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Characterization of Fluoropolymer Photonic Crystal Fiber for THz Regime

Research Article

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Abstract. In this paper, we present the propagation characteristics of Fluoropolymer based Photonic Crystal Fiber (PCF) exhibiting guiding properties in terahertz region. The variation of effective index of guided mode and dispersion with wavelength in hexagonal lattice Fluoropolymer PCF are investigated by using the fully-vectorial finite element method (FEM).

Keywords. Photonic crystals fiber; Dispersion; Fully-vectorial finite element method (FEM); Fluoropolymer; Terahertz waves

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1. Introduction

Photonic Crystal Fiber (PCF) [1–3] is a single material optical fiber with an array of periodic air holes across the cross-section running down its entire length. By leaving a single lattice site without an air hole, a localized region of higher refractive index is formed. This localized region acts as a waveguide core in which light can be trapped along the axis of the fiber. A considerable amount of interest has been generated in PCFs because of its unusual and attractive optical properties like single mode operation in wide wavelength range, large mode area, high birefringence, excitation of non-linear effects at small mode area, and manageable dispersion properties [4, 5]. In optical communication, dispersion plays an important role as it determines the information carrying capacity of the fiber. Therefore it becomes important to study the dispersion properties of PCF. Many modeling techniques have been applied to study its propagation characteristics, which include the effective index method, Plane wave Expansion Method, Finite Element Method etc. In recent past, different materials are used for the formation of PCF like chalcogenide glass, Telluride and plastic or polymer due to their unique optical properties.

Fluoropolymer or the fluorinated copolymer is a copolymer of 2, 2-bistrifluoromethyl-4, 5-difluoro-1, 3-dioxole (PDD) and tetrafluoroethylene (TFE) and amorphous in nature [6]. The PDD dioxole monomer in Fluoropolymers yields unexpected properties. Teflon or polytetraflourethylene is the trademark brand name of fluoropolymer produced by Dupont. Teflon has outstanding light transmission from the deep UV range including a significant portion of the IR range. Also, as Teflon does not absorb light, it will not deteriorate with exposure to light. These optical properties, over such a wide range of wavelength and possible exposure conditions, are unmatched by any other polymer. The properties of Teflon, including optical clarity, unusually low refractive index, high flexibility and exceptional UV stability and UV transmission capability, make it an ideal material for optical devices.

Fluoropolymer PCF can be easily manufactured and has low loss characteristics to be used as a waveguide for terahertz waves i.e. in the frequency regime of 100 GHz or 0.1 THz to 30 THz [7]-[9]. Following these issues, we present the propagation characteristics of Fluoropolymer PCFs exhibiting guiding properties in terahertz region. The variation of effective index of guided mode and dispersion with wavelength in hexagonal lattice Fluoropolymer PCF are investigated by using the fully-vectorial finite element method (FEM).

2. Design of Fluoropolymer PCF

A PCF is designed using the highly flexible plastic material Fluoropolymer: Teflon. Figure 1 shows the Cross-sectional view of floropolymer PCF; here the fiber cladding consists of a hexagonal lattice of circular air hole with a missing air hole in the centre, in a fluoropolymer background, whose refractive index is 1.44.

