КОНСТРУКЦИЯ ДВУХКАНАЛЬНОГО ОПТОВОЛОКОННОГО ОТВЕТВИТЕЛЯ НА ОСНОВЕ ФОТОННОГО КРИСТАЛЛА, ЗАПОЛНЕННОГО ЖИДКОСТЬЮ, И АНАЛИЗ ЕГО ОПТИЧЕСКИХ ХАРАКТЕРИСТИК

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Фотонно-кристаллические волоконные ответвители являются одними из замечательных устройств, играющих значительную роль в развивающейся области оптических коммуникационных сетей. Двухканальные фотонно-кристаллические волоконные ответвители по сравнению с обычными имеют более гибкую конструкцию и меньшую длину участка взаимодействия. В работе предложен кварцевый многоканальный фотонно-кристаллический волновод с гексагональной структурой, исследованы эффективный показатель его преломления, параметры распространения и длина участка взаимодействия, в сравнении с фотонно-кристаллическими волоконными ответвителями, пара каналов в которых заполнена жидкостями (бензен и хлороформ). Указанные параметры проанализированы при вариациях геометрических параметров – диаметра каналов и расстояния между ними – в широком диапазоне длин волн. При правильном конструировании двухканального фотонно-кристаллического волоконного ответвителя достигнуты длины участка взаимодействия 0,0006, 0,007 и 0,0008 м – в ответвителях с заполнением каналов кварцем, бензеном и хлороформом соответственно. Дисперсия составила −6987, −7055 и −6684 пс/(нм км), а постоянные распространения – 10,9, 11,08 и 10,6 (×106 рад/м) у тех же ответвителей.

DESIGN OF DUAL CORE LIQUID FILLED PHOTONIC CRYSTAL FIBER COUPLER AND ANALYSIS OF ITS OPTICAL CHARACTERISTICS

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Photonic crystal fiber coupler is one of the peculiar devices that play major role in the future optical networks. Dual-core photonic crystal fiber couplers have many advantages over the conventional optical couplers such as more flexible design and shorter coupling length. In this paper, we had proposed the silica based photonic crystal fiber coupler with hexagonal lattice structure and the important properties such as dispersion, effective refractive index, propagation characteristics and coupling length have been analyzed and compared it with the liquid filled photonic crystal fiber coupler such as Benzene and Chloroform. The above properties are investigated under different geometrical parameters, such as hole-to-hole spacing and different air-hole diameter within a wide range of wavelength. By proper adjustment of dual core photonic crystal fiber coupler, the coupling lengths of 0.0006 m is achieved in silica photonic crystal fiber coupler, 0.007 and 0.0008 m are achieved in benzene and chloroform filled photonic crystal fiber coupler and the dispersion value of −6987, −7055 and −6684 ps/(nm km) are achieved in silica, benzene and chloroform filled photonic crystal fiber coupler and propagation constant of 10.9, 11.08 and 10.6 (×106) rad/m are achieved in silica, benzene and chloroform filled photonic crystal fiber coupler respectively.

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I. Introduction

Photonic Crystal Fibers (PCFs) are optical fibers with a periodic arrangement of low-index material (air holes) surrounded by a high refractive index (undoped silica). PCFs may be divided into two categories as high index guiding fiber and low index guiding fiber. Similar to conventional fibers, high index guiding fiber guides the light in a solid core by the modified total internal reflection principle [1]. The term 'Modified' indicates that the refractive index of cladding changes significantly with respect to the wavelength.

In low index guiding fiber, the refractive index of core is lower than the cladding in which the guiding of light can be exploited by the presence of the photonic band gap. The strong wavelength dependence of the refractive index and inherently large design flexibility of the PCFs results in new range of innovative properties such as endless single mode fibers, extreme nonlinearity and fibers with anomalous dispersion in the visible wavelength region [2]. Photonic crystals are non-natural material which has opened up new ways to guide the flow of light [3] due to its novel guiding properties as splitters, twin core couplers, demultiplexers, ring laser cavity [4–6].

