Tri-layer Photonic Crystal Fibers with Low Dispersion

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***Abstract*— Photonic Crystal Fibers (PCFs) with circular holes of three different materials has been investigated. The three materials considered are ethanol, soft glass and nematic liquid. The proposed structure has reported very low dispersion. Moreover a very low confinement loss was also observed. The birefringence reported is also noticeable. FDTD method has been employed to investigate the proposed structure. The V-parameter and far field pattern were also observed.**

Keywords—Transparent boundary condition, dispersion, confinement loss, birefringence, V-number .

I. INTRODUCTION

It is clear that optical fibers and integrated optical waveguides today are finding extensive use, covering areas such as telecommunications, sensor technology, spectroscopy and medicine. The resemblance of PCFs with conventional optical fibers, however found to display important differences and are now emerging area of research. Photonic crystals become of more value by intentional introduction of spatial defects within them. The photonic crystals may act as reflecting boundaries and trap light at the defect region. The defects may be point, line or surface defects, which allow for the creation of micro cavities, waveguides, novel types of compact, functional components or various types of substrates[1-3]. The properties of PCFs like dispersion, makes it attractive for many nonlinear application. By modifying the structure of PCFs, it is possible to monitor the magnitude, as well as sign of the dispersion to make it an eligible candidate for applications. PCFs exhibit anomalous dispersion, which makes generation of solitons in the visible spectrum and near infrared possible[4-5]. In case of high speed, long distance optical communication systems, an increased attention is now being paid to polarization effects. For such fast systems even very low degrees of birefringence $(<10^{-7})$ occurring in conventional fibers may cause a crucial dispersion differences between the two polarization states, thereby setting up limits for transmission speed[6]. Besides V-parameter, confinement loss and other unique properties also draw attention of the researchers.

Various design of PCFs have been proposed[7]. Variation includes the increase in number of rings, increasing radius of holes and varying the shape of holes of PCFs[8-9]. Moreover the structures by varying the refrective index of the material has been also proposed[10]. A PCF structure whose geometrical dimensions have been derived from the polynomials of Dolph Chebyscheff has been reported[11]. In this paper a PCF structure with circular holes of three different materials have been investigated. The three material includes ethanol, soft glass and nematic liquid. The wafer has been made of lead silicate, thus an PCF showing the light

propagation under the effect of four materials with different refrective index has been investigated. The proposed trilayer PCF structure has been analyzed with full vector mode solver. The method used for analysis is FDTD method. OptiFDTD simulator has been employed to carry out simulations. The proposed trilayer PCF structure has reported very low positive dispersion. It is also noticed that a very low confinement loss was observed. Besides the structure has reported a high birefringence. Hence the structure is good for high data rate transfer.

II. PROPOSED STRUCTURE

A new index guided photonic crystal fiber structure with circular holes made of three different materials have been investigated. The proposed PCF structure consists of seven rings. The variation in the materials of the circular holes of seven rings is made by varying refrective index of different materials, hence we call it a trilayer PCF structure. The three different materials are ethanol, soft glass and nematic liquid. The wafer chosen is made of lead silicate. The three innermost rings consists of circular holes which are made of ethanol and the outermost two layer have circular holes filled with nematic liquid. The two sandwiched rings in between the rings made of ethanol and nematic liquid have circular holes of soft glass. The proposed structure consists of all circular holes of equal area.The intention of choosing such an PCF structure is to study the behavior of light in a medium with such variation in their refrective index. It would be interesting to study the group velocity dispersion, birefringent property, confinement loss, and other unique properties of the trilayer PCF structure. The dispersion properties of conventional fibers are receiving a continuously high research interest in connection with high capacity optical communication, soliton propagation and control of nonlinear effects. Hence the dispersion in PCFs is of high interest to investigate. The dispersion for the proposed trilayer PCF structures is calculated using the formula (equation 1)[12]:

$$D = -\frac{\lambda}{c}\frac{d^2 n_{eff}}{d\lambda^2}$$

(1)

where D is the waveguide dispersion measured in ps/(nm-km), n_{eff} is the effective refrective index number and λ is the operating wavelength ans measured in μm.. The c is considered as the velocity of light in free space. The second order derivative of modal index number is computed using the three point difference formula for approximating the derivative. The normalized frequency also known as V-parameter has been calculated. The normalized frequency can be obtained using[13]:

$$V = \frac{2\pi a}{\lambda}(\sqrt{n^2_{co} - n^2_{eff}})$$
(2)

Where the sumbols have there usual meaning.As well known from conventional fibers, deviations from the ideal structure cause the two polarization states to experience different $\frac{\beta}{k}$ values, while propagating along the fiber. This can be defined as birefringence, which results in different waveguiding properties for the two polarization states. The birefringence of the proposed trilayer PCF can be obtained by [14]:

$$B = \left|(n^x_{eff}) - (n^y_{eff})\right| \quad (3)$$

Where n^x_{eff} and n^y_{eff} are the effective refrective index of the horizontal and vertical polarized modes respectively.

The confinement loss can be seen as intrinsic to fiber structures, which solely consists of pure silica with air holes. However changes in the structure can make these losses arbitrarily small. The proposed trilayer PCF structure has reported low loss, which is calculated by using the formula [15]:

$$L_c = 8.686\,\mathrm{Im}[n_{eff}]k_0$$
(4)

where k_0 is the free space number and is equal to $\frac{2\pi}{\lambda}$, λ is the operating wavelength, $\mathrm{Im}[n_{eff}]$ is the imaginary part of effective modal index number.

The normalised wavelength which can be defined as the ratio of the wavelength to that of the pitch factor $(\wedge)$. The pitch factor that can be defined as spacing between the centre of two nearest holes.

