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# A Review on Dispersion in Various Photonic Crystal Fibre

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**Abstract**—This paper summarises dispersion characteristics of various geometrical configuration of Photonic crystal fibre. These geometrical configuration include square, circular, hexagonal, octagonal and decagonal Pcf. It discusses the effects of change in air hole diameter, hole to spacing and various other parameters on dispersion of fibre. It uses silica as its base material with refractive index 3.46. A comparative study is done so as to understand characteristic features of different geometry based photonic crystal fibres. Our aim is to understand the importance of these particular geometries based fibres for designing specific photonic crystal fibres that can be used for a particular function.

**Index Terms**—PCF based geometry, Total internal Reflection (TIR), chromatic dispersion.

## 1 Introduction

Optical fiber is one of the effective transmission media. It provides many advantages as compared to wireless transmission media in terms of reliability and versatility. The transmission of signals through this fibre is depend upon total internal reflection (TIR). As these fibres are not much flexible in designing as per our need so photonic crystal fibre came into existence. With these fibres we can design dispersion compensated fibres of desired wavelength by varying its geometrical properties. Photonic crystal is an optical periodic arrangement of air holes around a high index core in centre. It is also called microstructured fibre or holey fibre. Wings of butterfly and tail of peacock are two most common examples of photonic crystal found in nature. Photonic crystal fibres trap light waves in one or all direction hence can be used to manufacture various types of optical devices. It provides various important characteristics such as single mode operation over a wide range, high power handling, large mode area, high nonlinearity and controllable dispersion properties.

Photonic Crystal Fibre is a trending technology which attracts many researchers to work in the field of optical communication. It is quite popular due to its various important properties like high power handling capacity, high nonlinearity, single mode operation over wide range of operating wavelength, large mode area and controllable dispersion properties. It finds various applications such as soliton propagation and supercontinuum generation. Photonic crystal fibre is an optical fibre consisting of photonic crystal which obtains is waveguide properties from an arrangement of very tiny and closely spaced air holes.

## 2 Guiding Mechanism

Light can be guided in PCF in two ways. Based on these ways we can divide these fibres in two categories

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(i) Low index guiding fibres (ii) High index guiding fibres.

**High Index Guiding Fibre:**
In these fibres light is guided in a solid core by modified total internal reflection principle (M-TIR). It consists of high index core typically pure silica surrounded by lower refractive index cladding region. This cladding region consists of photonic crystal which has a large number of air holes which decreases its refractive index. This modified refractive index of cladding makes possible the phenomenon of modified total internal reflection. These fibres are also called solid core fibres.

**Low Index Guiding Fibre :**
These are also called photonic band gap fibres. These fibres are based on physical mechanism fundamentally different from M- TIR fibres. The periodic microstructure in PBG fibre results in photonic band gap. Certain wavelength of light can not propagate through this band gap. In these fibres core is created by introducing a defect region in photonic crystal region, hence an area is created where light can easily propagate. In this way we have created a low index guiding core to make propagation of light.

**Tailoring various PCF Designs:**
Photonic crystal fibre can be designed in various geometrical configuration such as square, rectangular, hexagonal, octagonal and decagonal. We will discuss these geometries of photonic crystal fibre in terms of various parameters such as effective area, confinement loss, propagation constant and waveguide dispersion. These parameters or properties of photonic crystal fibres have contributed to advanced developments in the field of optical communication, nonlinear optics and high power technology. Effective refractive index of these fibres is an important terms which controls various properties. The value of effective refractive index is complex and varies with wavelength of light. Effective area, propagation constant and waveguide dispersion depends on real pat of effective reflection coefficient. On the other hand, confinement loss depends on its imaginary value. Hence by changing the value of effective refractive index or by changing the diameter and pitch of

air holes in cladding we can design application oriented PCF. For different kinds of geometries based photonic crystal fibre, we observed some variation in these optical properties. To understand this in a better way we selected silica as background material.

