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Short Communication

Simulation of various *structures of photonic crystal fibers*

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Abstract

Two structures of Hexagonal Photonic Crystal Fiber have been designed in this paper. The first structure contains four circular shaped air hole rings in hexagonal configuration having Perfectly matched layer and Scattering Boundary Condition and the second structure contains a three rings Photonic Crystal fibers without Perfectly match layer and Scattering boundary condition. We have used COMSOL Multi physics (5.2) to design this models. Comsol Multi Physics uses Finite Element Method for the simulation process. And MATLAB is used to plot the effective refractive index with respect to wavelength. The variation of effective refractive index by varying wavelength and diameter of air holes have been analyzed.

Keywords: Photonic crystal fiber, Optical fiber, Finite element method, Perfectly matched layer.

Introduction

The importance of Photonic crystal fibers (PCF)[1-3] have been increased over the years since it was invented by P.St.J. Russell[1]. It consists of multiple air holes which act as cladding for this type of fiber. The index profile of core and cladding of PCF is different from an optical fiber. The optical properties such as birefringence, dispersion, effective area and confinement loss provides a great flexibility to this type of fiber than an optical fiber. Due to its novel optical characteristic[4-6,12] this type of fiber have received a lot of attention. The diameter of air hole (d) and pitch length (Λ) are two very important geometrical features of Photonic Crystal Fiber. Any variation in these two parameters directly effects the optical properties of Photonic Crystal Fiber which makes these of fiber very important. If the air holes are arranged in hexagonal fashion than this type of PCF is known as hexagonal PCF. These air holes can also be arranged in various other configurations such as decagonal, octagonal, squared[7-10] and circular[13] for the designing of PCF.

In this paper various properties of PCF like real part of effective index and confined electric field surface plot have been studied for Hexagonal PCF[11,14] having 4 and 3 ring of air holes.

Design of various structures

Figure-1 shows the four ring hexagonal PCF structure. Perfectly matched layer (PML) of thickness 0.4 µm acts as absorbing region is surrounding the four ring hexagonal PCF structure.

The hexagonal shaped 4 rings of circular air holes and 3 rings of circular air holes have been shown in Figure-1 and Figure-2 respectively. The diameter of air holes and distance between air hole (pitch) has been denoted by d and Λ respectively. Silica with refractive index of 1.45 has been used as background material.

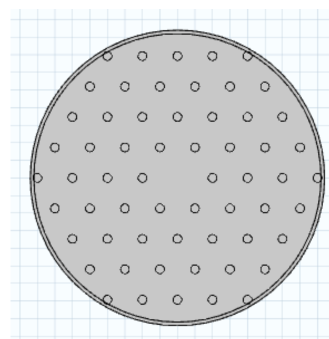

Figure-1: Hexagonal PCF with 4 rings of circular air holes, pitch Λ= 4µm and hole diameter d =0.5µm.

For the designing of first structure of the Photonic Crystal Fiber the value of the diameter of air hole (d) = 0.5µm and the value pitch length is Λ=4.0 µm. PML of 0.4 µm thickness have been used for these type of structure.

For the designing of second structure of the PCF value of diameter of air hole (d) =0.7µm and the value of pitch length (Λ) =2.3µm. No PML layer, Scattering Boundary Condition have been used in the second structure. By using FEM both of these structures have been simulated.

