Preface

As the research on photonic crystals progressed, people started to find more and more number of applications based on them. There is a periodic variation in refractive index and distance both, between two constituent units in a photonic crystal. Due to this variation, a particular frequency or a range of frequencies can be allowed to pass through a photonic crystal or can be stopped by the photonic crystal. An important term related to photonic crystals is their band-gap, which means a range of frequencies that are completely blocked by the photonic crystal to pass through them.

There are a quite number of techniques accessible to examine the dispersion phenomena and transmission scope of PCs like beam propagation method (BPM), multi-pole method (MPM), finite element method (FEM), transfer matrix method (TMM), plane wave expansion (PWE) and finite difference time domain method (FDTD) etc. FEM and FDTD are much sought out methods amongst all as FEM is easier to implement whereas FDTD is more accurate. FDTD can be applied to programming of 2-D or 3-D PC structure codes with equal power. The TMM is suitable to solve 1-D PC structure as it reduces the complexity of a linearly layered arrangement. The PWE technique is utilized to determine the PBG and proliferation methods of the PC structure especially in two-dimensions.

A wide range of optical devices based on the involvement of 2-D PCs, have been practically manufactured and further research is going on to make them more advance. 2-D PC structures can have naturally or be given hexagonal, square, triangular etc. type of symmetry. A significant application of PCs is in the fabrication of a special type of optical fiber known as, photonic crystal fiber (PCF). PCFs have proved to be advantageous in many respects than the conventional optical fibers. PCF structure contains an array of air holes as part of its cladding which distinguishes it from the conventional optical fibers which have only a core and cladding or a combined core and cladding in case of multi-mode graded index fiber. There are two types of PCF based on light guidance inside the core, one works on effective index method and the other on photonic band-gap (PBG) effect. A lot of research has been done on the optimization of the structure of PCF for improved applications. High negative dispersion has been achieved in PCF by modifying the structural parameters. Mainly we can control two parameters of PCF which are air-hole size in the cladding region and the distance between those air holes called pitch.

Light can also be trapped into a PC structure by formation of a resonant cavity. Optical filters, wavelength multiplexers and de-multiplexers, power couplers etc. optical devices can be built based on 2-D PCs. Photonic crystal ring resonator (PCRR) is an important application of 2-D PCs, in which a central ring cavity is formed by removing specific quantity of semiconductor rods from central region. PCRR is derived from the class of optical ring resonators in which there are two channel waveguides and a central ring cavity. PCRR can be formed by removing a specific number of dielectric rods in particular shapes from a 2-D PC structure. Optical devices such as Y-splitter, bio-chemical sensor, add-drop filter, frequency tuner etc. can be built based on PCRR. A photonic device based on the PCRR structure can specially be utilized in the medicine industry for testing of different types of chemicals.

The objective of the present research is to study different types of photonic crystal fibers established on different geometries and materials, a highly sensitive bio-chemical sensor based on photonic crystals is also proposed. Various parameters of PCF have been investigated viz. effective index, chromatic dispersion, effective area and normalized frequency.

In the present research**,** numerical study of the dispersion characteristics of a hexagonal PCF by varying the refractive index of core has been demonstrated. The effective refractive index (n_{eff}) parameters of PCF are calculated with the help of a frequency domain algorithm based on finite difference technique. The dispersion values are the then evaluated using effective index parameters and plotted against wavelength. The new aspect of hexagonal lattice PCF which has been studied in this work is the effect on dispersion values by changing the core's refractive index (n_{core}) or that of PCF otherwise. The wavelength band which is considered for finding out the values of effective index and thus dispersion parameters is taken to be S+C+L band which is used in telecommunication. There is observed dispersion flattening between 1.50-1.60 µm wavelength for $d/\Lambda = 0.78$ within a range of 2.5 ps/nm-km at each refractive index of core. This kind of PCF can be used in the applications such as dispersion flattening, dispersion compensation and band-pass or band-reject filters in optical communication systems. It has the potential to be used in multimode regime of wave propagation apart from single mode, thus making it to transfer more data at the same time.

