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Defect-Core Hexagonal-lattice Photonic Crystal Fibers with Flattened Chromatic Dispersion and Low Confinement Loss

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Abstract

Defect-core hexagonal photonic crystal fibers (DC-HPCFs) with nearly zero ultra-flattened dispersion of 0 ± 0.35 ps/ (nm-km), in the wavelength range of 1.397 µm to 1.675 µm exhibiting extremely low confinement loss has been presented.

***Key words**: Photonic crystal fiber (PCF), chromatic dispersion*

1. Introduction

Photonic Crystal Fibers (PCFs) also known as holey fiber or microstructure fiber, have been the subject of much research interest in the recent years for its promising and attractive properties, like single mode operation in a wide band, large waveguide dispersion, nonlinearity, ultra-flattened dispersion and so many [1-5] whereby can not be obtained by conventional optical fibers.

Index guiding PCFs have microscopic array of air channels running along its length that makes the low index cladding around the undoped silica core. In this way, light can be confined and guided properly through the fiber by the mechanism of total internal reflection (TIR). Compared to the conventional fibers, PCFs have additional design parameters namely, air-hole diameter, air-hole rings and hole to hole spacing known as the pitch, and hence offer design flexibility for the guiding properties [5].

Chromatic dispersion and losses in fibers limits the data carrying capacity in optical communication systems. Chromatic dispersion causes light pulses to spread causing inter-symbol interference and becomes a critical issue as transmission rate exceeds 10 Gb/s. The same challenge exists in the design of PCFs too. So far, various index guiding hexagonal PCFs (H-PCFs) with remarkable dispersion and leakage properties [5]-[7] have been reported. By using the defect-core HPCF as will be described in subsequent section, chromatic dispersion and confinement loss can be controlled. To the limit of authors' knowledge, the guiding properties with such design in HPCFs have not been reported yet.

In this paper, the proposed PCFs are in a structure of omitting several air holes in the core to form a defect-core and then having two sets of air-hole diameters, one set with small diameters next to the defect-core, while the other with the same hole size to the rest of the structure. With this design, it has been possible to achieve flattened dispersion with low confinement loss. The Finite difference method (FDM) with perfectly matched layer (PML) absorbing boundary condition has used to calculate dispersion properties [8, 9].

2. DC-HPCFs design

In conventional HPCFs, the cladding is usually formed by air-holes with the same sizes arrayed in a triangular lattice. Chromatic dispersion profile can be engineered by varying the air-hole diameter and hole to hole spacing; however it is difficult to control dispersion and dispersion slope by using PCFs with the same air-hole diameter in cladding region for wide wavelength range. We propose the index guiding defect-core hexagonal PCF as shown in Fig.1 to control both dispersion and dispersion slope. We consider a core having multiple defects characterized by omitting air holes A and B as can be seen. From Fig.1, d and d_1 are the air-hole diameters and Λ is the pitch. The precise control of air- hole diameters and lattice constant (pitch) facilitate flattened chromatic dispersion and low confinement loss simultaneously.

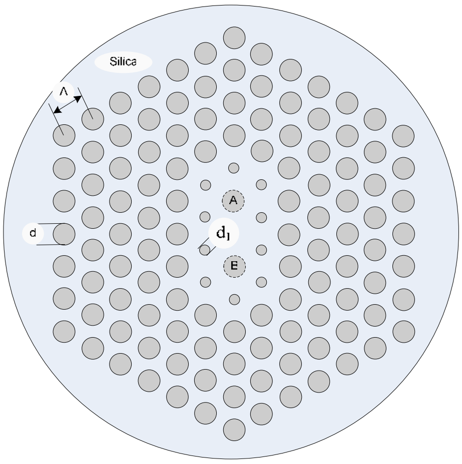

Fig1 Transverse section of the designed defect-core HPCF showing pitch, Λ, air-hole channels with diameters d and d_1, and background material, pure silica (n=1.45). A and B are omitted air-holes from the conventional HPCF.

3. Numerical simulation results

The chromatic dispersion of defect-core HPCF is calculated by [6];

$$\mathrm{D}\,(\lambda) = -\frac{\lambda}{c}\frac{d^2\,\mathrm{Re}\left[n_{eff}\right]}{d\lambda^2} \qquad (1)$$

With unit of [ps/(nm.km)],where, λ is the operating wavelength, Re (n_{eff}) is the real part of the refractive index, n_{eff} and c is the velocity of light in a vacuum.