Modeling Steps used for simulations

The fiber has been modeled by COMSOL, using this following steps: i. Constustruction of geometry required: In this section the geometry of Photonic crystal has been designed .In case of hexagonal PCF air holes are arranged in hexagonal fashion whereas in case of Octagonal PCF the air holes are arranged in Octagonal fashion. ii. Setting physical Parameters: In this section physical parameters such as wavelength, diameter of air hole, and pitch have been used as per as the simulation requirements. We have choosen 1.55 um as wavelength, diameter of air hole as 0.5 um and pitch as 4.0 um, iii. Mesh Generation: Physics Generated Mesh is used to evaluate the electric field pattern and to evalaute the real part of effective repractive index. iv. Computing: The computation of the simulation have been done by Modal analysis and Frequency Domain Analysis of the Comsol 5.2 Module. The effective index of fiber is thus computed by solving the eigen value equation for each of these physics controlled meshes using COMSOLs Finite Element Method (FEM). v. Post processing And Visulisation: Various observations have been made by varying wavelengths and structural parameters and these observations are plotted in Matlab. The effective area bar graph have been plotted using MS EXCEL. In this way we can study observations of various parameters of Photonic Crystal Fibers.

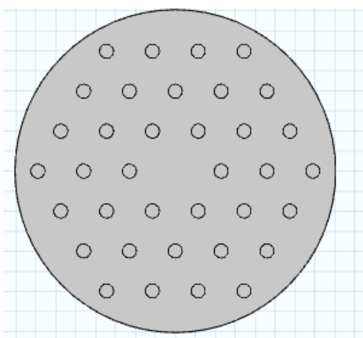

Figure-2: Hexagonal PCF with 3 rings of air holes, pitch Λ=2.3µm and hole diameter d =0.7µm

Simulations and Results

The electric field surface plot shown in Figure-4 have been obtained by using Finite element method using Comsol 5.2. Surface plot shows the electric field pattern in two dimensions. Repeating the process for various wavelength we get different values for real part of neff.

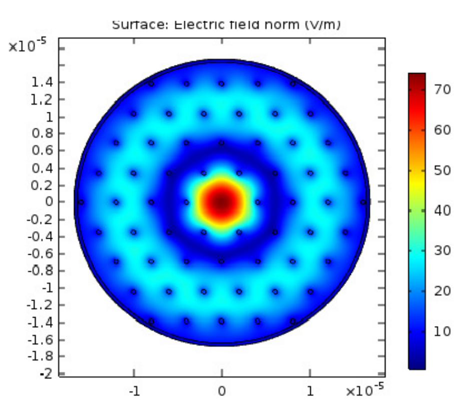

Figure-4: Electric field of PCF pitch Λ=4µm and hole diameter d =0.5µm at 1.55µm wavelength.

Time average power flow in the PCF can also be evaluated, which is useful for the studying the power flow in PCF and it can be seen that power is confined to core at 1.55 µm wavelength.

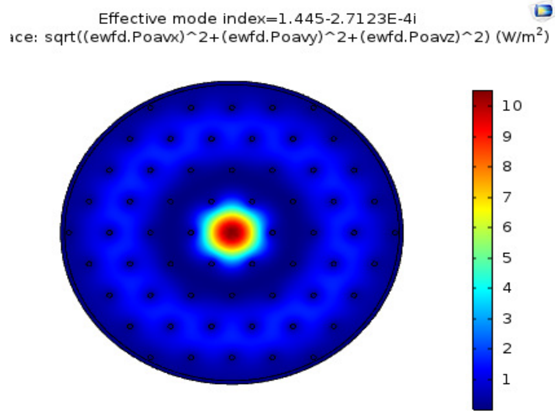

Figure-5: Time average power flow for Photonic crystal fiber with four ring structure with pitch Λ=4µm and hole diameter of 0.5µm.

Effective refractive indexes of the fiber for various wavelengths have been plotted, which is useful for study of dispersion in this photonic crystal fiber. For the 4 ring hexagonal PCF the variation of Real part of effective refractive index with respect to wavelength have been plotted in Figure-6.