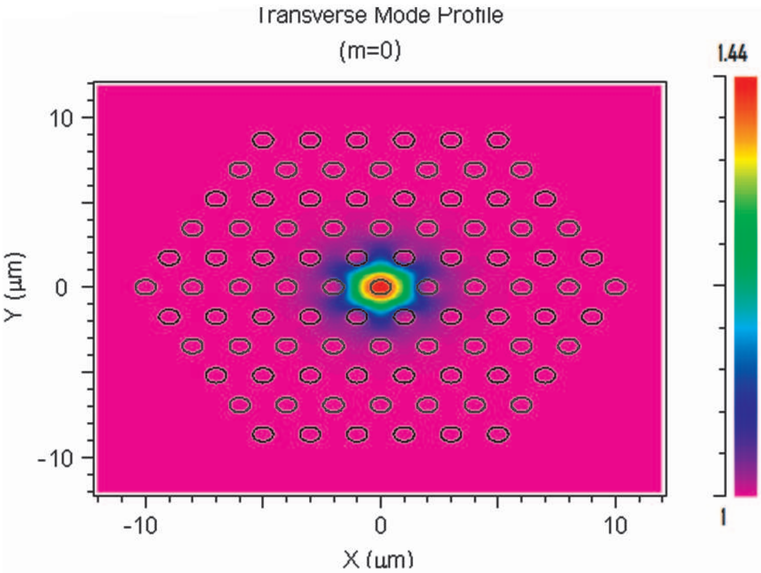


Figure 1. Cross-sectional view of Electric field intensity for designed Fluoropolymer PCF.

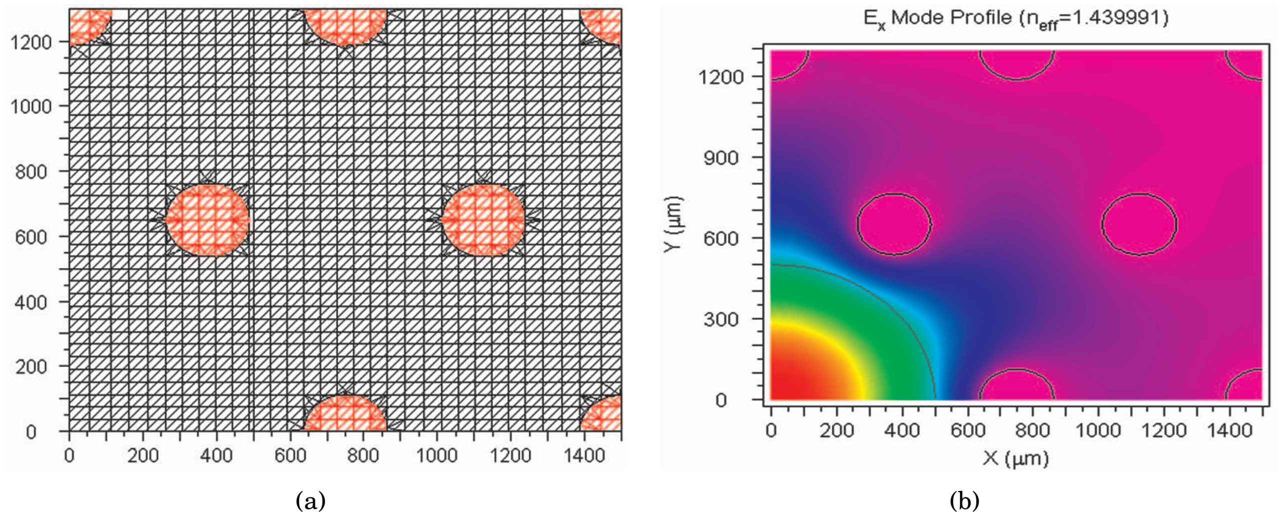


Figure 2. (a) Mesh distribution applied on a quarter of the PCF and (b) Distribution of the electric field of the fundamental mode into a PCF with $\lambda = 750\mu$m at $\lambda = 10\,\mu$m on a quarter of Fluoropolymer PCF using Rsoft-FemSIM software tool.

In the design, the pitch, Λ (i.e. the distance between the center's of two consecutive air holes or air hole spacing), is taken to be 750 μm, and the diameter of symmetric air hole is varied (from $d/\Lambda = 0.2\,\mu$m to $d/\Lambda = 0.5\,\mu$m). Following this optimization, finally obtained an optimized structure for our calculation having diameter ($d/\Lambda = 0.3\,\mu$m) of air hole in cladding while diameter of core ($d_c = 1000\,\mu$m) is larger than diameter of air hole in cladding. The mesh diagram and distribution of electric field inside the PCF design is shown in Figure 2.

