HIGHLY NEGATIVE DISPERSION USING PHOTONIC CRYSTRAL FIBER

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ABSTRACT

Design of Asymmetric Photonic crystal fiber (PCF) with suitable diameter (D) and pitch value (P) using COMSOL Multiphysics. Simulation using COMSOL Multiphysics illustrates that the designed fibers to achieve the light propagation with low confinement loss, high nonlinearity, large negative dispersion which is used for the long-distance communication. All the propagation characteristics such as the effective index mode, confinement loss, effective area, dispersion, mode field diameter is studied by varying the structural parameters. We observed low confinement loss and high negative dispersion at higher d/P. Achieving high d/P can be done in two ways: increasing the air hole diameter(d) or decreasing the lattice pitch(P). For Significant impact in achieving the high negative dispersion decreasing the lattice pitch over increasing the air hole diameter. Calculate Material and Waveguide dispersion using MATLAB to obtain highly Negative dispersion

Keywords: ***Photonic Crystal Fiber, Effective Refractive Index, Negative Dispersion, Effective mode area.***

I. INTRODUCTION

Photonic Crystal Fiber was first coined by Philip St. J. Russell in the 1990’s. Photonic crystal fibers are a new class of optical fibers. Their artificial crystal-like microstructure results in a number of unusual properties. They can guide light not only through a well-known total internal reflection mechanism but using also photonic bandgap effect. Photonic crystals are dielectric periodic structures on the scale of a wavelength of light. Photonic crystals can be incorporated into the cladding of an optical fiber, producing photonic crystal fibers. Combining properties of optical fibers and photonic crystals they possess a series of unique properties impossible to achieve in classical fibers.

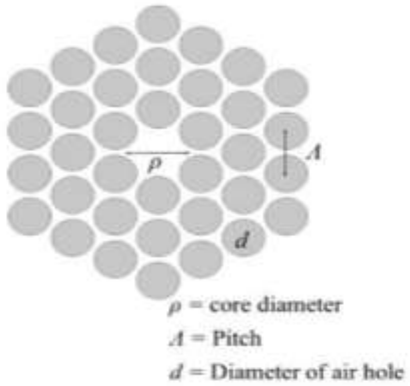


Figure 1. Photonic crystal fiber basic structure.

The core of this particular fiber is made of single material such as silica and can either be solid or empty. The core is surrounded by air holes which runs through the fiber hence it is known as 'holey' or' micro structured' fiber. Due to this structure the core acts as a cavity where the light is confined and transmitted. Light can be guided in PCFs either by total internal reflection (TIR) or PBG effect, depending on the core and cladding photonic crystal materials. Their core can be formed by pure silica, doped silica, high nonlinearity glasses, for instance tellurite, silicon, bismuth and lead silicate, air, liquids, gases, for example hydrogen, xenon, acetylene and methane, and quantum dots. The fibers have rigid design rules to fulfill the limited core diameter in the single-mode regime, modal cut-off wavelength, limited material choice (thermal properties of core glass and cladding glass must be the same). The design of PCFs is very flexible. There are several parameters to manipulate they are lattice pitch, air hole shape and diameter, refractive index of the glass, and type of lattice. Freedom of design allows one to obtain endlessly single mode fibers, which are single mode in all optical range and a cut-off wavelength does not exist. There are two types of Photonic crystal fibers based on light guiding mechanism. They are hollow core fiber and Index guiding fiber. Of these two types index guiding fibers are suitable for telecommunication application.

In fiber-optic communication, chromatic dispersion is a major drawback to high-speed data transmission. Single mode fibers (SMFs) experience broadening of pulses in the long-distance transmission system due to chromatic dispersion. This causes signal distortions that increase bit error rate (BER) per distance and decrease the bandwidth of the fiber. Therefore, to avoid pulse broadening, dispersion compensation is essential. However, different techniques, such as linearly chirped in-fiber Bragg grating, planar light wave circuit dispersion equalizer, optical phase conjugation, and dispersion compensating fibers (DCFs), have been developed to neutralize the dispersion. Among them, DCFs are preferred because they are simple, reliable, and suitable for broadband dispersion compensation, and their installation is cost effective. Traditional SMFs have positive chromatic dispersion, which is eliminated by inserting a comparatively small length of DCF. However, conventional DCFs have high losses, high dispersion slope, low effective area, and inflexible design.