**Square Geometry based PCF:**
When a centre atom is removed from the Photonic crystal material cross section whose atoms are arranged in square fashion then this type of detect creates square geometry based Photonic crystal. Remaining atoms are arranged in two layers. Inner layer consists of atoms in elliptical shape which have diameter d1=0.35um in x axis and 0.7 um in y axis. Outer layers consists of atoms in circular shape with diameter 1.4 um. Here hole to hole spacing, pitch Λ is kept 2 um. We observed that when pitch has small value of 1 um then fibre gives negative dispersion at wavelength around 1550 nm in C band. In this case we get minimum dispesion of -277ps/ km-nm. Other than this dispersion parameter is found to increase with their value of air hole diameter. Hence for a fibre having smallest air hole diameter d/ Λ = 0.5, value of dispersion parameter is -248 ps/km-nm at 1550 nm.

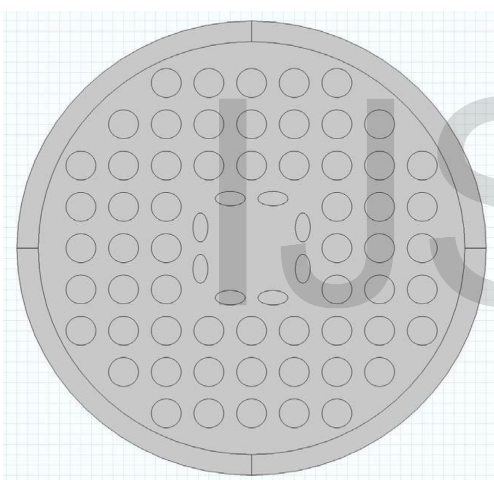

Fig 1: Analyzed square PCF model: (a) Transverse geometry

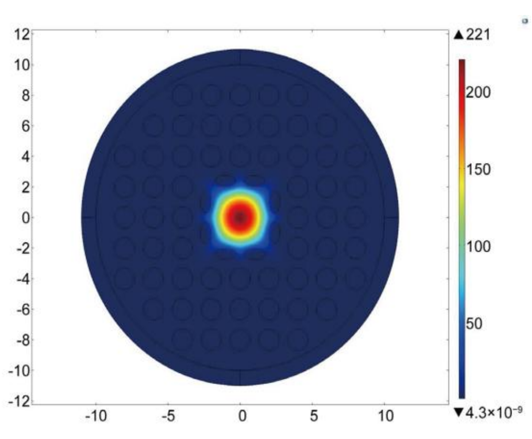


Fig 1: (b) Fundamental mode field of the square PCF geometry

**Higher Geometry based PCF:**

Higher geometry based pcf can be deigned in a different way. To achieve this we assumed an isosceles triangle with the vertex angle A. In this triangle length of identical legs is equal with the pitch length. The length of remaining side which is opposite of vertex angle is 2 p sin(A). Air holes are located at each vertex of basic triangle. In this way we have designed three geometries, hexagonal, octagonal and Decagonal. In hexagonal geometry, there are six air holes around central core. Vertex angle of basic triangle is 60°. Similarly in octagonal and decagonal geometries of pcf, there are eight and ten air holes around central position, with vertex angle of 45° and 36°respectively.

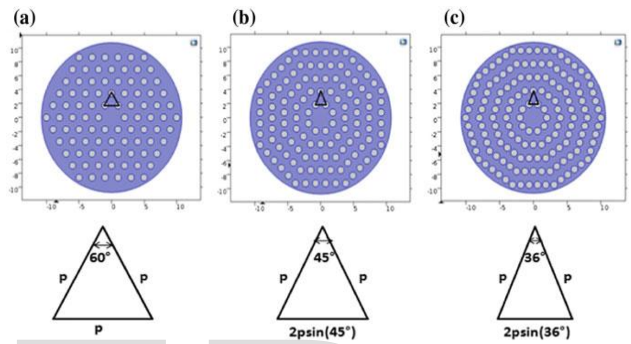


Fig. 2 Structural geometries of a Hexagonal b Octagonal c Decagonal PCF

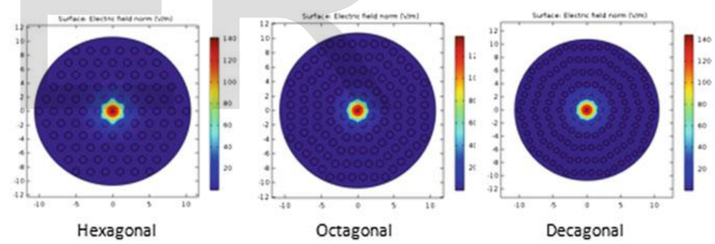


Fig. 3 Power confinement patterns of all three geometries hexagonal, octagonal and decagonal structure based PCF.