Confinement loss is the light confinement ability within the core region. The confinement loss, L_c is then obtained from the imaginary part of n_{eff} as follows [8];

$$L_c = 8.686\, k_0\, \mathrm{Im}[n_{eff}] \qquad (2)$$

with unit of dB/m. where , $k_0 = 2\pi/\lambda$ is the free space wave number.

And effective mode area, A_{eff} is calculated by[8];

$$A_{eff} = \frac{[\iint |E^2| dxdy]^2}{\iint |E|^4\, dxdy} \qquad (3)$$

where E is the electric field derived by solving Maxwell's equations.

Fig.2 shows the chromatic dispersion for the optimized DC-HPCF as a function of optical wavelength. It can be clearly seen that for the optimized set of parameters and air-hole ring configurations a flattened dispersion of 0± 0.35 ps/(nm-km) in the wavelength range of 1397 nm to 1675 nm has been realized. The optimized parameters which have been obtained through numerical simulations are Λ=1.6 μm, *d*=1.056 μm, d_1 =0.6 μm. At 1550 nm dispersion of +0.32 ps/(nm-km) was obtained. Also typical variations of design parameter, *d* by ±1% results in a shift of chromatic dispersion curve of about ±1 ps/(nm-km) ,giving an upper bound on the severity of the fabrication imperfection. Fig.3 shows the relation of confinement loss and effective area with wavelength for the above-mentioned optimized design parameters. It can be observed the remarkably low confinement loss, less than 10^{-4} dB/km at the entire communication window has obtained. In addition, from Fig.3, we can see the effective area, A_{eff} of about 10.79 μm^2 at 1.55 μm, which may be suitable for nonlinear applications.

4. Conclusion

With defect-core HPCF, ultra-flattened chromatic dispersion with low confinement loss was demonstrated. Through numerical simulation flattened dispersion of 0±0.35 ps/(nm-km) with low confinement loss of less than 10^{-3} dB/km over wavelength range of 1.397 μm ~ 1.675 μm was obtained. So, the designed DC-HPCF can be potentially used where nearly zero ultra-flattened dispersion and low confinement losses characteristics are simultaneously needed. Also, birefringence behaviors of this described structure attract our interest, these works are under study.

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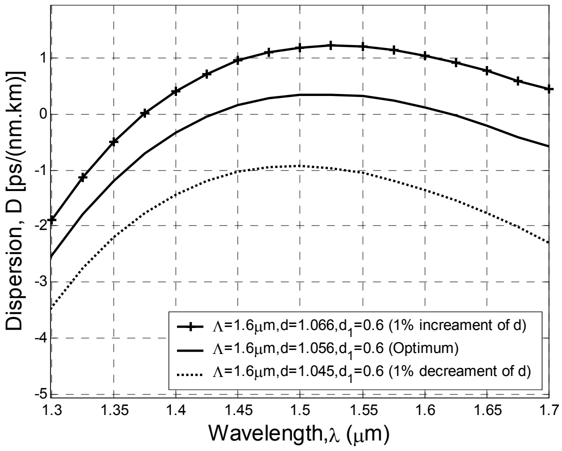

Fig.2 Dispersion properties of six rings DC-HPCF for the optimized design parameters, Λ=1.6μm, *d*=1.056μm, d_1=0.6μm and for ±1% variation of design parameter, *d*.

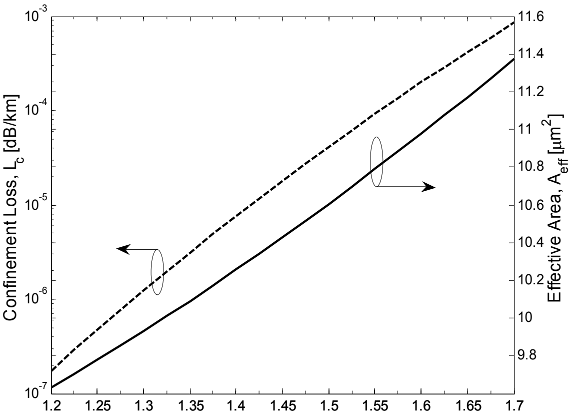

Fig.3 Confinement loss and effective area with wavelength for the optimized design parameters Λ=1.6μm, *d*=1.056μm, d_1=0.6μm.