer chosen is of Borosilicate crown glass with 1.5168 refractive index and the air hole refractive index is 1.0.

4. EQUATIONS

By using the Sellemeier formula we can calculate the value of refractive index of Borosilicate glass-

$$\eta^2=1+(A_1\lambda^2)/(\lambda^2-\lambda_1)+(A_2\lambda^2)/(\lambda^2-\lambda_2)+(A_3\lambda^2)/(\lambda^2-\lambda_3) \qquad (1)$$

Where λ is operating wavelength in micrometer and A1, λ1, A2, λ2, A3, λ3 are the Sellemeier constants which changes with the material properties. The Sellemeier constants are different for different material

For fused silica (fluorine-doped silica 1 mole %) Sellemeier constants are

A_1=0.69616630 λ_1= 0.068404300µm
A_2=0.40794260 λ_2=0.11624140µm
A_3=0.89747940 λ_3=9.8961610 µm

For Borosilicate Crown Glass Sellemeier constants are

A_1=1.03961212 λ_1= 0.774642 µm
A_2=0.231792344 λ_2=0.141484677 µm
A_3=1.01046945 λ_3=10.1764753 µm

Dispersion [8] of the transmitted optical signal causes the distortion for both the digital and analog transmission along optical fiber. When considering the major implementation of optical fiber transmission which involves some form of digital modulation than dispersion mechanism within the fiber cause broadening of the transmitted light pulse as it travel along the channel. It is proportional to the second derivative of effective index of guided mode with respect to 'λ' as given in equation (2) is defined as

$$D = -\left(\frac{\lambda}{c}\right)\frac{d^2}{d\lambda^2}\eta_{eff} \text{ (ps/(nm-km))} \quad (2)$$

Where λ is the operating wavelength and c is the velocity of light. DM is the material dispersion, DW is the waveguide dispersion.

Table 2 shows the material dispersion of borosilicate crown glass and fused silica glass from the wavelength 0.5 to 2.0 μm.

TABLE 2: MATERIAL DISPERSION BOROSILICATE AND SILICA GLASS

Wavelength (μm)	Borosilicate Crown Glass	Fused Silica Glass
0.5	-354.28680	-768.57340
0.6	-330.57870	-368.10470
0.7	-250.01460	-204.07450
0.8	-149.77030	-121.48400
0.9	-92.83923	-74.15130
1	-57.45642	-44.44742
1.1	-33.57323	-24.21675
1.2	-16.41135	-9.60665
1.3	-3.79429	1.51772
1.4	6.30436	10.39052
1.5	15.01038	18.01246
1.6	22.41551	24.68374
1.7	28.92001	30.76295
1.8	34.97420	36.62534
1.9	39.76918	41.51205
2	43.53011	45.69828

Confinement or leakage loss originates from the finite width of the cladding structure. In PCFs, by choosing the parameters d and Λ properly, the confinement loss can be negligible. Nevertheless, for small core fibers where the core size is comparable or smaller in dimension than the carried light wavelength, confinement loss gives a significant contribution to the total loss of the fibers.

$$\text{Confinement Loss (dB/m)} = 8.686\,\text{Im}\,[k_0 * \eta_{eff}] \quad (3)$$

Where $k_0=\frac{2\pi}{\lambda}$ and λ is wavelength of light and η_{eff} is the effective refractive index of the proposed structure [10].

5. RESULTS

The results, so obtained gives that the dispersion calculated for proposed photonic crystal fiber using the scalar index method gives best results in comparison of other structures. In this paper we obtained the result of near zero dispersion at the wavelength of 1.55 μm, where the pitch value is 2.08 as shown in Fig. 5. We have also calculated the minimum confinement loss and we have also compared the confinement loss at different pitch values which gives the result at the pitch of 2.08 as shown in Fig. 7.

Fig. 3 and Fig. 4 show the mode field pattern of the proposed PCF structure with different values.

