Realization Of Beam Splitter Using Photonic Crystal Fiber(PCF) With And Without Nonlinearity

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ABSTRACT

This paper presents the field distributions of a linear and nonlinear hexagonal structure photonic crystal fiber(PCF), formed by a number of air holes on different background material considered for beam splitter application using FDTD simulation. Simulation results show that PCF having background material like linear and nonlinear SF57,BK7,Silica and Ge, are suitable for beam splitter application. It is seen that beam splitting ratio changes from material to material. It is also found that some PCF structure having linear and nonlinear splits the signal into different direction.

Keywords: Field distribution, Finite difference time domain (FDTD), photonic crystal fiber(PCF), Kerr nonlinearity,

I. INTRODUCTION

Photonic crystal fibers (PCF) have attracted a lot of attention in optics research in recent year[1]. PCF is a silica optical fiber with ordered array of microscopic air holes running along its path. Unlike the conventional fiber, the guidance properties of the photonic crystal fiber are determined by the size, pattern of air holes rather than by the properties of optical glass[2]. Light is guided through small solid core PCFs, where high intensities can be maintained for interaction lengths of several meters resulting in large nonlinear effect. It has been shown that PCF possess a variety of unique properties that are unachievable by conventional optical fibers, such as endlessly single mode propagation, highly configurable dispersion, tailorable modal area, high birefringence, optical components, wavelength division multiplier and also material processing[3,4]. Apart from these PCFs have remarkable control to use in optical communication because PCFs has made it possible to overcome the attenuation and reliance on total internal reflection of the single mode fiber (SMF). Beside these highly nonlinear (HNL) fibers are an important family member that applies very small core dimension to provide tight mode confinement to obtain enhanced the nonlinearity by tailoring and engineering the unusual dispersion properties such as solution generation, super continuum and ultra short pulse compression[5,6]. It is also seen that traps lights in a hollow core by means of 2D photonic crystal of microscope air capillaries running along the entire length of the fiber. Appropriately designed such that array would support a photonic band gap(PBG) for incident from air, prevent the escape of light from the core into the photonic crystal cladding and avoiding the need for total internal reflection(TIR)[7,8]. Beside these lattice constant 'a' and atomic radius 'r', the field distribution of PCF depends on the parameter like length of fiber, height of triangle cell and background material.

In this paper, we have investigated the field distribution of different types of hexagonal PCFs, Apart from this; we also discussed the beam splitter application of PCFs by comparing linear and nonlinear simulation of different PCF structure. Several modeling techniques have been employed to study the characteristics of PCFs, including the plane wave expansion(PWE), Fourier transformation(FT), finite difference time domain (FDTD), transform matrix method, finite element method and effective index method are being used to find out the structure and field distribution of PCFs, but we have chosen FDTD method due to high efficiency and more accuracy result.

II. NUMERICAL ANALYSIS

To study the field distribution of hexagonal photonic crystal fiber, we have used 2-dimensional finite difference time domain (FDTD) method[9]. Considering the material is isotropic, linear, and lossless, the time dependent Maxwell's equations can be written as

$$\frac{\partial H}{\partial t} = \frac{1}{\mu(r)} \nabla \times E \quad \text{---------------------------------(1)}$$

$$\frac{\partial E}{\partial t} = \frac{1}{\varepsilon(r)} \nabla \times H - \frac{\sigma(r)}{\varepsilon(r)} E \quad \text{------------------------------ (2)}$$

E, H are electric field and magnetic field.

Where $\varepsilon(r)$, $\mu(r)$, $\sigma(r)$ are permittivity, permeability and conductivity of the material and all are in the function of position.

Equations (1) and (2) can be discretized using Lee's technique. Considering spatial and time discretization, equations (1) and (2) can be written for TE polarization as follows

$$H_{x(i,j)}^{n+1/2} = H_{x(i,j)}^{n-1/2} - \frac{c\Delta t}{\mu \Delta y}\left(E_{z\left(i,j+\frac{1}{2}\right)}^{n} - E_{z\left(i,-\frac{1}{2}\right)}^{n}\right) \quad \text{---------- (3)}$$

$$H_{y(i,j)}^{n+1/2} = H_{y(i,j)}^{n-1/2} + \frac{c\Delta t}{\mu \Delta x}\left(E_{z\left(i+\frac{1}{2},j\right)}^{n} - E_{z\left(i-\frac{1}{2},j\right)}^{n}\right) \quad \text{--------- (4)}$$

$$E_{z(i,j)}^{n+1} = E_{z(i,j)}^{n} + \frac{c\Delta t}{\varepsilon\Delta x}\left(H_{y\left(i+\frac{1}{2},j\right)}^{n+\frac{1}{2}} - H_{y\left(i-\frac{1}{2}\right)}^{n+\frac{1}{2}}\right) - \frac{c\Delta t}{\varepsilon\Delta y}\left(H_{x\left(i,j+\frac{1}{2}\right)}^{n+\frac{1}{2}} - H_{x\left(i,j-\frac{1}{2}\right)}^{n+\frac{1}{2}}\right) \quad ....(5)$$

