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Comparative study on solid core photonic crystals fibers: dispersion for fixed hole diameter and fixed pitch length

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Abstract

In this study, the dispersion properties of the PCFs with triangular lattice for both the structures with a fixed hole-diameter (d) and with a fixed pitch length (Λ) are investigated comparatively. The PCFs studied in this work have a core formed a missing air-hole at the center in a silica background and a photonic crystal cladding with a regular triangular lattice having 4-rings of air-holes around the core. Simulations are executed for both fixed diameter (d=0.84 μm) and for the fixed pitch length (Λ=4.2 μm) separately for the same d/Λ interval from 0.1 to 0.7. It is found from the simulations that a change in Λ affects the dispersion behavior of the PCF more dramatically relative to a change in d.

Keywords:
Photonic crystal fiber, triangular lattice, dispersion.

Özet

Bu çalışmada, üçgen örgülü fotonik kristal fiberlerin (PCFs) dispersiyon özellikleri, sabit hava boşluk çapına (d) ve sabit adım uzunluğuna (Λ) sahip yapılar için karşılaştırılmalı olarak incelendi. Bu çalışmada ele alınan fotonik kristal fiberler (PCFs), silika arka alanın merkezinde bir tek eksik hava boşluğundan oluşan öze ve özün çevresinde hava boşluklarının 4 halkasına sahip düzenli üçgen örgülü bir fotonik kristal yeleğe sahiptir. Simülasyonlar, 0.1-0.7'lik aynı d/Λ aralığında sırasıyla sabit çap (d=0.84 μm) ve sabit adım uzunluğu (Λ=4.2 μm) için yapıldı. Simülasyonlardan, Λ'daki bir değişimin fotonik kristal fiberin dispersiyon davranışını d'deki bir değişime göre çok daha çarpıcı bir biçimde etkilediği bulundu.

Anahtar Kelimeler:
Fotonik kristal fiber, üçgen örgü, dispersiyon.

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Introduction

Photonic crystal fibers (PCFs), also known as micro-structured optical fibers (MOFs) or holey fibers (HOFs), as a new class of fibers, have attracted a great interest. PCFs generally guide light by two different guiding mechanisms: index guiding (IG) 1 or bandgap guiding (BG) 2. Recently, PCFs confining light by both mechanisms (hybrid PCFs) are proposed 3. In IG-PCFs, similar to conventional fibers, light is guided in a higher index core by modified total internal reflection from a photonic crystal cladding with low effective index; in BG-PCFs, light is confined in a low index core by trapping the light having the wavelength falling in the bandgap of the photonic crystal structure. Because of their novel guiding mechanism and variety in design, PCFs have a number of novel properties and significant applications. For IG-PCFs, the properties include endlessly sing-mode 4, large-mode-area 5, high numerical aperture 6, high birefringence 7, high nonlinear coefficient 8 and dispersion management 9.

Single-mode operation of PCFs is extensively investigated by using several techniques both theoretically and experimentally 10-15. Dispersion calculations and measurements of PCFs for different designs are made 13, 14, 16-21.

To date, a wide range of methods has been considered to study the modal characteristics of PCFs. The plane wave expansion (PWE) method 22 needs a larger super cell that demands periodicity of the PCF cladding and suffers from an inefficient computation time. The effective index (EI) method 23 is a scalar approach that treats PCF as an equivalent step index fiber that can not gives the PCF's actual modal field profile and birefringence. More effective methods than the PWE are the localized basis function method 24, the multipole method 25, and the supercell lattice method 26 but these methods have limitations in defining practical finite lattice periods, modal solutions near the cut-off region and the arbitrary transverse variation of the PCF cross-section, such as describing non-circular holes or non-identical multipole defects. Beside these field expansion approaches, the more powerful and versatile finite difference (FD) method 27, the finite element method (FEM) 28 and the beam propagation method (BPM) 29 are used to study such complex structures.

In this work, a comparative study on the dispersion properties of the solid core PCFs having triangular lattice photonic crystal cladding is executed for both a fixed hole diameter, d, and a fixed pitch length, Λ.

Chromatic dispersion

Chromatic dispersion of the optical fibers is a major factor causing optical pulse broadening. This dispersion is caused by combined effects of material and waveguide dispersion. In the case where dispersion is positive, shorter wavelengths propagate faster than longer wavelengths. In the opposite case of negative dispersion, this regime is considered to be normal. Control of the chromatic dispersion in PCFs is an essential matter for practical applications to optical communication systems, linear and nonlinear optics and dispersion compensation, ultra-broad supercontinuum generation and ultra-short soliton pulse propagation 9, 13, 16, 30.

The chromatic dispersion D of the PCF is obtained from the effective refractive index n_{eff} of the fundamental mode for different wavelengths using

$$D = -\frac{\lambda}{c}\frac{d^2\,\mathrm{Re}(n_{eff})}{d\lambda^2} \qquad (1)$$

where c is the velocity of light in a vacuum and $\mathrm{Re}(n_{eff})$ is the real part of the n_{eff}. Materials dispersion refers to the wavelength dependence of the refractive index of material caused by the interaction between the optical mode and ions, molecules or electrons in material. Waveguide dispersion depends among others on the core diameter and on the refractive index contrast between core and the cladding of the PCF. In this study, commercial software (BandSOLVE) 31 based on PWE method 22 is used to calculate the effective indices for both the core and the cladding of the solid-core PCFs

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considered, and material dispersion obtained from Selmeier's formula of materials 32 is directly included in the dispersion calculations .