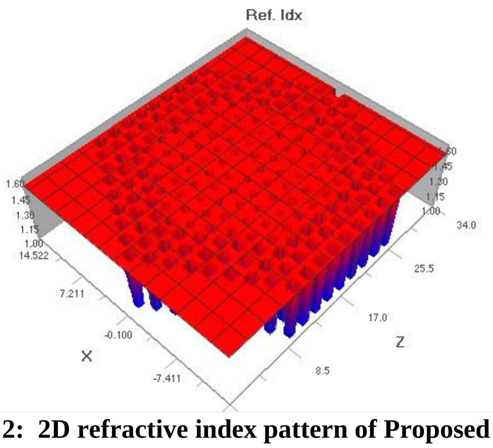

Figure 2: 2D refractive index pattern of Proposed PCF

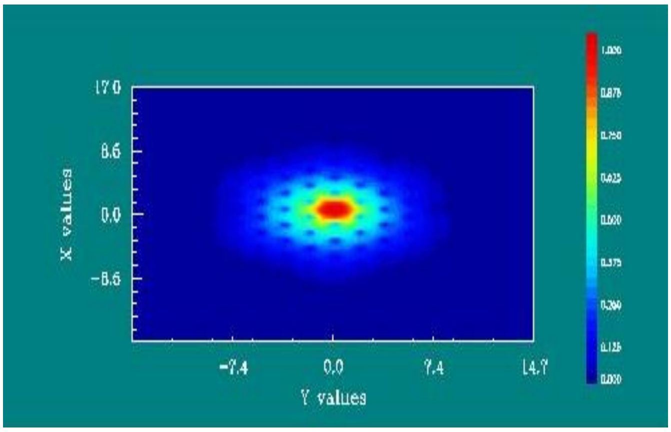

Figure 3: Mode field pattern of Proposed PCF

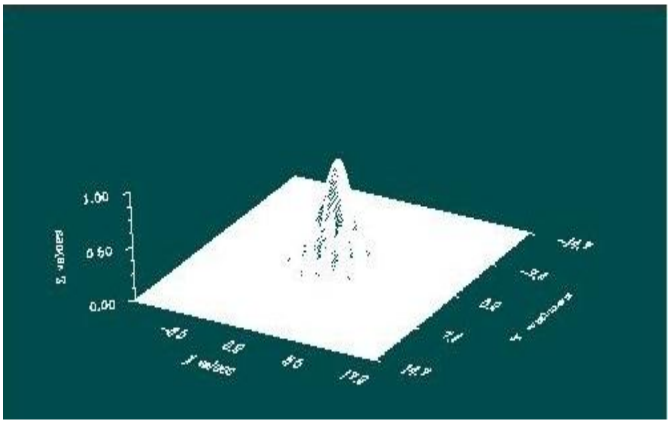

Figure 4: 3D Mode field pattern of Proposed PCF

With the same PCF structure, we obtained the results with the silica material then we get the dispersion value of 2.5 ps/(km-nm) at 1.55 µm of wavelength. Fig. 6 shows the chromatic dispersion comparison of Borosilicate crown glass PCF with Silica glass PCF. We investigate the value of confinement loss at this wavelength and we observed that at λ=1.5 µm confinement loss is -0.00036 and at λ=1.6 µm confinement loss is -0.00034 as shown in Table 3. The Comparison of the proposed PCF with different pitch to get the best results and the output of those results are plotted as shown in Fig. 5.

TABLE 3: CHROMATIC DISPERSION OF PROPOSED PCF AT DIFFERENT PITCH

Wavelength (µm)	Pitch 2.0 µm	Pitch 2.05 µm	Pitch 2.08 µm	Pitch 2.10 µm
0.5	-338.33	-343.18	-383.94	-341.23
0.6	-302.13	-310.79	-333.4	-314.62
0.7	-212.25	-215.79	-223.4	-229.25
0.8	-117.34	-111.23	-117.47	-122.52
0.9	-67.808	-68.566	-68.849	-61.998
1	-32.533	-35.058	-32.064	-30.03
1.1	-20.99	-12.562	-15.53	-20.354
1.2	-21.453	-14.245	-16	-18.178
1.3	-14.26	-13.978	-14.177	-9.6798
1.4	-5.3622	-6.2448	-5.7907	-2.9701
1.5	-5.3324	-0.6142	0.10006	-2.8657
1.6	-11.998	-0.8139	-0.0987	-1.5464
1.7	-12.633	-4.0516	-3.1117	2.30935
1.8	-6.4485	-4.8288	-3.3518	2.03541
1.9	-2.0138	-3.3067	-1.5211	-2.1659
2	0.90562	-1.6562	0.37359	-6.3928