Meanwhile, introduction of photonic crystal fiber(PCF) has had are mark able effect on the transmission system. PCFs are optical fibers with a periodic arrangement of low-index material, such as air channels, and for the background, higher-index materials are used, such as silica (SiO_2). They exhibit unique properties of propagating light wave and have high design flexibility, which are convenient in wavelength division multiplexing (WDM) systems. In recent days, PCFs have applications in different sectors, such as chromatic dispersion compensation, polarization mode dispersion compensation.

ADVANTAGES OF PCF

- Endlessly single-mode guidance over very wide wavelength regions.
- Extremely small or extremely large mode areas than a conventional fiber, leading to very strong or weak optical nonlinearities.
- The possibility to fill gases or liquids into the holes and make extremely strong birefringence for polarization-maintaining fibers.
- Very unusual and engineerable chromatic dispersion properties, e.g. anomalous dispersion in the visible wavelength region.
- Control over dispersion: size of air holes may be tuned to shift point of zero dispersion into visible range of the light.
- They provide single-mode guidance for a very wide wavelength range.
- They suffer less bend loss & Attenuation loss is very small.
- It provides viability for multi core design.
- They maintain the state of polarization of the input light.
- They exhibit anomalous dispersion in visible wavelength region.
- No rigid design rules to achieve desire single mode operation
- They exhibit high birefringence larger than conventional fibers.
- They achieve high degree of mode confinement.

II. PROPOSED STRUCTURE

Fibers with higher air-filling fraction can be used to achieve very high negative dispersion and birefringence. Recent research and development facilitate fabrication of such fibers Figure 2 proposed PCF with higher air-filling fraction.The cladding region of the PCF is formed with circular air holes only, and no doping is introduced at the core region. The background material silica (SiO_2) is also very common in the fiber fabrication industry. The design comprises 13 rings of air holes divided into two sectors. The first three rings of air holes have formed the inner sector of the cladding region with a pitch value of $P1 = 0.665$ μmandholediameterofd1 = 0.631 μm. The remaining 10 rings of air holes are organized to form the outer sector of the cladding with a pitch value of $P2 = 1$ μm and hole diameter of $d2 = 0.8$ μm. Air-filling fractions (d/p) of inner and outer cladding sectors remain 0.95and0.8, respectively. The removal of a single air hole from the center introduces the solid core region, and removal of two air holes from the first ring introduces asymmetry, which is a requisite for obtaining high birefringence. Distances of inner and outer sectors from the center point are kept at P1 and 3P2, respectively.

