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Hybrid square-lattice photnic crystal fiber with single mode operation and normal dispersion

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A fiber with high birefringence, normal dispersion and single mode operation synchronously adds a terrace in optical communication. In this study we put forward a new photonic crystal fiber (PCF) which concurrently offers normal dispersion and single mode operation. This hybrid square lattice PCF (HS-PCF) design has two circular air holes of different alternating diameters in the cladding and a pure silica defective core in the center. The finite-element method [FEM] has perfectly matched boundary conditions which analyze the optical properties of the numerically guided modes. The optimized HS-PCF is observed to have a minimum dispersion at wavelength of 1.62µm. The proposed fiber design has square air holes of two different dimensions in the cladding region for which effective refractive index and minimum dispersion is obtained.

Keywords: Photonic crystal fiber; Hybrid lattice; dispersion; Square

I. Introduction

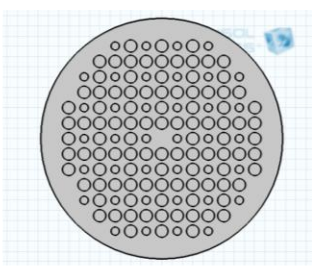
The basic construction of fiber optic is based on the constant refractive index differences of core and cladding. Light travels through the core as a result of the refraction property of light, which is caused by the difference between refractive indexes of the core and cladding. During extended distance communication this refracted light bears much higher loss during propagation. This results in the need for amplifiers and repeaters for extended distance communication. This loss is resolved in PCF. PCF is the new domain of optical fiber based on the properties of the photonic crystal. PCF is also known as micro-structured or holey fiber. In PCF, light is trapped in the core, providing a much better waveguide to photons than standard fiber optics. PCF is a kind of optical fiber that uses photonic crystals to form the cladding around the core of the cable. The photonic crystal is a low-loss periodic dielectric medium constructed using a periodic array of microscopic air holes that run along the entire fiber length [2]. Using photonic crystals we can create- a novel LEDs that emit light in a very narrow wavelength range, a highly selective optical filter, a mirror that reflects a selected wavelength of light from any angle with high efficiency. In PCF the polymer used instead of glass is more flexible fiber which allows for easier and less expensive installation [3]. PCF has etched its applications in fiber-optic communications, nonlinear devices, high-power transmission, highly sensitive gas sensors, and other areas.

The geometry of PCF is characterized by the micro-structured air-hole cladding running along the entire length of the fiber which surrounds the core that can be solid or hollow [9]. The solid core PCF [SC-PCF] has a solid core surrounded by a periodic array of microscopic air holes, running along its entire length. Hollow-core PCF [HC-PCF] has an air hole as a core, surrounded by a micro-structured air-hole cladding. The designed fiber succeeds to provide minimum dispersion for the observed wavelength bands. The effective index of the fiber is observed to decrease linearly with increasing wavelengths.

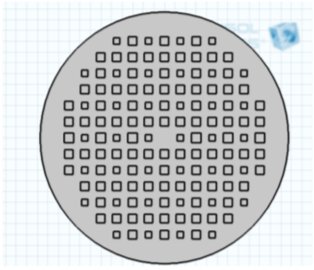
II. Fibre Design

The hybrid square lattice fibre with square air holes has been designed based on the HS-PCF with circular air holes in the cladding region [1]. The square air hole fibre is designed using air holes of different dimensions and arranging them in square lattice structure. The cross sectional view of the fibres can be observed in Figs. 1(a) and 1(b). The dimensions of air holes and the centre to centre distance between the air holes i.e. the pitch of the PCF play a significant role in how the transmitted light propagates and behaves within a fiber. We have introduced a defective core by placing two air holes of smaller dimension in the core region of the fiber. The main objective is to obtain minimum dispersion at the receiver end of the optical fiber to prevent information loss for a given band of frequency. This can be achieved by minimizing the dispersion or broadening of pulse, which occurs in long distance transmission of signal through negative dispersion values. Control of chromatic dispersion in PCFs is very important problem for realistic applications of optical fiber communications, dispersion compensation, and so on [6].

