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Analysis of dispersion characteristics of solid-core PCFs with different types of lattice in the claddings, infiltrated with ethanol

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Abstract—In this paper, we propose three solid-core photonic crystal fibers based on silica, with hexagonal, circular and square lattices as a cladding, composed of 8 rings of air-holes surrounding the core, infiltrated with ethanol. Using commercial software, we simulated light propagation in these structures. The size of air-holes was from 1 μm to 4 μm. We have shown that the fibers with hexagonal lattices are optimal for supercontinuum generation since their dispersion characteristics are flat and the smallest.

Photonic crystal fibers (PCF) were invented by Knight and his colleagues in 1996 [1]. Since then, they have allowed for a breakthrough in fiber optic technology due to their unique properties and possibilities of application not achievable with conventional optical fibers.

The properties of PCFs can be tuned with a properly designed internal structure. Geometrical parameters related to the structure include the shape and size of lattice in the cladding, the shape and size of air-holes, and the lattice constant [2]. In addition, for solid-core and hollow-core PCFs, the transmission mechanism is different [3, 4]. The most important optical parameters of PCFs include an effective refractive index, effective mode area, dispersion, and attenuation [5, 6].

The choice of the type of lattice constituting the fiber photonic cladding is determined by the planned application. Hexagonal lattices were used, e.g., for efficient femtosecond laser grating inscription [7], dispersion management [8], confinement loss control [9], and broadband infrared supercontinuum generation [10]. Circular lattices were presented to achieve effective dispersion compensation over E to L wavelength bands [11], large effective area [12], improved optical characteristics [13], high birefringence [14]. Square lattices were also studied [15] and a single-mode regime was presented [16] as well as large solid-cores [17, 18] and possibility of dispersion control [19]. Comparisons of different types of these lattices can be found for triangular and square lattices [20], hexagonal and square lattices [21], and square, circular and hexagonal lattices [22].

Most of the publications cited above use gas infiltrating into the air-holes. However, in such a case, the control of characteristic quantities is difficult because its zero dispersion wavelength range is quite narrow. To overcome the mentioned limitations, recently a number of publications have been published, focused on infiltrating liquids into lattices in the photonic cladding or into cores of PCFs [23]. Selected aspects of such fibers have been analyzed, such as dispersion engineering [24], temperature sensitivity [25], influence of temperature on dispersion properties [26], infiltration with water [27], selective liquid-infiltration [28]. Liquid-infiltrated PCFs allowed for applications in fiber optic technology, e.g., in sensing [29] and supercontinuum generation [30, 31].

Most publications on liquid-infiltrated PCFs consider only hexagonal lattices. In this paper, we propose three solid-core PCF structures based on silica, with hexagonal, circular and square lattices, composed of 8 rings of air-holes surrounding the core, infiltrated with ethanol. The dispersion characteristics of these fibers were analyzed numerically. As a result, the optimal geometrical parameters set was determined to be used in applications in fiber optic technology.

In our work, the Lumerical Mode Solutions software was used [32] to design three solid-core PCFs with different types of lattice in the claddings, namely hexagonal, square and circular. Each structure has the same silica glass (SiO_2) as the base material. The lattices consist of 8 rings of air-holes surrounding the core, infiltrated with ethanol as shown in Fig. 1, where d is the air-hole diameter and Λ is the lattice constant.

In our simulations we used $\Lambda = 5$ μm, which allows to achieve an effective mode area comparable to the mode area of standard single-mode step-index fibers. The diameter of air-holes was set to 1.0 μm, 2.0 μm, 3.0 μm, and 4.0μm [26]. To ensure fabrication feasibility and minimize loss in photonic crystal fibers, we have chosen

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Table 1. Chromatic dispersion of the PCFs with various air-hole diameters, at 1.55 µm wavelength, infiltrated with ethanol, for a) hexagonal, b) square, and c) circular lattices.

λ (µm)	*d* (µm)	*D* (ps.(nm.km)$^{-1}$)		
		Hexagonal	Square	Circle
1.55	1.0	22.2	22.9	23.1
	1.5	22.8	24.1	25.3
	2.0	30.0	31.8	32.6
	2.5	35.2	37.1	38.3
	3.0	38.8	39.9	41.2
	3.5	41.4	42.9	43.7
	4.0	43.7	44.5	45.4

Table 2. ZDWs for the PCFs with various air-hole diameters, infiltrated with ethanol for a) hexagonal, b) square, and c) circular lattices.

d (µm)	ZDW (µm)		
	Hexagonal	Square	Circle
1.0	1.235	1.224	1.191
1.5	1.196	1.187	1.165
2.0	1.136	1.124	1.112
2.5	1.127	1.119	1.100
3.0	1.096	1.076	1.057
3.5	1.073	1.067	1.048
4.0	1.066	1.058	1.043

In conclusion, the dispersion characteristics of solid-core photonic crystal fibers with different types of photonic lattice in the claddings, infiltrated with ethanol, have been simulated numerically and analyzed. The results show that the dispersion characteristics of the hexagonal lattice are flat and smaller than for the square and circular lattices. When the diameter of air-holes varies from 1 µm to 4 µm, ZDW for the hexagonal lattice shifted more than for the square and circular lattices and, thus it can be applied for supercontinuum generation.

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