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Short communication

Investigation on chalcogenide and silica based photonic crystal fibers with circular and octagonal core

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ABSTRACT

In this paper, a novel chalcogenide and silica photonic crystal fiber (PCF) structure is designed with circular air-holes located in the cladding and the various optical properties, namely, dispersion, nonlinearity and group velocity dispersion parameters are compared for two different core structures, namely, circular and octagonal. The objective is to obtain high nonlinearity with dispersion flattened PCF. The prime focus is to obtain high non-linear effects as it plays great role in speed and capacity of optical communications. The proposed chalcogenide octagonal and circular PCF exhibits a dispersion of +77.55 ps/(nm km) and +77.34 ps/(nm km), respectively, whereas, the nonlinearity is in the order of 4506 W^{-1} km^{-1} and 4498 W^{-1} km^{-1}, respectively. Also, the silica octagonal and circular PCF exhibits a dispersion of +19.03 ps/(nm km) and +0.97 ps/(nm km) respectively, whereas the nonlinearity is in the order of 169.41 W^{-1} km^{-1} and 182.41 W^{-1} km^{-1} respectively.

1. Introduction

Supercontinuum is a broad continuous spectra formed due to the propagation of high power pulses through a nonlinear media. It is widely used in spectroscopy, pulse compression and the design of tunable ultrafast femtosecond laser sources. Especially, in telecommunication systems, these broadband sources are highly preferred to enhance the information carrying capacity of the communication system. Photonic crystal fiber (PCF) is a new type of optical waveguide that exhibits the properties of both optical and photonic crystals. Generation of new frequency components is an intrinsic feature of nonlinear optics that has been studied intensively since the early 1960's. These newly generated spectral components broaden the resulting spectrum and this leads to the supercontinuum generation (SCG).

The first observation of SCG is the generation of a white light spectrum which covers the entire visible range from 400 nm to 700 nm after propagating 5 μJ picosecond pulses at 530 nm in bulk BK7 glass [1]. It is concluded that space time focusing and self-steepening causes optical shock behind the pump pulses which leads to a white light continuum generation in bulk material. But, SCG in bulk material is a highly complex process that involves an intricate coupling between spatial and temporal effects [2]. Then SCG is investigated using a conventional optical fiber. SC generation experiments at first in optical fiber is done by introducing high-power pulses in the visible spectral region into standard silica based optical fiber with zero group velocity dispersion (GVD) at wavelength around 1.3 μm [3]. The spectral broadening that was observed is attributed to cascade stimulated raman scattering and self-phase modulation (SPM) [3].

Then pumping is done in the anomalous GVD regime, where the spectral broadening arises from soliton-related dynamics [4]. The numerical simulations of SC generation involve three phases: (i) An initial period of spectral broadening and temporal compression, (ii) Fission into a series of distinct fundamental Soliton components and (iii) The continued propagation of these solitons [5–7]. But, the majority of SC generation studies in conventional fiber were focused on the regime where pumping that uses ultrafast pump pulses and the detailed physics underlying SCG using longer pump pulses or continuous wave (CW) excitation remained a subject of active research [8]. This has encouraged the researchers to conduct experiments using a new type of optical waveguide PCF.

An additional advantage in PCF was that the broadband single mode guidance properties that resulted in the generated SC retaining a uniform spatial profile that overcomes the SCG in bulk materials was often associated with filamentation effects [8]. Then, the use of a generalized nonlinear schrödinger including higher-order dispersion and Raman scattering is reported to model the SCG process in PCF [9]. The Numerical modelling of SCG in PCF using femtosecond pulses and the crucial role of Soliton fission in the

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spectral broadening process was initially reported which enhanced for the first time [10]. As a result of this extensive research, the dominant spectral broadening mechanisms underlying SCG in PCF were clearly identified. PCF consists of a core bounded by number of air-holes in a specific arrangement which act as a cladding [11]. The refractive index of core is lower than the surrounded photonic crystal cladding. As in conventional fiber, PCF also comprises two mechanisms such as single mode and multimode mechanisms. It is highly attractive because of its high design flexibility, i.e. we can modify the design parameters such as diameter and pitch in order to tune the optical properties [11].

Owing to the PCF's tight field confinement capability and its wavelength scale structure, it offers small effective mode areas A_{eff} and enhances the effective nonlinearity by an order of magnitude [12]. Recently, it has been expanded with the PCF's fabrication from multi-component soft glasses that possess intrinsic material nonlinearities which is greater than that of pure silica [12,13]. The result is a dramatic magnification of the feasible effective nonlinearities, compared to those achieved with conventional fibres. This advance offers totally new possibilities in the field of all-optical signal processing, since it enables the realization of compact nonlinear devices with low power requirements [14].

The organisation of the paper is structured as follows. In Section 2, the proposed system model with chalcogenide and silica photonic crystal fiber (PCF) for two different core structures, namely, circular and octagonal is presented. Detailed results and discussion is in described in Sections 3 and 4 concludes the major findings.