In the present research the effect of dispersive materials on the dispersion and normalized frequency characteristics of a square photonic crystal fiber have been studied. Metals have been applied in the cladding air holes of PCF and dispersion, normalized frequency parameters are computed. The dielectric function (permittivity) of those metals follow Drude-Lorentz dispersive model and their refractive index varies with the incident field. Gold, silver, copper, aluminium, chromium and nickel are filled into the cladding holes of PCF one by one. It is seen that the dispersion graph of PCF with only air in the cladding holes is confined in the range -5.9 to +10.6 ps/nm-km on the vertical dispersion parameter scale. In the same graph dispersion flattening is observed between 0.7-0.9 um wavelength with a deviation of only 1.0 ps/nm-km. The dispersion graphs of the metals applied in the PCF viz. gold, copper, aluminium and chromium show a large amount of negative dispersion for the wavelength taken into consideration. Positive dispersion generated in a conventional optical fiber in the range of thousands of ps/nm-km could be compensated with the help of metal based PCF's.

Talking about the normalized frequency, the PCF with only air in the cladding holes show a decrease in the values of V_{eff} with increase in the wavelength. The number of modes that can enter and travel along the length of a photonic crystal fiber for a particular wavelength range can be adjusted according to the metal chosen for filling the cladding holes of the fiber.

In the present research work**,** a square hole in square lattice photonic crystal fiber has been studied. A PCF with 5 rings of air-holes containing one central solid core of pure glass (flint) having higher refractive index is proposed. The calculation of effective index parameters of PCF and thus chromatic dispersion is done by using a fully vectorial finite element method. Simulation results show that negative dispersion has been achieved for wavelengths in the range of 1.3 to 1.8 μm and beyond for this structure. A flattened dispersion with maximum variation of 5 ps/nm-km is obtained for C and L band combined together i.e. from 1530-1610 nm for d/Λ ratio=0.47. The distinctively significant feature of this structure is it's high dispersion tolerance capability at the communication wavelength of 1.55 μm.

In the present research, effect of temperature on the dispersion properties of a photonic crystal fiber is studied. Indium antimonide (InSb) has been filled into the cladding holes of PCF whose dielectric constant is a function of temperature. In the areas where temperature is not constant and it varies from one point to another, this type of PCF can be applied to compensate multiple values of dispersion. It can be employed with different optical communication links according to the value of dispersion compensation required. Also, this type of PCF when utilized in harsh environments can provide flattened dispersion at the abnormal surrounding temperature without the use of any special equipment. In addition to dispersion, effect of temperature on the normalized frequency characteristics is also studied. It is observed that the mode carrying capacity of the PCF remains the same irrespective of the surrounding temperature. This application is particularly useful when the number of modes or quantity of information needs to be preserved but dispersion of the PCF is to be varied with temperature.

Finally**,** a bio-chemical sensor based on photonic crystal ring resonator has been proposed. The sensing characteristics of two types of ring resonator structures based on square and circular ring are studied and compared. The refractive index of coupling rods, inner ring rods and coupling as well as inner ring rods combined together are varied according to the sample which is to be sensed. Normalized transmission peaks at resonance condition are plotted against wavelength using finite difference time-domain (FDTD) technique. Plane wave expansion (PWE) method has been used to calculate the photonic bandgap of the proposed structures. It is found that both types of ring resonators have shown high sensitivity when the refractive index of sample is varied from 3.1 to 3.7 in steps of 0.2.

It is deduced that both the square and circular ring photonic crystal resonators can act as real time bio-chemical sensors when the sample to be sensed are applied only on the inner ring for achieving high sensitivity. Nano photonic device based on our ring resonator structure can act as a potential candidate to serve in industrial or research sector which are working in the field of medicines, food testing, defence etc.

Keywords: *Photonic crystal fiber, Effective index, Dispersion, Normalized frequency, Finite-difference, Ring resonator*