TABLE 4: CONFINEMENT LOSS OF PROPOSED PCF(dB/nm)

Wavelength (µm)	Pitch 2.0 µm	Pitch 2.05 µm	Pitch 2.08 µm	Pitch 2.10 µm
1.1	0.0000	0.0000	0.0000	0.0000
1.2	-0.1300	0.0000	0.0000	-0.6250
1.3	-0.0822	0.0000	-0.4196	-0.9966
1.4	-0.1387	-0.8961	-0.7793	-1.7046
1.5	-0.1818	-0.5600	-2.5456	-1.9546
1.6	-2.7274	-2.1922	-6.8185	-1.9665
1.7	-2.5830	-2.2782	-6.7383	-2.1030
1.8	-2.7274	-2.4244	-8.7883	-2.3486
1.9	-2.6040	-2.2968	-10.9096	-2.5224
2	-5.2069	-4.9093	-12.2733	-2.6674

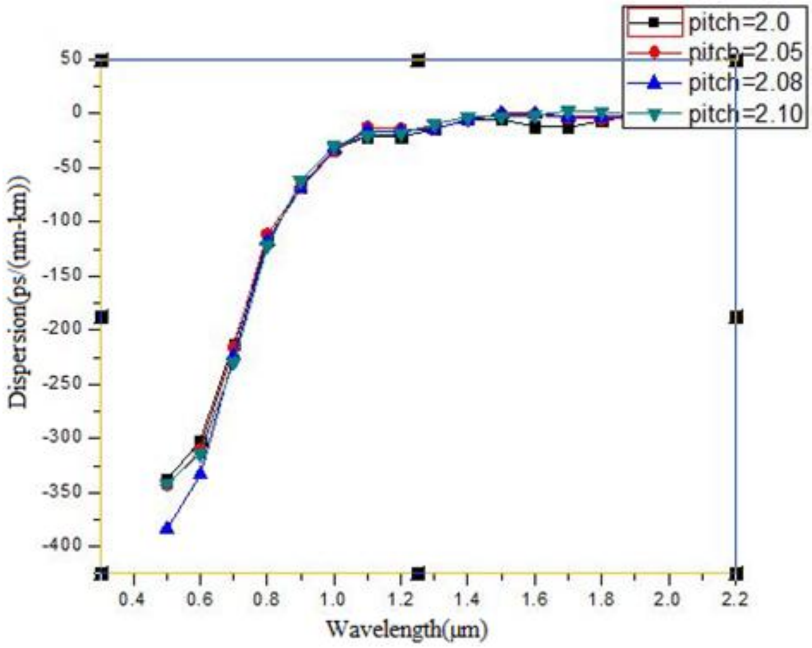

Figure 5: Chromatic dispersion of proposed PCF at different pitch.

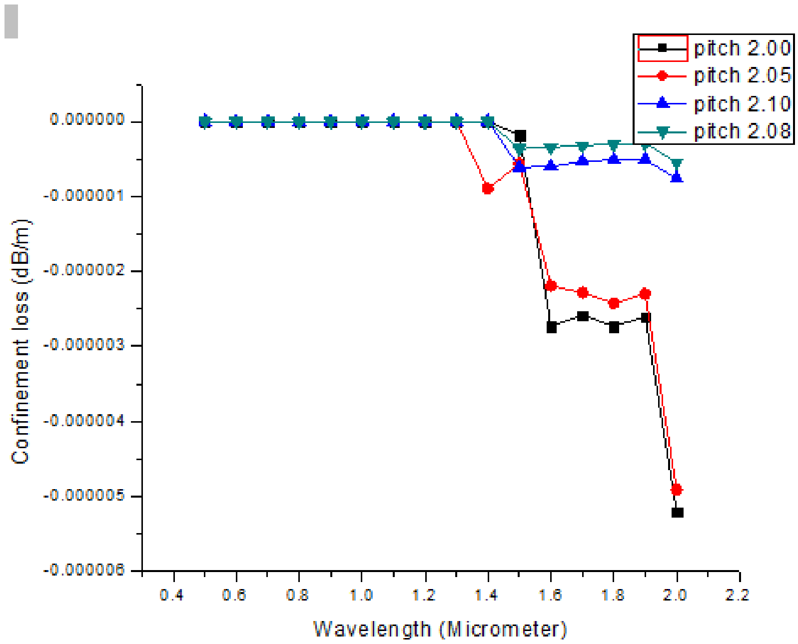

Figure 6: Confinement loss of proposed PCF at different pitch.

