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Annular core photonic quasi-crystal fiber with wideband nearly zero ultra-flat dispersion, low confinement loss and high nonlinearity

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ABSTRACT

We propose an annular core photonic quasi-crystal fiber with ultra-flat dispersion, low confinement loss and small effective mode area covering O, E, S, C, L and U bands. The proposed design has a six-fold symmetric quasiperiodic array of air holes with a central air-hole in the core (an annular core), which induce wideband nearly zero ultra-flattened dispersion of 0 ± 0.11 ps/(nm.km) from 1.15 μm to 1.65 μm, low confinement loss in level of 10^{-4} and the small effective mode area of 5.55 μm^2 at 1.55 μm.

1. Introduction

In high-speed optical communication systems, dispersion management for optical fibers is a crucial factor that has great influence on any optical system supporting ultrashort soliton pulse propagation. In order to decrease the dispersion effect, dispersion-shifted fiber and zero-dispersion single-mode fiber are designed for communication wavelengths. Photonic crystal fibers (PCFs) [1], have been extensively investigated because of their unique properties compared to conventional fibers. Due to high degree of freedom in geometries, PCF offers great possibility to control its dispersion properties, particularly useful in designing dispersion flattened fibers over a wide range of wavelengths. So far several designs for the PCF have been proposed to achieve the nearly zero ultra-flattened dispersion properties [2–14]. To achieve improved dispersion flatness over a wider bandwidth, the design of PCF have become more and more complicated. From the previous report, it is demonstrated that the small sized air hole of the first layer in the cladding is particularly important for the overall dispersion flatness [8]. However, the small air-hole diameters around the core significantly increase the confinement losses even with large number of air-hole layers and increase the effective mode area. It is hard to simultaneously obtain high nonlinearity and ultra-low dispersion slope for conventional highly nonlinear optical fiber [15]. The nonlinearity with low dispersion slope should be compromised for conventional highly nonlinear optical fibers.

To make up the problems above, Saitoh et al. proposed a simple structure for dispersion flattened PCF based on a conventional triangular lattice with a defected core of a central air hole. [16]. The basic idea of this study comes from introducing a central air hole into the core which may flatten dispersion and reduce confinement loss [17]. More recently, Zhang et al. proposed a square lattice PCF with a defected core of central air hole using the superiority of square lattice PCF [18]. From these

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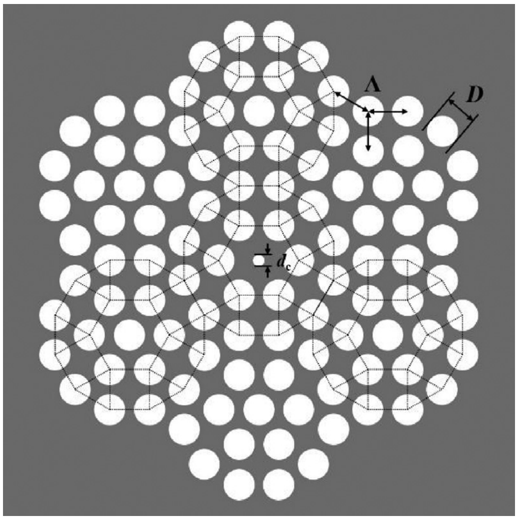

Fig. 1. Cross slice of the proposed annular core photonic quasi-crystal fiber.

reports, the conventional PCF with a defected core of a central air hole shows ultra-low dispersion slope, low confinement loss and small effective mode area.

Compared with the traditional PCFs, photonic quasi-crystal fiber (PQF) has superior optical properties such as nearly zero ultra-flattened dispersion [19,20], high negative dispersion [21], high nonlinearity [22], large effective mode area [23], and high birefringence [24]. In 2007, our group introduced the concept of PQF and proposed the six-fold symmetric PQF [25]. Introducing quasi-periodic array of microscopic air holes in optical fibers could give rise to unique properties that were not found in the conventional PCFs. The PQF without any defect has nearly zero ultra-flattened dispersion with dispersion of 0 + 0.05 [ps/(nm.km)] over the range 1490 ∼ 1680 nm, which exhibits larger cutoff ratio for endlessly single mode operation than triangular lattice PCF [25].

In this paper, we proposed an annular core to PQF by a single air-hole defect in the core, which maintains nearly zero ultra-flattened dispersion, low confinement loss and high nonlinearity for wide band width including O, E, S, C, L and U bands. Design strategy consists of two steps. First, the starting point of idea for the proposed PQF depends on the mutual cancellation of the waveguide dispersion and the material dispersion by introducing a defected air-hole in the core [16]. Second, the superiority of the PQF for nearly zero ultra-flattened dispersion makes it possible to obtain wide band flattened dispersion, low confinement loss and high nonlinearity. Using an efficient full vector finite element method (FEM) with anisotropic perfectly matched layers (PML), we analyzed numerically the proposed PQF and followed the approach by Saitoh et al. [16]. By comparative research of triangular lattice PCF [16], square lattice PCF [18] and the proposed PQF with a defected core, it is demonstrated that the defected core PQF has more nearly zero ultra-flattened dispersion than other two PCFs. Moreover, the optimized lattice constant of the proposed PQF is larger than those of other two PCFs, which makes it easier to manufacture and shows higher coupling efficiency between the nearly zero ultra-flattened PQF and the conventional optical fiber.

2. Geometries and numerical model

The cross section of the proposed annular core PQF is shown in Fig. 1, which is composed of quasiperiodic array of air holes in the cladding with a central small air hole (d_c) in the core regions, resulting in an annular core. White circles denote air holes and elementary units of the quasicrystal are denoted by black line.

Pure silica is the only used material, and its refractive index is obtained from the Sellmeier equation [26]. Λ is the distance between neighboring air holes and D is the diameter of air holes in cladding.

At first, we show the results on the mode field. Fig. 2 shows electric intensity profile of two-polarized fundamental modes at $\lambda = 1.55\ \mu m$, for the proposed annular core PQF, where $\Lambda = 2.09\ \mu m$, $D/\Lambda = 0.78$, and $d_c/\Lambda = 0.273$. The two degenerated fundamental modes in the proposed PQF have annular distributions due to the central air hole as a defect and are well confined within the core silica region.

In this paper, the three main optical properties of PCF, namely chromatic dispersion, confinement loss, and effective mode area are numerically analyzed using FEM with anisotropic PML. Once the effective refractive index n_{eff} versus the wavelength is obtained by the FEM approach [27], the dispersion parameter can be derived by using simple finite-difference formulas:

$$D = -\frac{\lambda}{c}\frac{d^2 Re\left[n_{eff}\right]}{d\lambda^2} \tag{1}$$