**Hexagonal Geometry based PCF:**
For hexagonal geometry based Photonic crystal fibre, values of dispersion monotonically decreases with the increase of air-hole diameter in wavelength from 0.6 um and 1.8 um. Dispersion slope keep almost constant with the increase of air hole diameter (d) at wavelength between 0.6 um and 1.2um. As the value of pitch decreases, dispersion curve is upshifted. Zero flattened dispersion of 0.1- 0.58 ps/km-nm is achieved in wavelength from 1.31um to 1.58 um.

If we keep the value of pitch length constant at Λ = 2 um, and increases the air filling fraction d/p ratio then dispersion increases. Hence minimum dispersion -13.32ps/km-nm can be achieved at d/p = 0.3. The value of zero dispersion wavelength decreases as we increases air filling fraction. The maximum wavelength of 1.28 um can be achieved at d/p = 0.3. Nonlinearity and V parameter are directly proportional with change in air filling fraction. Effective mode area decreases as we increases the value of air filling fraction d/p ratio. At d/p=

0.3 its value is 28.545 um2 which decreases to 6.518um2 at d/p = 0.5. Therefore it is clear that to get a dispersion compensating fibre we have to make a compromise with effective mode area.

**Octagonal Geometry based PCF:**

For octagonal geometry based fibres we get better expected results in comparison to hexagonal geometry based Photonic crystal fibre. We kept pitch length Λ = 2 um, and observe the effects of change in air filling fraction d/p on various parameters such as zero dispersion wavelength, chromatic dispersion , V parameter, non linearity and effective mode area. We observe that as we increases d/p ratio, chromatic dispersion increases and we get minimum dispersion -16.30 ps/km-nm at d/p = 0.3 at wavelength of 1.55um. Other than this the value of zero dispersion wavelength decreases with increase in d/p ratio. Maximum value of zero dispersion wavelength at d/p = 0.3 is 1.10um which is lower than that for hexagonal structure based Photonic crystal fibre. For this fibre minimum effective mode area achievable is 5.348 um2, it is lower than that for hexagonal Photonic crystal fibre. But as in this case also effective mode area is decreasing with increase of air filling fraction unlike dispersion values, hence we have to make a compromise between these two. V parameter and nonlinearty increases with increase in d/p ratio.

**Decagonal Geometry based PCF:**

It is highest order geometry which gives best results to manufacture optical devices. When we investigated the optical properties of this fibre we found that change in the value of air filing fraction is same in this case also. Particular values of each optical parameter are approaching to desired results. Its zero dispersion wavelength is little small from that of octagonal fibre. Its value at d/p = 0.3 is 1.04um. minimum value of chromatic dispersion achieved is -1.74 ps/km-nm, which is very much lower than that of octagonal and hexagonal structure based Photonic crystal fibre. V parameter and nonlinearity of decagonal fibre Photonic crystal fibre is directly proportional to d/p ratio. Hence more value of air filling fraction is required to get more nonlinearity. Effective mode area decreases with increase in d/p ratio. We are able to achieve minimum effective mode area of 4.911 um2, which is least value among all the geometries, at d/p = 0.5. Hence dispersion compensated fibre can be formed with decagonal geometry.

**Application:**

Photonic crystal fibres finds a wide application in optical domain due to its various important characteristics. Some of these applications are as under:

1. Optical devices such as optical detectors, optical filters, optical multiplexers, optical demultiplexers and optical sensors, routers etc.
2. Highly efficient photonic crystal laser
3. High efficiency light bulbs
4. Optical computers
5. Supercontinuum generation

## Conclusion

In this paper we have discussed various geometries of photonic crystal fibres. Different parameter variation has been studied and compared for each of the photonic crystal fibre geometry. A comparative study is done to analyse specific property associated with each pcf geometry. These geometries can be selected accordingly for the purpose of making a specific type of optical device or any other application. The structural parameter can be changed to get desired results with a particular geometry of Photonic crystal fibre. We found that as we move to decagonal geometry based Photonic crystal fibre from square based geometry the value of effective mode area decreases. Hence in order to create numerous designs of circuits in smaller area we can use high order geometry based Photonic crystal fibre. In this way depending on a particular application of Photonic crystal fibre we can select a particular geometry of Photonic crystal fibre such as square , hexagonal , octagonal and decagonal based geometry.

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