3. Results and Numerical Calculations

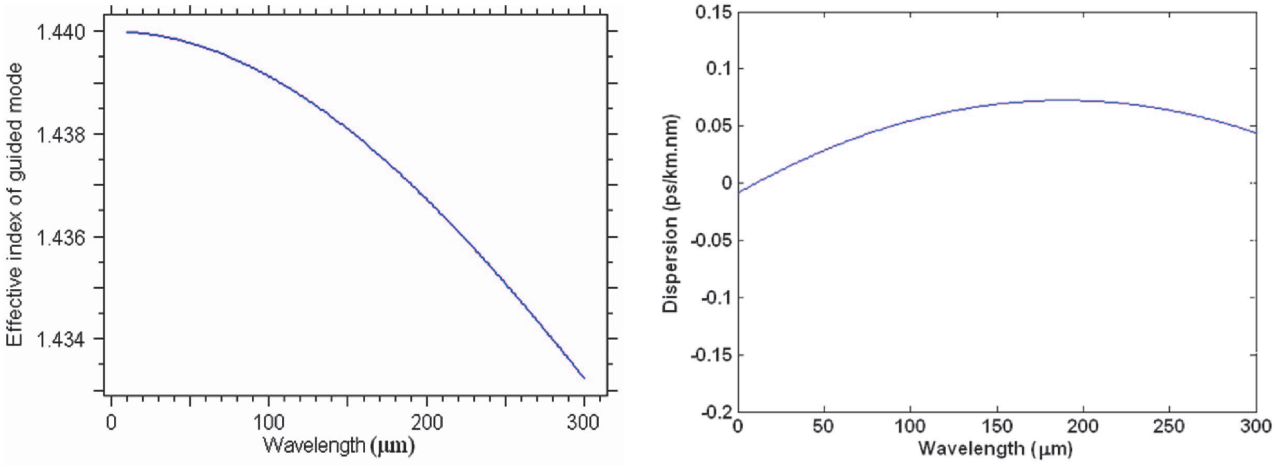
We calculate the effective index of fundamental polarization modes by using Finite element method (FEM) which is highly suited for the analysis of our periodic structure. The chromatic dispersion and the effective area are then deduced from the determination of the effective index.

Chromatic dispersion is the main contribute to the optical pulse broadening. Chromatic dispersion $D(\lambda)$, includes both waveguide and material dispersion, and is proportional to the second derivative of effective index of guided mode with respect to wavelength 'λ' and is given as [5]

$$D(\lambda) = -\frac{\lambda}{c}\frac{d^2 n_{\text{eff}}}{d\lambda^2}. \tag{1}$$

Where, 'n_{eff}' represents the effective index of guided mode, c is the velocity of light in vacuum. Figure 3, shows the variation of effective index of guided mode, chromatic dispersion with wavelength in fluoropolymer PCF in wavelength range 10 μm to 300 μm.

The variation of effective index of guided mode shows a sharp decrease with wavelength depicts that the effective refractive index of the cladding region relative to the core is reduced due to the presence of the air holes in the higher wavelength range and effective index shows a strong wavelength dependency. The variation of chromatic dispersion graph shows a flattened dispersion thereby opening the door for dispersion flattened PCF.



(a) (b)

Figure 3. Variation of (a) Effective index of guided mode, (b) Chromatic dispersion with wavelength in Fluoropolymer PCF.

4. Conclusion

In this paper, we design a simplified PCF structure based on Fluoropolymer in the wavelength range of 10 μm to 300 μm. The effective index and chromatic dispersion of proposed Fluoropolymer PCF are reported by using full-vector finite element method. The obtained results add remarkable contribution for the use of Fluoropolymer PCF in numerous applications of sensing, imaging and spectroscopy.

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Competing Interests

All the authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed equally and significantly in writing this article. All the authors read and approved the final manuscript.

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