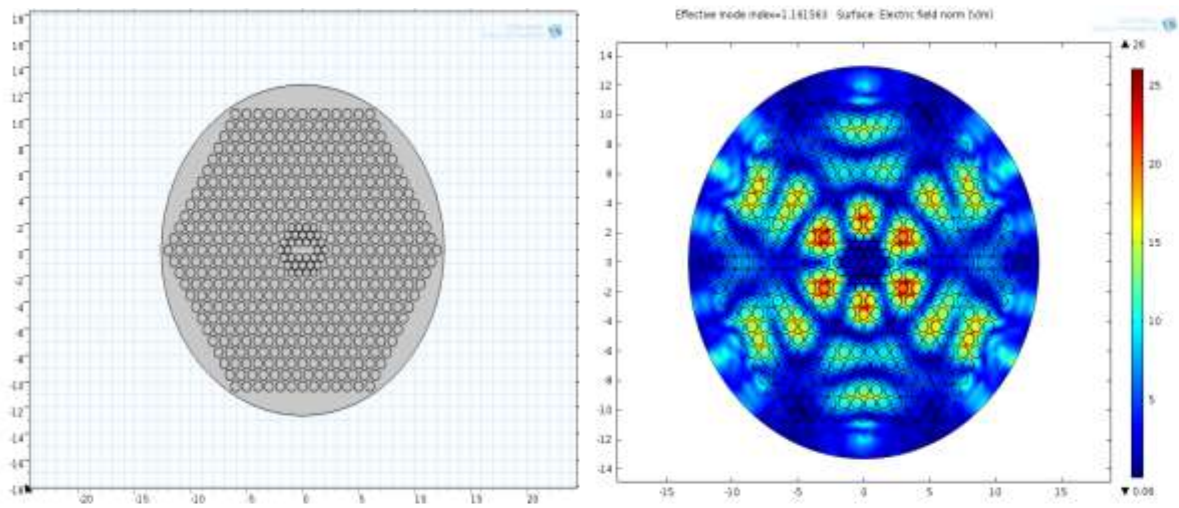


Figure 2. Proposed PCF Structure

III. PARAMETERS CALCULATION

The fiber is designed and simulated using COMSOL Multiphysics tool. The analysis gives the electric field by solving wave equation. In simple terms, mode analysis obtains eigen values and hence the mode field obtained from the simulation is simply the eigen vector. Finite element analysis is preferred widely in recent works because the results are accurate even for complex fiber structures.

A. *Effective mode area (A_{eff})*

Effective mode area is the measure of the area covered effectively by a mode within the fiber.

$$A_{eff} = \frac{\left[\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x,y)^2 dx\, dy\right]^2}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x,y)^4 dx\, dy} \qquad (1)$$

Where E denotes the magnitude of electric field component. For our model we assume that the fiber is homogeneous and no free charges inside the fiber. A_{eff}depends on mode field radius and varies exponentially.

B. Effective refractive index (n_{eff})

It is the measure of optical intensity distribution. The effective refractive index of PCF lies between the refractive index of core and cladding, and it lies close to refractive index of core.

C. Non-linear coefficient (γ)

Wavelength is related with nonlinear coefficient as,

$$\gamma = \frac{2\pi * n_2}{\lambda * A_{eff}} \qquad (2)$$

Silica is used as background material for the design. non-linear effects arise due to the contribution of third order susceptibility ($\chi^{(3)}$). For silica $n_2=2.2*10^{-20}$ m^2/w. for silicon it is $4.5*10^{-18}$ m^2/W.

D. Dispersion parameter (D)

Dispersion arises as a result of frequency dependence of refractive index of dielectric materials. Dispersion decreases the peak power of the pulse and increases pulse width. D is expressed in ps^2/km and is obtained from solution of Helmholtz-Eigen value.

The dispersion parameter (D) is obtained from propagation constant β(ω)

$$D(\lambda) = -\frac{\lambda}{c}\frac{d^2\,\mathrm{Re}[n_{\mathrm{eff}}]}{d\lambda^2}, \qquad (3)$$

IV. SIMULATION RESULTS

A full vector mode solver COMSOL Multiphysics5.0 based on the finite element method (FEM) is used to simulate various properties of the proposed PCF. A perfectly matched layer (PML) is positioned outside the outermost ring as the absorbing boundary in order to reduce the simulation window. The Sellmeier equation is used to introduce the material dispersion under consideration.

$$n_1(\lambda) = \sqrt{1 + \frac{a_1\lambda^2}{\lambda^2 - {b_1}^2} + \frac{a_2\lambda^2}{\lambda^2 - {b_2}^2} + \frac{a_3\lambda^3}{\lambda^2 - {b_3}^2}} \qquad (4)$$

Where coefficients are as follows

a_1=0.6961663; a_2=0.4079426; a_3=0.8974794

b_1=0.0684043; b_2=0.1162414; b_3=9.8961617

Even though the change in wavelength is large the effective mode area increases slowly. Smaller the mode area, higher the confinement. At higher wavelengths light is not at all tightly confined. Dispersionproperties of the designed PCF depends on the wavelength at the fiber is operated. Also the core diameter affects dispersion.