TABLE 5: CHROMATIC DISPERSION OF BOROSILICATE AND SILICA AT PITCH 2.08

Wavelength (μm)	Borosilicate Glass	Fused Silica glass
0.5	-383.94	-798.23
0.6	-333.40	-370.92
0.7	-223.40	-177.46
0.8	-117.47	-89.19
0.9	-68.85	-50.16
1	-32.06	-19.05
1.1	-15.53	-6.17
1.2	-16.00	-9.19
1.3	-14.18	-8.85
1.4	-5.79	-1.69
1.5	0.10	2.84
1.6	-0.10	2.18
1.7	-3.11	-0.63
1.8	-3.35	-1.67
1.9	-1.52	-0.08
2	0.37	2.96

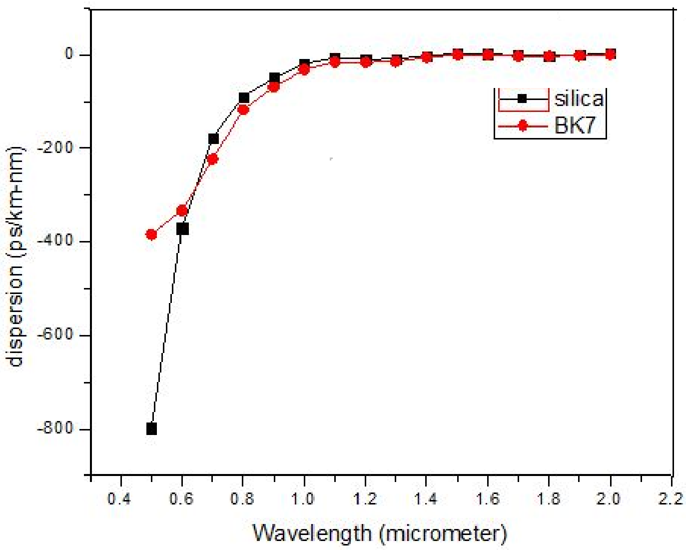

Figure 7: Chromatic Dispersion comparison at pitch 2.08.

TABLE 6: CONFINEMENT LOSS AT PITCH 2.08

Wavelength (μm)	Borosilicate Glass	Fused Silica glass
1.1	-0.09	0.0000
1.2	-0.35	0.0000
1.3	-0.41	-0.4196
1.4	-0.42	-0.7793
1.5	-0.61	-2.5456
1.6	-0.60	-6.8185
1.7	-0.85	-6.7383
1.8	-1.42	-8.7883
1.9	-1.66	-9.0960
2	-2.39	-12.2733