Simulation results

The PCFs studied in this work have a core formed a missing air-hole at the center in a silica background and a photonic crystal cladding with a regular triangular lattice having 4-rings of air-holes around the core (figure 1). The diameter of air-holes and hole-to-hole spacing (pitch length) are denoted by d and Λ respectively. Simulations are executed for both fixed diameter (d=0.84 μm) and for the fixed pitch length (Λ=4.2 μm) separately for the same d/Λ interval from 0.1 to 0.7. The silica core index is n_{co} is taken as 1.45 for λ=1.55 μm.

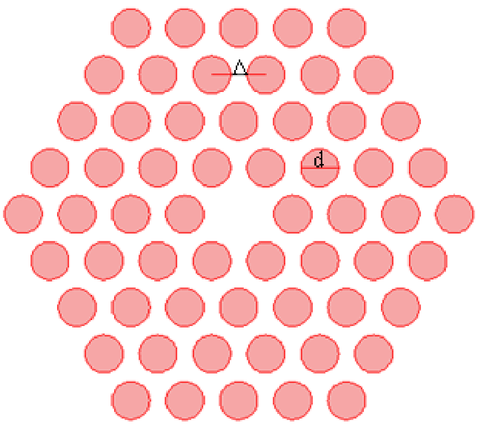

Figure 1. The cross-section of the solid core PCF

The dispersion curves are given in figure 2 for the fixed d and in figure 3 for the fixed Λ. Dispersion slopes changes more rapidly, especially for large d/Λ values, than those for the fixed Λ structures. When the d/Λ increases, dispersion zeros shift to the shorter wavelengths for the fixed d more rapidly than those for the fixed Λ. The dispersion curves for the fixed d for the d/Λ interval of 0.3-0.5 are flattened within the wavelength range considered. For the wavelength of 1.55 μm, dispersion has an approximately same value for different d/Λ ratios for the fixed d structure, but for the fixed Λ structures it changes dramatically.

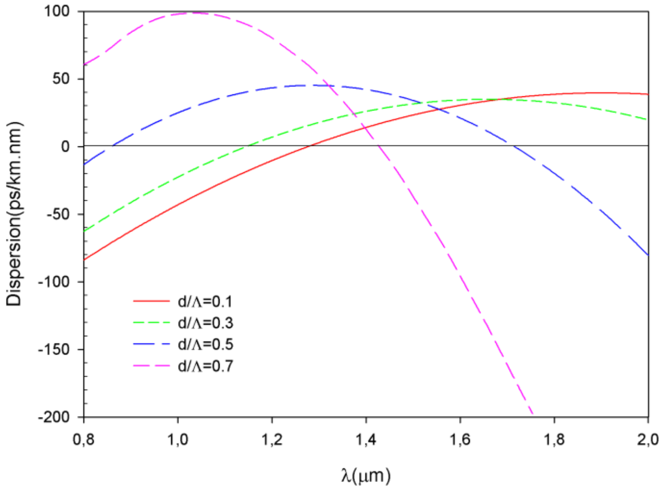

Figure 2. The dispersion variation with the wavelength for the fixed diameter

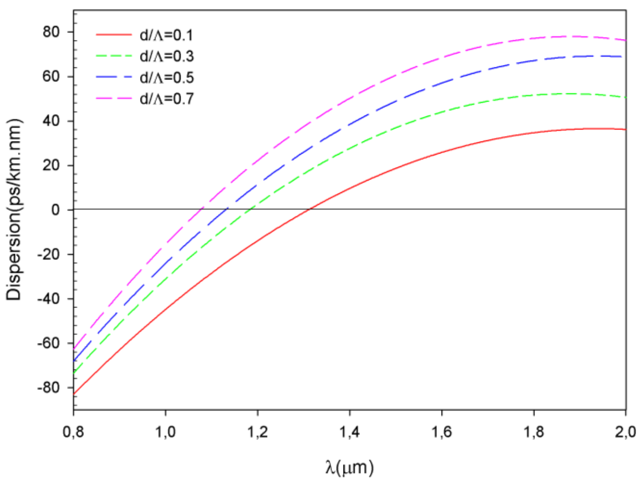

Figure 3. The dispersion variation with the wavelength for the fixed-Λ

Conclusion

In this study, solid-core photonic crystal fibers with fixed air-hole diameter d and with fixed pitch length Λ are investigated for different d/Λ ratios. The dispersions are obtained and compared for both of the structures. A change in Λ affects the dispersion behavior of the PCF more dramatically compared to a change in d. For the fixed-d structures, the dispersion is being almost the same for the range of d/Λ from 0.1 to 0.5. For the fixed-Λ structures, on the other hand, the dispersion changes in an important amount within the range of d/Λ from 0.1 to 0.7. Furthermore, the dispersion management is easier by using the fixed d structures, but for working around the same zero dispersion points is available for the fixed Λ structures in a large interval of d/Λ.

It is worth noting that, high level of flexibility in the PCF fabrication processes and techniques for post-processing 33-37 gives us a great flexibility to control the design parameters of PCFs having the desired characteristics.

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