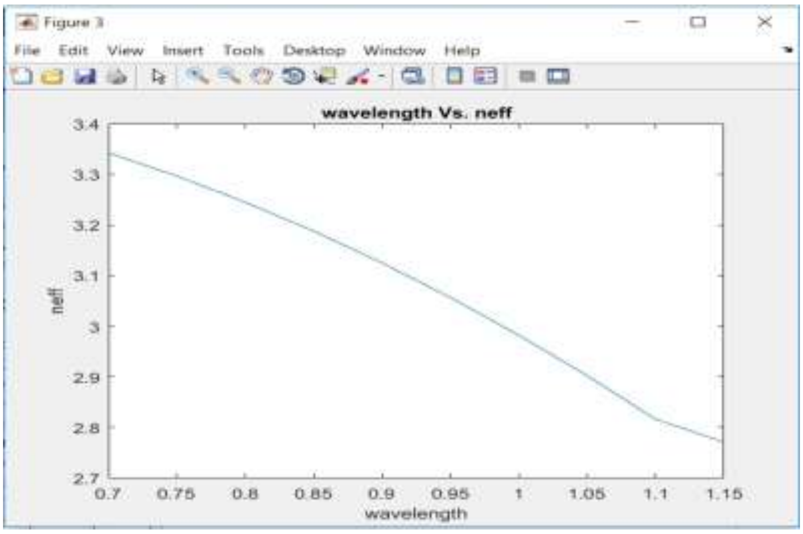
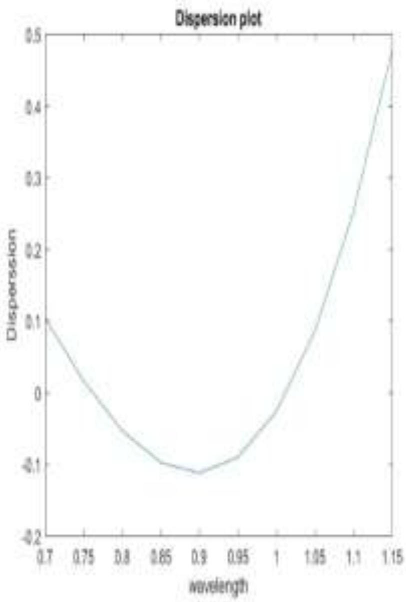
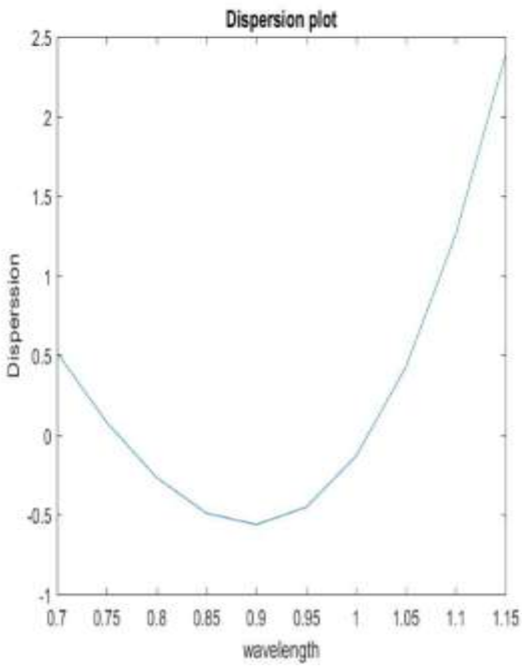