Optical couplers can be implemented from photonic crystal fiber by removal of two neighbouring air holes from the central region which makes the silica environment to behave as guiding cores. Such photonic crystal fiber couplers (PCFC) favours many of the exciting light guiding features, when compared to that of the fiber namely endless single mode operation over a wide wavelength range, enhanced nonlinearity and desired zero dispersion wavelength, required coupling length, low bending loss and high design flexibility for the desired applications. Such desired properties can be achieved by suitable regulation of the PCF structure parameters namely air hole diameter, air hole separation, inter-core separation and core radius [7–9]. Dual core PCF is a device in which the light is guided through any one of the input core with inter-core division and the light is transferred to the neighbouring core by the excitation of the propagating evanescent mode [10].

Coupling characteristics plays a major role in wavelength division multiplexing, coupling, switching and multiple frequency generation. Hence this paper focuses mainly on the coupling characteristics of liquid filled PCFC. The dispersion results obtained for the dual-core PCF closely resembles the dispersion pattern of single-core PCF presented previously [11–13]. An innovative design of cladding is proposed in which the diameter (d) of air holes (Λ) changed by keeping the d/Λ as fixed facilitates the use of PCF coupler for wavelength-selective applications. Dispersion control for single-core PCF was reported [14–17].

In this paper, the assessment of dispersion along with the coupling coefficient for liquid filled PCFC is proposed. To the best of our knowledge, dispersion control along with coupling properties for a dual-core PCF has not been reported anywhere in literature.

II. Design of dual core PCFC

The schematic of the proposed dual core PCFC is shown in Fig. 1 where cores are realized by deliberately missing air holes on the silica substrate and the claddings are realized by the area with air holes. Figure 2 shows a dual core PCFC with cores filled with liquid benzene and chloroform. The dimensions of the PCFC, such as air hole diameter d, pitch between two neighboring holes Λ, and inter core separation ($R = 2\Lambda$) were optimized to obtain the desired values of coupling length and dispersion. The precise coupling length of the even and odd stability biased modes and the dispersion value for the proposed model is calculated.

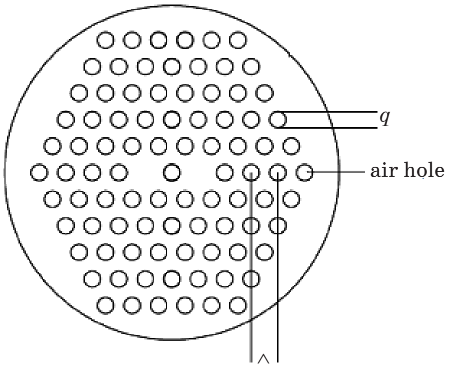

Fig. 1. Schematic diagram of dual core PCFC.

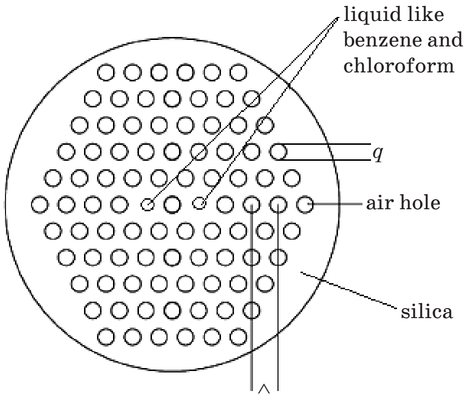

Fig. 2. Schematic diagram of dual core liquid filled PCFC.

III. Simulation results and discussions

The field distribution and effective modal index (n_{eff}) for the designed dual core PCFC is calculated using a finite-difference time domain method (Fig. 3). The Cladding layers are formed by distributing the circular air holes in hexagonal lattice and the core is formed by distributing the silica in the rest of the lattice and liquids such as benzene and chloroform are filled in the central core region. The material dispersion of silica, benzene and chloroform are taken into consideration for calculation [18]. The coupling length (L_c), propagation constant (β) and chromatic dispersion (D) are expressed as follows.

A. Coupling length

Coupling length is the distance which allows the possibility of the leaky modes that transfer the light from one guide to other as evanescent waves.

