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Effect of germanium doping on the performance of silica based photonic crystal fiber

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ABSTRACT

In present communication, a germanium doped hexagonal photonic crystal fiber is presented to obtain highly nonlinear coefficient with flat dispersion property for supercontinuum generation applications. The dispersion in the hexagonal photonic crystal fiber can be modified by doping level of germanium along with its geometrical parameters. As a result of this doping nonlinear coefficient of 0.0166 W^{-1} m^{-1} and the flattened dispersion of less than the −11.8 ps/(nm.km) are obtained at 1.55 μm. The numerical results confirmed that the proposed germanium doped hexagonal photonic crystal fiber could be used for wideband supercontinuum generation. In comparison with other reported papers our suggested photonic crystal fiber provides much better nonlinear coefficient with flat dispersion for supercontinuum generation.

1. Introduction

The supercontinuum (SC) effect is generated in the fiber when collections of nonlinear effects together act upon the pump pulses in order to cause spectral broadening of the original pulses [1]. The higher pump intensity along a fiber, the broader the supercontinuum spectra [2]. The length of broadening of SC depends on the pump intensity, nonlinear effects and dispersion [2,3]. During the last decade, the development of SC sources emerged as an active research field [4–6]. Now a days SC sources are used in various applications such as optical coherence tomography [7], optical communication [5], frequency metrology [8] and many others [9,10]. The photonic crystal fiber (PCF) is very suitable for SC generating light source due to its high nonlinearity and adjustable dispersion properties as compare to the well-known standard fibers [11]. In recent years, PCF technology has attracted the researchers due to its extraordinary applications [12–14]. PCFs can be made from silica material with a periodic arrangement of air holes along the longitudinal axis of fiber. The presence of air holes in cladding region offer additional control on design and PCF performance parameters. Moreover, the dispersion profile, effective area and nonlinearity of PCFs can be controlled by using design parameters of PCF such as pitch of air holes, inner and outer holes diameters etc. [11,15–17]. Practically, for high SC generation, it is desired that nonlinearity should be high along the fiber while maintain the flat dispersion profile which reduced pump power requirement [3]. Initially, silica based

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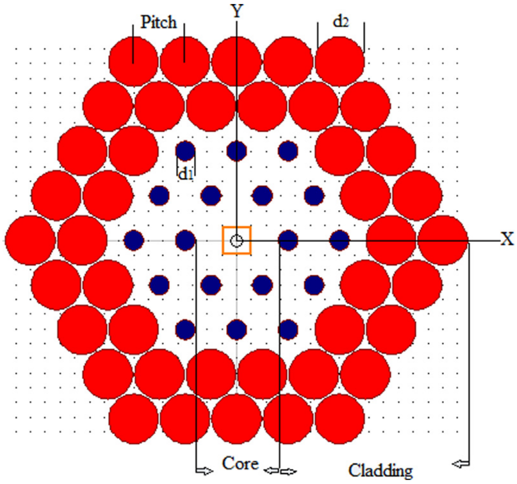

Fig 1. Cross section of Ge-doped PCF.

PCFs were considered the best medium for SC generation because of their inherent property of adjustable dispersion and high nonlinearity. Along with this, these fibers have a great limitation of low nonlinear index [11].

Afterwards, Razzak et al. proposed an octagonal PCF for high nonlinear coefficient. Although this structure increases the nonlinearity coefficient but dispersion profile have limited flattened bandwidth i.e. 0.2 μm around 1.55 μm [18]. Further to enhance the nonlinearity Camerlingo et al. proposed a lead silicate fiber with a W-type index profile. The main feature of this fiber is, it exhibits high nonlinearity coefficient 0.82 W^{-1} m^{-1} with the near zero flat dispersion profile in 1.55 μm region. But, this fiber has a limited flat dispersion region of one octave only except this region it did not provide coherent SC generation [19]. An experiment suggest that to further enhance the flatness of dispersion profile, the different concentration of germanium doping (Ge- doped) in silica can be used [20]. In this regard, Wang et al. proposed a heavily Ge-doped silica fiber with a four-layer refractive index profile [21], which exhibits a near zero broadband flat dispersion profile with higher nonlinear coefficient of 0.0096 W^{-1} m^{-1} in the 1.55 μm region. Ge-doped silica fiber has larger flat dispersion profile and lower nonlinearity coefficient than that of the W-type index profile [19].

Hence, in present paper Ge-doped silica based PCF with a hexagonal geometry is studied to obtain the high nonlinearity with flat dispersion for SC generation. The obtained results are compared with the reported results. Here FDTD method is used for the numerical modelling of proposed hexagonal PCF.

2. Proposed Ge-doped hexagonal PCF structure

The cross-sectional view of the proposed hexagonal PCF is shown in Fig. 1. This has single substrate of silica glass with different concentration of Ge i.e. 0 mol% to 13.5 mol%. The core of fiber is solid silica and cladding consists of four rings of air holes in a hexagonal lattice with two different sizes. The holes diameter of inner two rings are d_1 and the holes diameter for outer two rings are d_2 [8]. The air hole pitch is Λ.

The refractive index for air hole is 1.The Sellmeier equation is used to express the refractive index of pure silica and doped silica [21],

$$n^2(\lambda) = 1 + \sum_{i=1}^{3} \frac{A_i \lambda^2}{\lambda^2 - \lambda_i^2} \tag{1}$$

where A_i is constant obtained experimentally and λ_i is wavelength of resonances. The six Sellmeier coefficients are A_i and λ_i where i=1, 2, 3 will characterize the refractive index $n(\lambda)$ and material dispersion of glass [9]. The Sellmeier coefficients of pure silica and doped silica are summarized in Table 1.

Table 1
Sellmeier coefficients of pure and Ge-doped silica glass used in PCF design.

Mole Percent		Sellmeier Coefficients					
SiO_2	GeO_2	A_1	λ_1	A_2	λ_2	A_3	λ_3
100	0	0.6961663	0.0684043	0.4079426	0.1162414	0.8974994	9.896161
95.9	4.1	0.68671749	0.072675189	0.43481505	0.11514351	0.89656582	10.002398
93	7	0.68698290	0.078087582	0.44479505	0.11551840	0.79073512	10.436628
86.5	13.5	0.73454395	0.0869176930	0.42710828	0.11195191	0.82103399	10.846540