The dispersion value is dependent on the effective refractive index, which in turn depends on the design of the fiber. PCFs are usually made from pure silica, and so the guided modes are inherently leaky because the core index is the same as the index of the outer cladding region without air holes [5].The materials used to make the fiber also affect the effective refractive index at any given wavelength. In this study we have designed the fiber using silica glass and air to fill the square holes of cladding region.



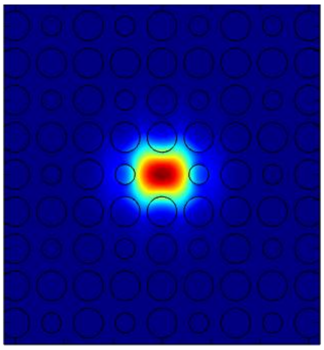
1(a)



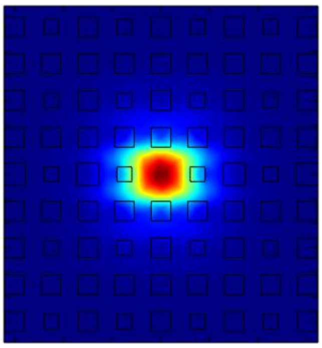
1(b)

FIG.1. Cross sections of the fibres (a) Hybrid lattice fiber with circular air holes. (b) The proposed hybrid lattice fiber with square air holes

We have used air holes of dimensions w1=0.45um and w2=0.3um and a pitch value of 0.752um. The dimensions considered for the square lattice fiber with circular air holes are d1=0.60um and d2=0.30um and the same pitch value of 0.752um



2(a)



2(b)

FIG.2.Single mode dispersion for (a) Hybrid fiber with circular air holes (b) The proposed hybrid lattice fiber with square air holes

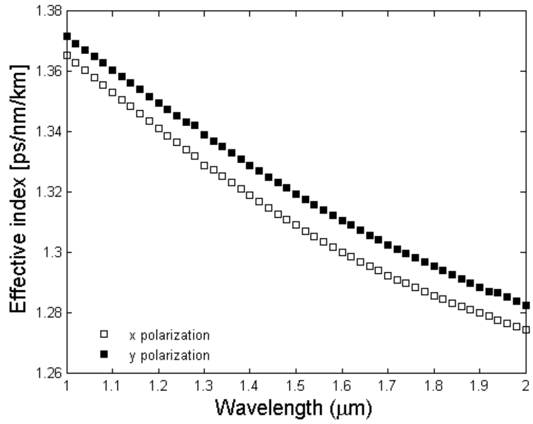
III. Study of Effective Refractive Index and Dispersion in the Hybrid Fibers

The designed fiber is simulated using COMSOL and the effective refractive index values for wavelengths 1.00-2.00µms have been recorded and observed. The effective refractive index value is then used to calculate dispersion by using Sellmeier's formula for material dispersion which in turn gives the total dispersion of PCF. The formula that gives the relation between wavelength, dispersion and effective refractive index is

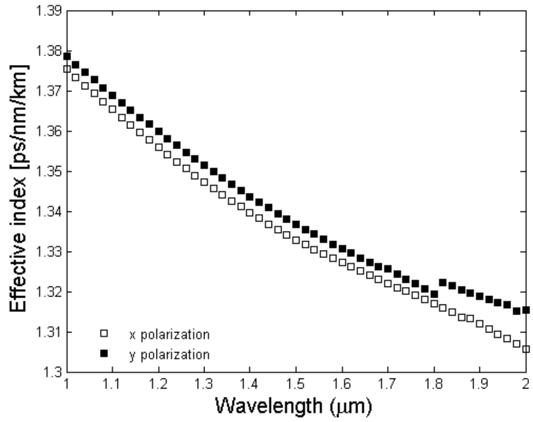
$$D = -\frac{\lambda}{c}\frac{d^2 Re[n_{eff}]}{d\lambda^2} \qquad (1)$$

Where, Re [n_{eff}] is the real part of effective refractive index, λ is the wavelength, c is the velocity of light in vacuum[1].