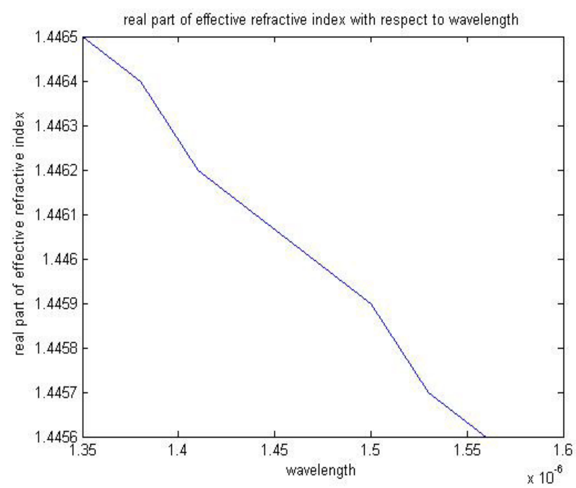

Figure-6: Re(neff) vs. wavelength for with four ring hexagonal PCF structure with pitch Λ=4µm and hole diameter d =0.5µm.

For a 4 ring structure,the real part of refractive index is calculated by varying dimensions of air holes from 0.55 µm to 0.95 µm at 1.55 µm wavelength and it has been observed that real part of effective index decreases with increase in diameter of various air holes.The varation of Real part of effective refractive index with repect to diameter have been plotted in Figure-7.

Similarly electric field in PCF with pitch 2.3 µm and hole diameter d =0.7µm is evaluated by Finite element method and surface plot is plotted.

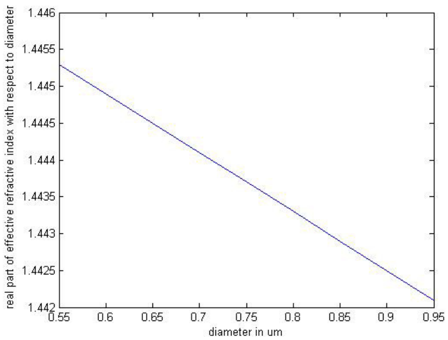

Figure-7: Real part of Neff v/s diameter of the air hole.

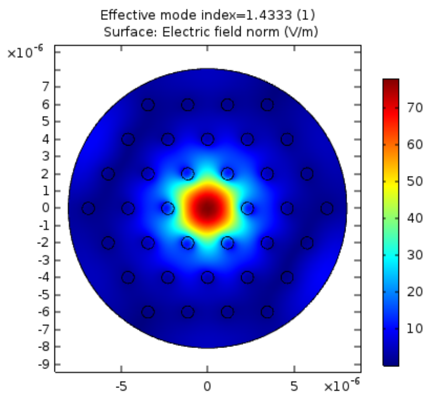

Figure-8: Electric field of three ring structure with d=0.7µm and pitch Λ=2.7 µm.

By using Comsol multiphysics time average power inside the three ring fiber have been evaluated, which is very useful for analysis of the power flow inside the PCF.

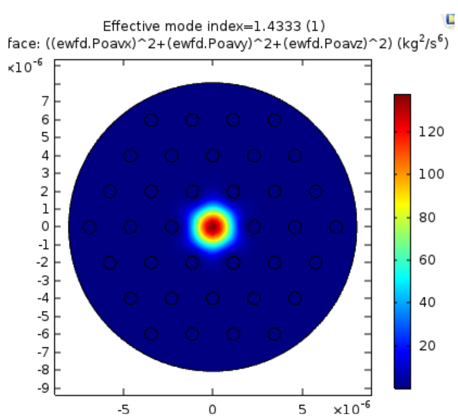

Figure-9: Time average power flow for PCF three ring structure with d=0.7µm and pitch Λ=2.7 µm.

Conclusion

It has been observed that effective refractive index of PCF with 0.5 µm diameter and pitch with 4 µm decreases with the increase in wavelength, hence by evaluating the real part of refractive index we can easily calculate the dispersion of the fiber.

It can also be seen that effective refractive index decreases with the increase in diameter of air holes air holes varies from 0.55 µm to 0.95 µm for 4 ring hexagonal PCF.

The electric field is confined to the core for both the structures at 1.55 µm.

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