The coupling length of the coupler mainly depends upon the inter core separation, core radius and transmitting wavelength. Also the coupling length increases with the increase in the effective core area because of increase in the inner core separation. Thus, for increase in the Λ the coupling length also increases [19]. Increase in coupling length also possesses higher nonlinearity due to its larger effective core area. The coupling length is given by

$$L_c = \frac{\lambda}{2|n_{\text{even}} - n_{\text{odd}}|},$$

where λ is the wavelength of the input optical pulse, n_{even} and n_{odd} are the effective refractive indexes of even and odd propagation modes respectively. Figure 4 shows the coupling length for silica, benzene and chloroform filled PCFC with respect to the wavelength. The coupling length is found to be the maximum for shorter wavelength, due to the decrease in difference between the value of even and odd modes (order of modes is 2) and vice-versa.

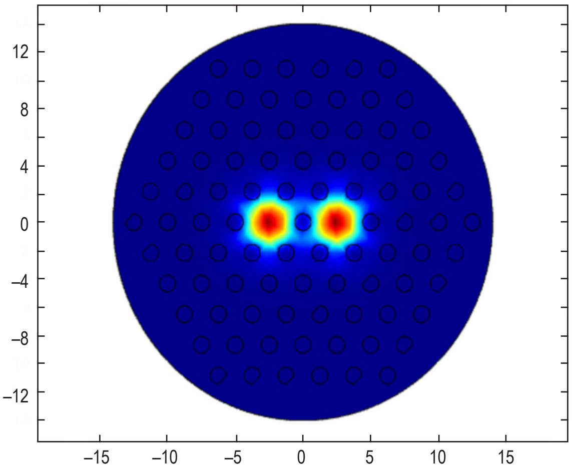

Fig. 3. Simulation model of dual core PCFC.

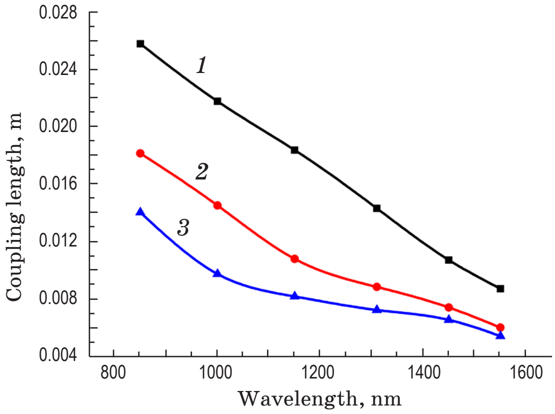

Fig. 4. Variation of coupling length for different wavelengths of dual core liquid filled PCFC. *1* – Silica, *2* – Benzene, *3* – Chloroform.

Figures 5a, 5b and 5c show that the variations of coupling length for different pitch constant for dual core silica, benzene and chloroform filled PCFC. For smaller pitch values the coupling length increases due to larger core area whereas the increase in pitch results in decreased coupling length.

Figures 6a, 6b and 6c show the variation of coupling length with respect to different d/Λ ratio for dual core silica, benzene and chloroform filled PCFC. For smaller values of d/Λ, the coupling length decreases and for larger values of d/Λ, the coupling length increases due to changes in core size.

B. Propagation constant

Propagation constant of an electromagnetic wave is a measure of the change undergone by the amplitude of the wave as it propagates in a given direction.

The propagation constant β is given by

$$\beta = n_{\text{eff}} 2\Pi / \lambda.$$

Figure 7 shows, that the variation of propagation constant with respect to wavelengths for dual core silica, benzene and chloroform filled PCFC. For shorter wavelengths, propagation constant is directly proportional to effective mode index and found to be maximum and for further increase in wavelength, the propagation constant decreases with respect to the effective mode index (order of modes is 2).

