Geometrical Parameters Identification for Zero Dispersion in Square Lattice Photonic Crystal Fiber using Contour Plots

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Abstract. – A square lattice photonic crystal fiber is analyzed by means of finite element method. Using contour plots, the geometrical parameters like lattice period \( \Lambda \) and air filling ratio \( (d/\Lambda) \) ratio for zero dispersion at a wavelength of 1.55 \( \mu \text{m} \) have been identified.

Keywords: Photonic crystal fibers (PCFs); Finite-element method (FEM);

I. INTRODUCTION

Optical fibers with silica-air microstructures, called photonic crystal fibers (PCFs) are very attractive transmission media since PCFs can provide dispersions and mode field diameters that are not obtainable in conventional single-mode fibers [1],[2]. PCF is commonly characterized by a series of air holes that runs throughout the length of the fiber[3]. Prior to drawing, the structure is formed by stacking a number of tubes that are generally arranged to form square lattices or triangular lattices; then, the preform is drawn into the fiber using conventional drawing techniques.

PCFs guide light with two kinds of effects: one is based on total internal reflection; the other is based on photonic band gap (PBG) [4],[5]. An essential effect of the transverse periodic structure is to alter the effective refractive index for propagation along the direction of the fiber leading to new dispersive properties.

Many new properties unattainable through ordinary fibers can be obtained by this class of fibers. These include fibers with a single-mode property over a wide wavelength range while still offering a large mode field diameter and zero-dispersion wavelength down to the visible wavelength. PCFs which are specially designed with this property are called the endlessly single-mode (ESM)-PCFs. A desirable property of PCFs is that, the additional design parameters of hole diameter \( d \) and the lattice period \( \Lambda \), offer greater flexibility in the design of dispersion to get the required application[6]. It is possible to change the zero-dispersion wavelength or to engineer the dispersion curve to be ultra-flattened [7].

II. FIBER STRUCTURE

The structure of the fiber is shown in Fig.1. The important parameters of this fiber are hole diameter \( d \) and hole to hole spacing \( \Lambda \) (lattice period). The refractive index of the air holes is considered to be one and the refractive index of the undoped silica has been calculated using Sellmeier’s constants [8] since silica refractive index is wavelength dependent. In this paper, FEMLAB, Finite element based application software is used.

Fig.1. Square Lattice Photonic Crystal Fiber

III. FINITE ELEMENT ANALYSIS

In order to obtain a precise description of the field distribution over PCF, the Maxwell differential equations must be solved for a large set of properly chosen elementary subspaces, taking into account the continuity of the fields. The first step consists in splitting the cross section of the modeled guide into distinct homogeneous subspaces. This parceling results in a mesh of simple finite elements, triangles. The Maxwell equations are discretized for each element leading to a set of elementary matrices. Finally the effective index and the distributions of the amplitudes are numerically computed taking into account, the conditions of the continuity at the boundary of each subspace.

IV. DISPERSION CHARACTERISTICS OF PCFS

The guiding and dispersion properties of square-lattice PCFs have been analyzed as a function of the geometrical parameters, that is lattice period \( \Lambda \) and the diameter \( d \) of the air-hole in the fiber cross-section.

The FEM software can accurately calculate chromatic dispersion by the following procedure. First, the effective index \( n_{\text{eff}} \) of the fundamental mode of the PCF is computed as a function of wavelength. Then the chromatic dispersion \( D \) is calculated using the formula

\[
D = \frac{\lambda}{c} \frac{d^2 n_{\text{eff}}}{d\lambda^2}
\]

where \( c \) is the velocity of light in vacuum.
V. RESULTS AND DISCUSSIONS

The aim of this section is to identify the zero dispersion photonic crystal fiber. In order to find the $d/\Lambda$ ratio and lattice period $\Lambda$ for zero dispersion fiber, the following cases have been considered. The lattice period $\Lambda$ is varied from 1.5 µm to 2.5 µm while $d/\Lambda$ ratio is varied from 0.25 to 0.65. The contour plots are shown in Fig.2 to Fig.5.

Fig.2. Dispersion Characteristics at $\Lambda = 1.5$ µm

From Fig.2, it is very clear that for a lattice period of 1.5µm, zero dispersion can be achieved when $d/\Lambda$ ratio is varied between 0.4 to 0.6 in the wavelength range of 1.1 µm to 1.8 µm and also we get zero dispersion when $d/\Lambda$ ratio is varied between 0.25 to 0.33 for wavelength range of 1.5 µm to 1.8 µm. Since our interested wavelength is 1.55 µm, the PCF becomes multimoded when $d/\Lambda$ ratio is greater than 0.4. If $d/\Lambda$ ratio is less than 0.25, the leakage loss is more. Hence this lattice period is not suitable for zero dispersion fiber under both the cases.

Fig.4. Dispersion Characteristics at $\Lambda = 2.0$ µm

At $\Lambda = 1.75$ µm, it is possible to get zero dispersion over a wavelength range of 1.2 µm to 1.8 µm while keeping $d/\Lambda$ ratio between 0.35 and 0.4 so that the fiber is single moded with less leakage loss.

In Fig.4, we can see that when lattice period is 2.0 µm, zero dispersion can be achieved when $d/\Lambda$ ratio is kept below 0.3 for a wavelength range of 1.1 µm to 1.4 µm. When the wavelength is 1.55 µm, it is possible to get zero dispersion when $d/\Lambda$ ratio is less than 0.25, where leakage loss is severe. Hence this lattice period is also not suitable for zero dispersion fiber.

Fig.5. Dispersion Characteristics at $\Lambda = 2.5$ µm

From Fig.5, it is very clear that lattice constant 2.5 um can not be used for zero dispersion at $\lambda=1.55$ um since the
dispersion parameter becomes positive (40 ps/nm.km). In order to identify the lattice period and $d/\Lambda$ ratio for zero dispersion, another contour plot has been plotted for various $\Lambda$ and $d/\Lambda$ ratio values. From Fig.6, we can conclude that when $d/\Lambda$ is kept below 0.4, it is possible to get zero dispersion for a single mode square lattice PCF for a lattice period around 1.70 $\mu$m.

![Fig. 6. Dispersion Characteristics at $\lambda = 1.55$ $\mu$m](image)

VI. CONCLUSION

In this paper, contour plots have been used to identify the geometrical parameters for a square lattice photonic crystal fiber with nearly zero dispersion parameter. It has been observed that, when $\Lambda$ increases, dispersion parameter becomes more positive. At a wavelength of 1.55 $\mu$m, nearly zero dispersion can be achieved by keeping the lattice constant around 1.7 $\mu$m for a $d/\Lambda$ ratio below 0.4 so that the fiber is endlessly single mode fiber. With further optimization of the structure, we expect to design a square lattice PCF for wavelength division multiplexing.

REFERENCES