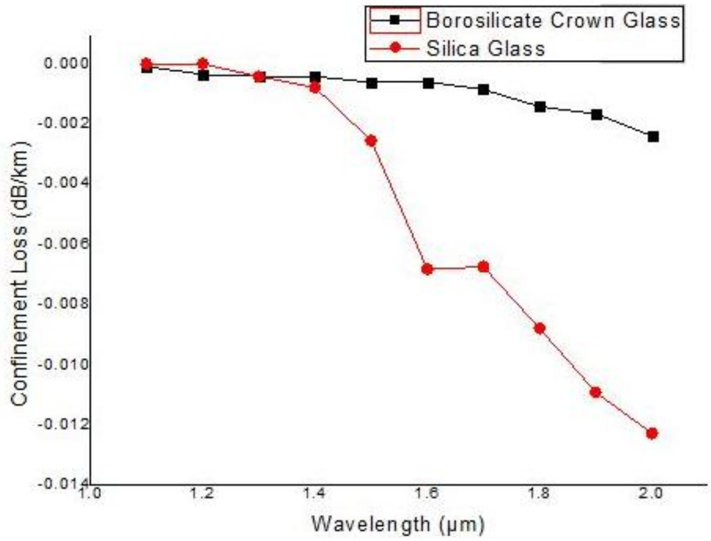

Figure 8: Confinement loss comparison at pitch 2.08

Table 3 and Figure 5 show the value of chromatic dispersion for the above proposed design and their dependence on the wavelength respectfully. From this design, we observed that at wavelength 1.5 µm and 1.6µm, the value of chromatic dispersion for proposed design is 0.10006 and -0.0987 and the value of confinement loss is -0.0025456 and -0.0068185 dB/km. From the above result, we conclude that above design at pitch 2.08 µm gives more flattened dispersion and its value is zero at 1.55µm

From the result of chromatic dispersion in Table 5 at pitch 2.08µm, we observed that the value of chromatic dispersion with borosilicate is nearly zero and for silica it is 2.50 ps/(nm-km) at 1.55 µm.

From the above result, it shows that the value of confinement loss is also near to zero in the case of borosilicate material when compare to silica material. Figure 8 shows that the value of confinement loss for borosilicate crown glass is -0.0025456 and -0.0068185 dB/km at wavelength 1.5 and 1.6µm and for silica material the value is -0.0025456 and -0.0068185 at wavelength 1.5 and 1.6µm correspondingly. This shows that the value of confinement loss is near zero with the borosilicate material and gives the better results when comparing to the silica material.

6. CONCLUSION

In general, silica material is used in the different application of the optical fiber, but recently Borosilicate material is the replacement of the silica material with its different properties. Material dispersion is always unchanged for any structure (hexagonal or square). It is also independent of structure parameter as air hole diameter'd' and pitch 'Λ'.

Here we have calculated the dispersion for various data but it shows that when we consider different air holes diameter of inner 5 layers and same square holes of the outer three layers then it gives best result. The fiber parameters are optimized to yield best agreement with available data.

References

1. Agrawal A, N. Kejalakshmy, J. Chen, B.M.A. Rahman and K.T.V. Grattan, "Golden spiral photonic crystal fiber: Polarization and dispersion properties", Opt. Lett, Vol. 33, 2008, pp 2716- 2718.
2. Shen L.P, W.P. Huang and S.S. Jain, "Design of photonic crystal fiber for dispersion related applications", J. LightwaveTechnol, vol. 21, 2003, pp 1644- 1651.
3. Poletti F, V. Finazzi , T.M. Monro , N.G.R. Broderick, V. Tsc and D.J. Richardson, " Inverse design and fabrication tolerences of ultra-flattened dispersion holey fibers", Opt. Express, vol. 13, 2005, pp 3728- 3736.
4. Huttunen A and P. Torma, "Optimization of dual core and microstructure fiber geometries for dispersion compensation and large mode area", Opt. Express, Vol. 13, 2005, pp 627- 635.
5. Dong X and H.Y. Tam, "Temperature insensitive strain sensor with polarization maintaining photonic crystal fiber based on sagnac interferometer", Appl. Phys. Lett, Vol. 90, 2007.
6. Liu X, X. Zhou, X. Tang, J. Ng, J. Hao, T. Chai, E. Leong and C. Lu, " Swithable and tunable multiwavelength erbium doped fiber laser with fiber bragg grating and photonic crystal fiber", IEEE Photon. Technol. Lett, Vol. 17, 2005, pp 1626- 1628.
7. Sapulak M, G. Statkiewicz, J. Olszewski, T. Martynkine, W. Urbanczyk, J. Wojcik, M. Makara, J. Klimek, T. Nasilowski, F. Berghmans and H. Thienpont," Experimental and theoretical investigations of birefringent holey fibers with a triple defect", Appl. Opt., Vol. 44, 2005, pp 2652- 2658.
8. Anthkowia K.M, R. Kotynski, T. Nasilowski, P. Lesiak, J. Wojcik, W. Urbanczyk, F. Berghmans, and H. Thienpont, "Phase and group modal birefringence of triple defect photonic crystal fibers", J. Opt. A. Pure Appl. Opt, vol. 7, 2005, pp 763- 766.

9. Chen D and L. Shen, "Highly birefringent elliptical hole photonic crystal fibers with double defect", J. Light. Technol, vol. 25, 2007, pp 2700- 2705.

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