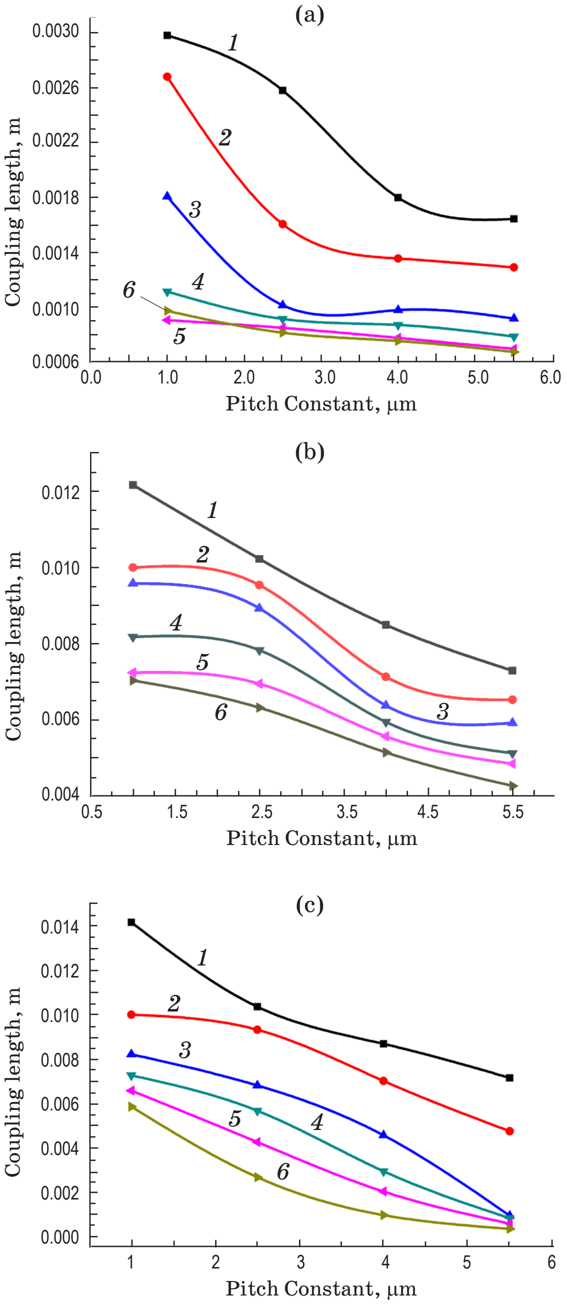

Fig. 5. Variations of coupling length with respect to different pitch constants (a) for dual core silica PCFC, (b) for dual core benzene PCFC, (c) for dual core chloroform PCFC. *1* – 850, *2* – 1000, *3* – 1150, *4* – 1310, *5* – 1450, *6* – 1550 nm.