Figure 3. Wavelength& Effective Refractive Index





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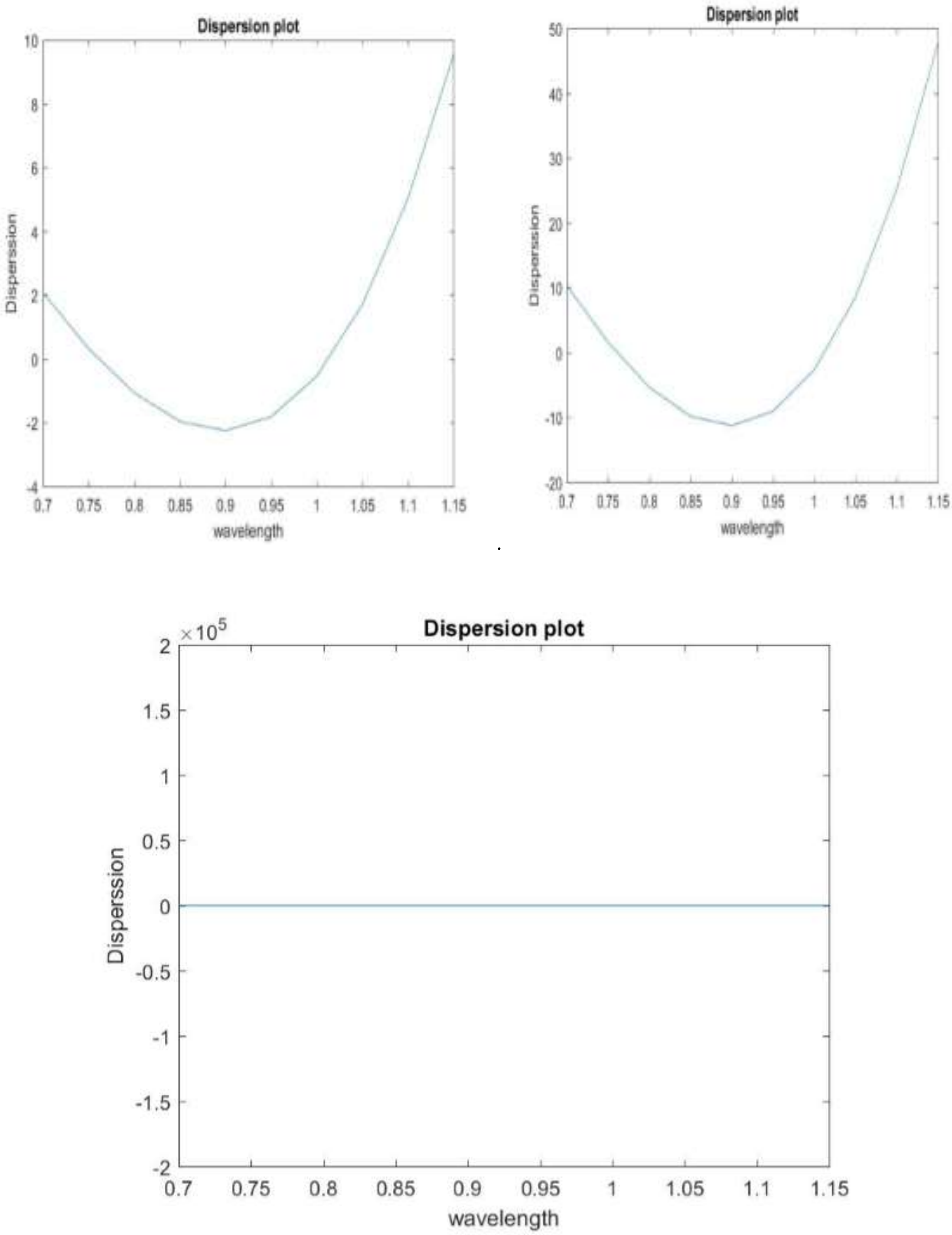

Figure 4 Dispersion graph for different kilometers

V. CONCLUSION

In this paper, a triangular lattice DC-PCF with polarization maintaining properties is proposed. The fiber demonstrates a very large negative dispersion. The fiber is immune to intermodal dispersion and requires a small length for dispersion compensation, which accumulates pretty small loss.fiber can be used as an in-line dispersion compensator in fiber-optic transmission links. Moreover, due to high birefringence, such a DC-PCF could be suitable for dispersion compensation with single-mode propagation, which is necessary for coherent communication and other polarization maintaining applications The designed fiber demonstrates that it is possible to obtain a very large negative dispersion of −9486.1 ps ∕ nm·km at 1550 nm wavelength with a negative dispersion more than −7000 ps∕nm·km over the entire C-band (1530–1565 nm), which is suitable for broadband dispersion compensation.

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