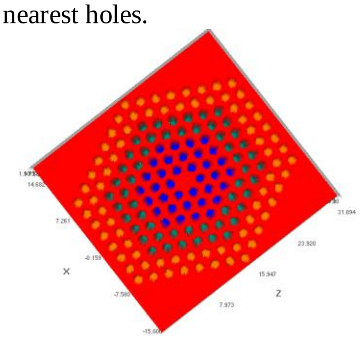

Fig. 1. The trilayer PCF structure.

III. Simulation Results

The simulation results of the proposed trilayer PCF structures carried out in the OptiFDTD software has been presented. The proposed PCF structure consists of three layers of materials with different refrective index. The pitch factor $(\wedge)$ for the structure proposed is taken as $\wedge = 1.0\mu m.$ The wafer taken is of lead sillicate and has refractive index, $n = 1.802$. The innermost three layer circular holes of the proposed PCF structure is made of ethanol with $n = 1.36$. The outermost two layer of the proposed PCF structure consists of circular hole filled with nematic liquid material having refrective index $n = 1.76$. The sandwiched layer of the proposed structure consists of circular hole made of soft glass with refrective index $n = 1.502$. Transparent Boundary Condition (TBC) has been considered as the boundary condition for simulation. The mesh size considered for the finite difference time domain (FDTD) simulations is taken as $\Delta x = \Delta z = 0.106\mu m.$ The wafer length and width chosen for the structures proposed is $32\mu m$ and $30\mu m$ respectively. The radius chosen of the circular holes for the proposed trilayer PCF structure is $r = 0.6\mu m.$ We calculate the dispersion for the proposed trilayer PCF structure at operating wavelengths by using (1). The corresponding result have been plotted in Fig. 2.

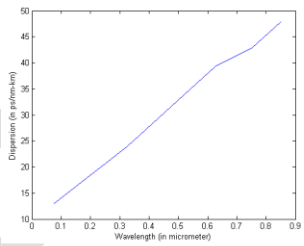

Fig. 2 The curve showing relation between dispersion at corresponding wavelength of the proposed trilayer PCF structure.

The proposed trilayer PCF structure has shown an increase in an uniform manner. The value of dispersion increases with the increase in wavelength. The dispersion reported at the operating wavelength of $0.85\mu m$ was $47\,ps/nm-km$. This value of dispersion was found to be maximum for the proposed tri-layer PCF structure.

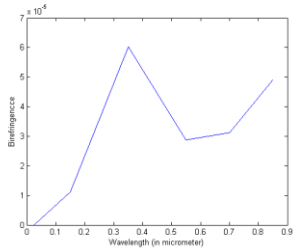

Fig. 3 The curve showing relation between birefringence and wavelength of trilayer PCF structure.

The birefringence for the proposed trilayer PCF structure can be obtained using (3). The birefringence observed is of the order of 10^{-5}. The birefringence reported at an operating wavelength of $0.4\mu m$ was found to be maximum.

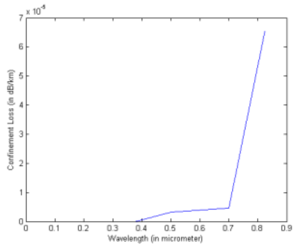

Fig. 4 The curve showing the relation between confinement loss and wavelength of proposed trilayer PCF structure.

The confinement loss of the trilayer PCF structure proposed has been calculated using (4). The corresponding results were shown in Fig. 4. The proposed trilayer PCF structure reported very low confinement loss, which is of the order of 10^{-5}. The confinement loss was almost zero up to a wavelength of $0.7\mu m$.

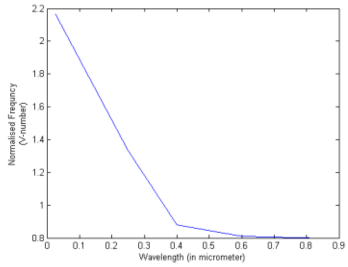

Fig. 5 The curve showing relation between normalised freuency and wavelength of the trilayer PCF structure.

The modal index number versus normalised wavelength curve were obtained for the trilayer PCF structure proposed in this paper using (2). It is to noted that this kind of analysis is made under the assumption that the refrective index of he base material is constant as a function of wavelength. The value of modal index number decreases with increasing value of normalised wavelength.

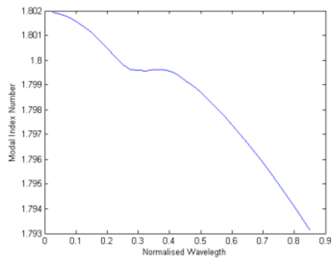

Fig. 6 The curve showing relation between modal index number at its normalized wavelength of the trilayer PCF structure.

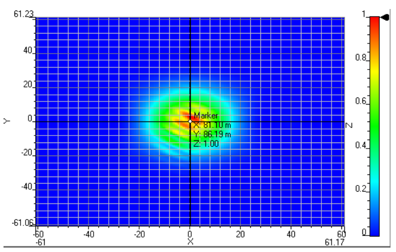

Fig. 7 The Far field Pattern radiation of proposed trilayer PCF structure.

IV. Conclusion

Thus we have investigated an PCF structure with circular holes of different materials. The proposed structure consists of circular holes of three inner rings of ethanol and next two ring has circular holes of soft glass. The outermost two rings consists of circular holes filled with nematic liquid. The structure reported very low dispersion and very low confinement loss. The dispersion reported at the wavelength of $0.85\mu m$ was maximum and is $47\, ps/nm-km$. The proposed trilayer PCF structure reported a low confinement loss, which is in the order of 10^{-5}. Hence the structure can be considered as a good candidate for high rate data transfer and for various optical communications purposes too.

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