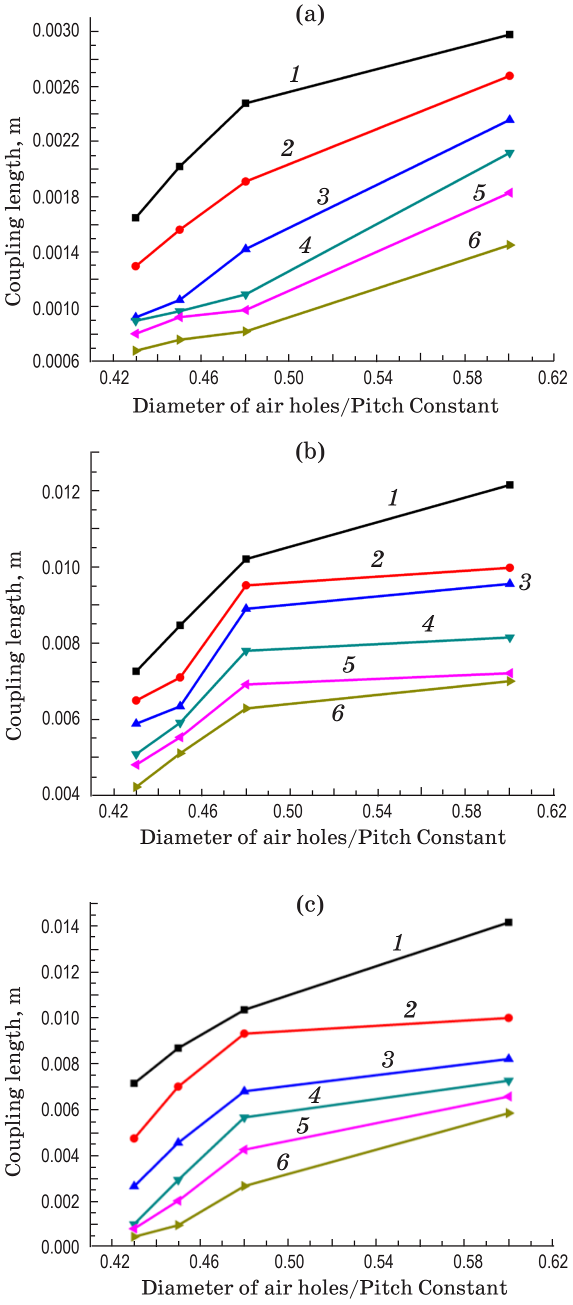

Fig. 6. Variations of coupling length with respect to different d/Λ ratio (a) for dual core Silica PCFC, (b) for dual core Benzene PCFC, (c) for dual core Chloroform PCFC. *1* – 850, *2* – 1000, *3* – 1150, *4* – 1310, *5* – 1450, *6* –1550 nm.

C. Dispersion

The tendency of different wavelengths to travel at different speeds is a crucial factor in the field of telecommunication system. The broadening of light pulses changes with respect to the wavelength. In PCFs the dispersion can be controlled and tailored with unprecedented freedom.

Due to the high refractive index difference between silica and air, and flexibility of changing air hole sizes and patterns, a much broader range of dispersion behaviors can be obtained in PCFs than with standard fibers [20–22]. The dispersion is given by

$$D = -\lambda / c\left(d^2 n_{\text{eff}} / d\lambda^2\right),$$

where λ is the wavelength and c is the velocity of light in vacuum.

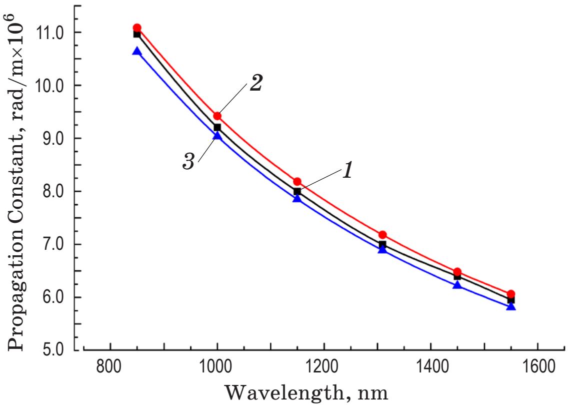

Fig. 7. Variation of propagation constant with respect to wavelengths for dual core Liquid filled PCFC. *1* – Silica, *2* – Benzene, *3* – Chloroform.

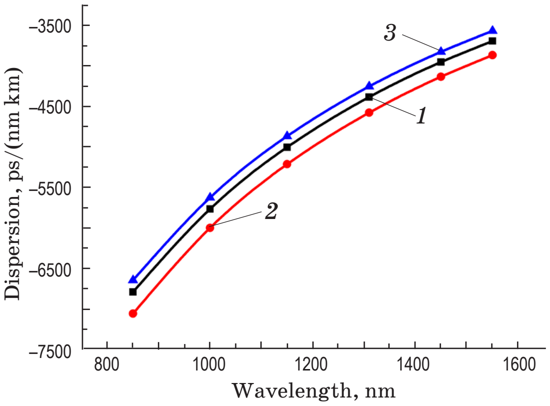

Fig. 8. Variation of dispersion with respect to different wavelengths of dual core Liquid filled PCFC. *1* – Silica, *2* – Benzene, *3* – Chloroform.

Figure 8 shows the dispersion profile of silica, benzene and chloroform filled dual core PCFC. The PCFC offers ultra-negative dispersion for wide wavelength range (850 to 1550 nm).

IV. Conclusion

In this paper, a four ring hexagonal lattice PCFC with even air hole diameter is proposed. The designed dual core PCFC offers ultra negative dispersion in wide range of wavelength from 0.8 to 1.55 μm. It is believed that the proposed PCFC will have promising future in ultra broadband transmission applications. The optical steering characteristics of PCFCs are investigated theoretically for wide wavelength range. It is concluded that very short coupling length using dual core silica PCF coupler at wide wavelength range can be achieved.

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