The effective modes both the fast mode and slow mode i.e. X-Polarization value and Y-Polarization values have been calculated and plotted. Figs. 2(a) and 2(b) represent the effective index values of both the fibers with circular air holes and square air holes respectively.



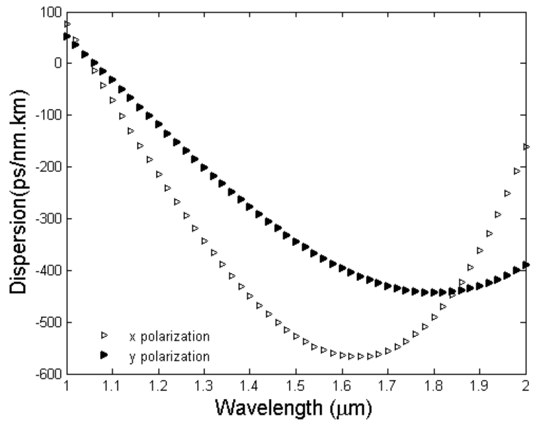
3(a)



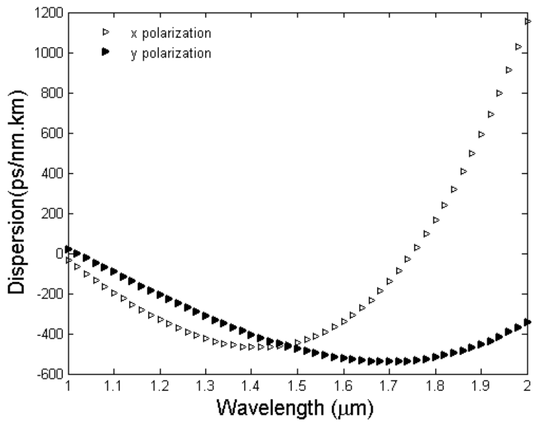
3(b)

FIG.3. Effective refractive index of (a) HS-PCF with circular air holes (b) HS-PCF with square air holes for wavelengths of range 1.00-2.00um

It can also be observed that the polarization crosstalk is minimum for the proposed structure i.e. the hybrid structure with square air holes and it is also minimum for the hybrid structure with circular air holes. the effective refractive index decreases linearly with increasing wavelength.



4(a)



4(b)

FIG.4. Modal dispersion in the (a) HS-PCF with circular air holes (b) HS-PCF with square air holes for wavelengths of range 1.00-2.00um

From the graphs, it can be observed that as the wavelength increases the effective refractive index decreases almost linearly in the case of the hybrid structured fiber with circular air holes. The effective refractive index also decreases with the increasing wavelength in the hybrid structured fiber with square holes but starts increasing after certain values. This effects the dispersion of light in the fiber which can be observed from the fig 2(d). The minimum dispersion does not occur around 1.6um but around 1.7um due to the nonlinearity in the effective refractive index.

IV. CONCLUSION

In this paper we have designed fibers having square shaped air holes and circular air holes. These fibers have equal number of rings in the cladding region and have the same pitch value. They show minimum dispersions at different wavelengths caused by the difference in their dimensions. However, at higher wavelengths we can see that the design having the square air holes doesn't maintain uniformity in the effective index values, effecting the dispersion of light. We can also propose in future a design having same pitch and equivalent dimensions for both circular and square air holes. The same design can be modified using different materials to fill the air holes and study the dispersion properties of light. The fiber can also be designed using triangular lattice structure to obtain single mode dispersion in PCF.

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