2. Proposed design

In this paper, we design a chalcogenide PCF using a finite element method (FEM) [15]. The core of a proposed design is a solid core made of chalcogenide glass As_2Se_3 and Silica. A chalcogenide PCF provides a better confinement of light than silica PCF. The cladding consists of the number of circular air-holes [16,17]. If the normalized value $d/\Lambda \leqslant 0.45$ then the PCF act as single mode fiber [17,18]. With this motive, this work compares the optical parameters such as dispersion, nonlinearity and GVD Parameters by introducing five circular ring-air cladding with a chalcogenide and silica solid core of Octagonal and Hexagonal structure.

The geometrical structure of the proposed PCF is shown in Fig. 1. Here, the geometrical parameters are kept constant and only the shape of core is varied. This PCF comprises five rings of air holes arranged in silica and chalcogenide background. The first three ring air-hole diameter, the last two ring air-hole diameter and hole-to-hole spacing is denoted as d, D and Λ, respectively. The design parameters of the proposed PCF are $d/\Lambda = 0.41$ and $\Lambda = 1.9\ \mu m$. Here, we assign the diameter of the air-holes and the core as constant. We clearly demonstrate that the variation in the optical parameters due to the variation of core structure.

3. Results and discussions

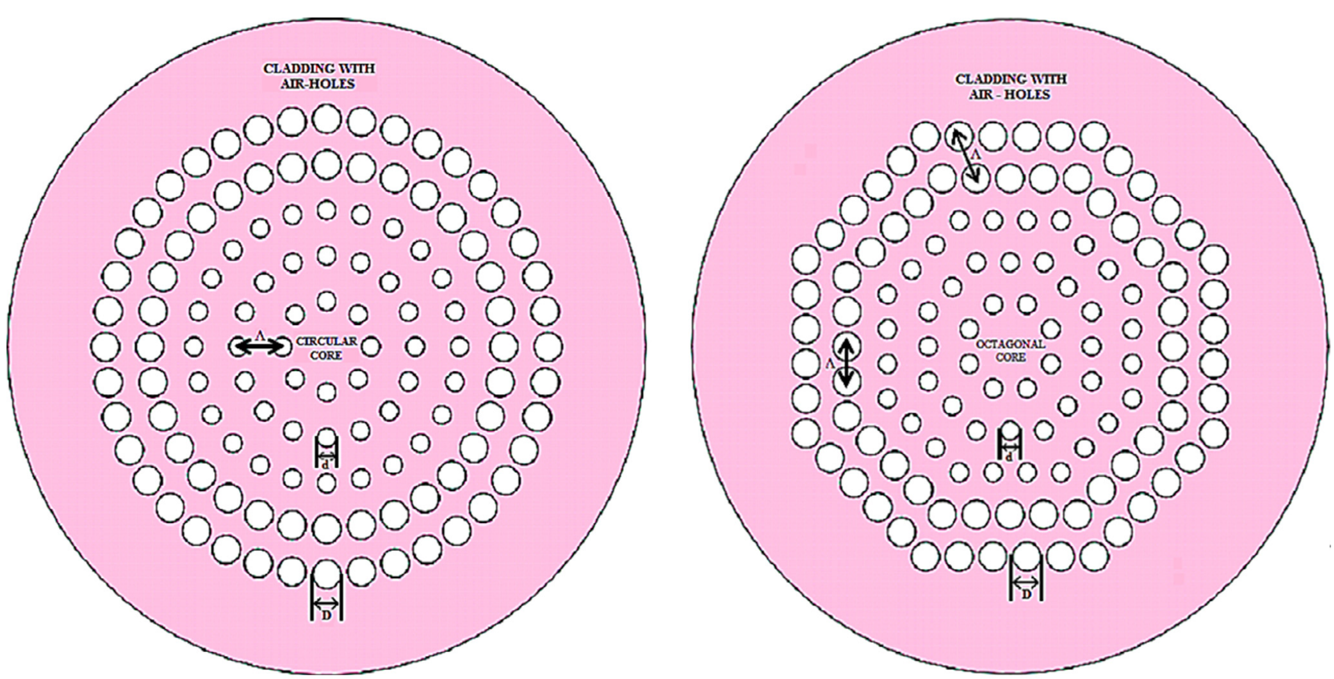
Optical properties of PCF such as dispersion and nonlinearity are compared by varying the core structure and keeping the geometrical parameter as constant. Also, the properties such as effective mode area (A_{eff}) and effective indices (n_{eff}) are compared, which is useful in calculating dispersion and nonlinearity.

3.1. Dispersion

The process in which the pulse changes per unit distance of propagation is known as dispersion D (λ) (i.e. ps/(nm km)) [19]. As a result of different frequency components of the pulse which travels at different velocities, a short pulse of light spreads in time due to D (λ). The dispersion D is given as,

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

where operating wavelength is denoted as ?? and effective index is denoted as n_{eff} which is obtained as 2.788258 and 2.788251 for Chalcogenide Circular and Octagonal PCF, respectively. Similarly, for Silica Circular and Octagonal PCF, the n_{eff} value is 1.416535



(a) (b)

Fig. 1. Geometrical structure of the proposed PCF (a) circular PCF and (b) octagonal PCF.