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Studies of the modal properties of circularly photonic crystal fiber (C-PCF) for high power applications

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Abstract

The guiding properties of a new type of photonic crystal fibers where air-holes are arranged in a circular pattern (C-PCF) with a silica matrix have been investigated. The dispersion properties of the fiber with different spacing of circle and air-hole diameter have been studied in detail. It is shown that C-PCFs with smaller values of radius and higher air-filling fraction can be used as dispersion compensating fiber. A comparison between fibers with circular and triangular lattice has also been performed, taking into account the dispersion properties and the effective area in the wavelength range between 1200 nm and 1600 nm. C-PCF can better compensate the inline dispersion for both single wavelength and broadband wavelength applications which is a unique property not observed by regular triangular-lattice or square-lattice PCFs. The fiber provides higher effective area, making it a better candidate for high power accumulations in the core of the fiber. The fiber also shows red-shifting of the first zero dispersion wavelength (ZDW), flatter dispersion slope and lower Group Velocity Dispersion (GVD) in the normal dispersion region thereby making it a better candidate for high power nonlinear applications like super-continuum generation, soliton pulse propagation *etc*. With the above advantages, we have considered a series study of these circular-lattice structures for various geometrical parameters and temporal pulses in order to explore the characteristics of broadband supercontinuum generation. This design study for high power supercontinuum generation will be very helpful for potential application of new sources in various fields like astronomy, climatology, spectroscopy optical tomography and sensing *etc*. to name a few.
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1. Introduction

Photonic Crystal Fibers (PCFs) where air-holes are arranged in either triangular lattice of square lattice with a silica background have been extensively studied in details for different applications. They posses some novel guiding properties, related to the geometric characteristics of the air-holes in their cross-section, and have been successfully exploited in different application [1,2]. Most of the air-holes in the PCFs cladding have been arranged either in a periodic triangular or periodic square orientation. The modal properties, in particular, the dispersion properties of the above types of PCFs can be altered by varying the hole-to-hole spacing (Λ) and the air-hole diameter (d) with air-hole fraction being d/Λ [3,4]. Both types of PCFs with a silica

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background can be successfully implemented to compensate the positive dispersion parameter and dispersion slope of the existing inline fibers [3,4]. These fibers can be engineered for designing ultra-flattened near zero dispersion [5–12] or can be engineered to have ultra negative dispersion values near the communication wavelength [13–19].

Photonic Crystal with air-holes arranged in circular layer arrangements have been investigated for different applications [20–27] such as studying thermal properties for electrical driving [20], high transmission waveguides [21], high quality factor microcavity lasers with isotropic photonic band gap effect [22], localization of electromagnetic waves [23] and achieving ultra-flat dispersion [24] *etc*. Argyros et al. [28] realized PCF with circular air-holes arrangement with polymer background. Though the above results demonstrate few works have been accomplished, still a detail guiding and modal properties of CPCF with silica background has not yet been explored for its potential in the communication wavelength window or Infrared (IR) or *far-IR* applications.

In this work, different guiding and modal properties, especially the dispersion properties of PCFs with air-hole arranged in a circular pattern have been investigated. It is interesting to analyze how a regular circular air-hole disposition, different from the triangular one, usually studied so far, can affect the characteristics of the guided mode. Moreover, it is important to understand in which terms all the results previously obtained for the triangular PCFs can be applied to the circular-lattice ones. Our numerical investigations reveal that C-PCF can *better compensate the inline dispersion for both single wavelength and broadband applications*. C-PCF has also been found out to be a better candidate for high power applications like wide band supercontinuum generation (SCG) because of its unique properties like (i) *larger mode area* that can accumulate high power in the core, (ii) *red-shifting of zero dispersion wavelength* (*ZDW*) that is preferable towards mid-IR SCG specially with chalcogenide materials, (iii) *lower dispersion slope in the anomalous dispersion region* that leads to a broader spectrum and (iv) *low Group velocity Dispersion GVD in the normal dispersion region* that leads to higher Dispersion Length (L_D) and higher degree of solitonic interaction. With the above advantages for a desired application with a target broadband and spectral power, we have explored the SCG property of the designed fiber by varying different geometrical parameters, considering the influence of varying pulse widths, peak powers and pumping wavelengths in detail.

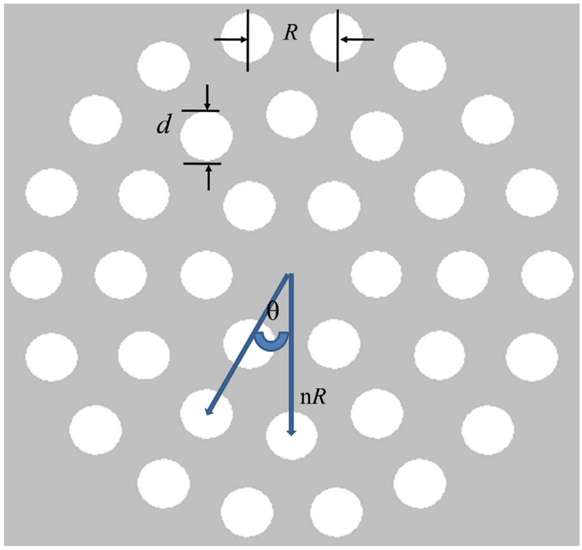

Fig. 1. The schematic diagram of the studied fiber. The spacing between the air-holes in a particular circle is *R* and the distance from the center to *n*th circle is n*R* with silica background.

2. Geometry of the studied structure and modal analysis

The schematic diagram of the C-PCF is shown in Fig. 1 with the air-hole diameter *d* and *R* is the spacing between two neighboring air-holes in a particular circle. Also, n*R* is the distance from the center of the fiber to each air-hole of *n*th circle. Subsequently, the distance from the center to the first circle to the center is *R* whereas; the distance from the center to the 2nd circle is 2*R* and so on. The C-PCF with circular symmetry is constructed by repeating the circular unit around the core center. The circle has 6*n* (with $n = 1, 2, 3$ *etc* for *first, second* and *third* ring of air-holes) no of air-holes in a particular air-hole ring. The angular spacing between any two consecutive air-holes in a circle can be given by $\theta = (360/6n)$, where $n = 1, 2, 3$ *etc* for first, second, third layer of the circles forming the cladding cross-section. The structure has been designed based on C_{2v} symmetry. We compare the propagation characteristics of C-PCF with triangular-lattice PCF for the structural parameters, the pitch 'Λ'(hole to hole distance of regular triangular-lattice PCF) was found to have the direct equivalence with '*R*' (the radius of the circle and the distance between two consecutive circles). Thus, employing the above analogy under the same air-hole diameter *d*, d/Λ (the air-filling fraction) for triangular-PCF can be compared with *d/R* of C-PCF. Another important geometrical parameter is air-filling fraction *f*. The corresponding value for triangular-lattice PCF

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