For stability, the time step

$\Delta t \le \frac{1}{c\sqrt{\Delta x^{-2}+\Delta y^{-2}}}$, where Δt is the time increment, c is the velocity of light, Δx be the lattice increment in x direction, Δy be the lattice increment along y direction.

Considering equation (3),(4) and (5) , we have calculated the field distribution of PCFs in TE polarization mode.

For a nonlinear optical waveguide having Kerr—type non-linearity related permittivity ε_r depends on electric field E_y and can be expressed as

$$\varepsilon_r = \varepsilon_{r.L} + \alpha|E_y|^2 \quad ---------------------------------(6)$$

Where $\varepsilon_{r.L}$ is the linear relative permittivity and α is the non linear co-efficient. A hybrid implicit FDTD method[10], is used to simulate the field for 2D PCS with nonlinear rods. The overall stability of this hybrid FDTD scheme is determined by the stability in the linear medium regions. Consequently, nonlinearity in the structure does not effect stability and hence the grid size and time step.

III. HEXAGONAL DESIGN

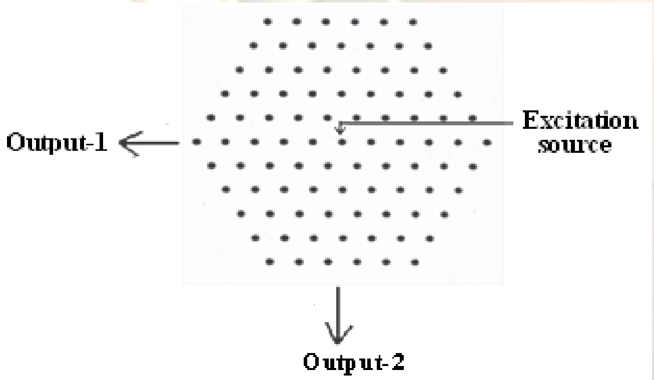

Figure 1. Hexagonal structure of PCFs

The structure of photonic crystal fibers plays a vital role, because different structure gives different type of application. Here we have chosen hexagonal PCF. This hexagonal structure can be realized by drilling air holes on the background material which is shown in fig.1 to calculate the field distribution of photonic crystal fibers, we have chosen proper input parameters of the structure such as refractive index of air holes and background material, lattice constant of the structure and lattice parameters of the hexagonal structure, we have chosen for different types of linear and nonlinear material such as SF57,BK7,Silica and Ge. The input parameters are different from different hexagonal structure.

III. SIMULATION RESULT

To verify our FDTD method for the possible application of the proposed 2D photonic crystal structure as a beam splitter which is mentioned in the previous section? The excitation is initiated at the centre of the structure and the output is obtained at two adjacent faces. The schematic diagram of this principle is shown in fig.1.

For the simulation of field at two adjacent faces, we use linear and nonlinear SF57 as a background material (refractive index of 1.802) and lattice constant 4.4µm at wavelength of 1550nm. The simulation result shown in fig.2 represents that the signal in any one of the adjacent faces is divided into different direction for both linear and nonlinear material introduced in to the air holes.

Another configuration (lattice constant of 3.8µm) as a background material BK7 (refractive index of 1.5), however the FDTD simulation shows the signal splits into different direction for linear case and behaves as beam splitter (2:1) for nonlinear case is shown in fig.3. It is interesting to note that if the hexagonal photonic crystal structure is modified by changing lattice constant to 2.3µm and background material as silica (refractive index of 1.42) here the result shows the signal is divided almost into two equal parts behaving as beam splitter (1:1) for linear and 3:1 for nonlinear. (simulation result are not shown).

Taking another configuration (lattice constant of 0.78µm) as background material Ge (refractive index of 1.47), the FDTD simulation shows a completely different trend, here the signal is almost divided into two equal parts behaving as beam splitter (1:1) for linear and behaves as 1x2 beam splitter for nonlinear case.(simulation result are not shown here) However when the lattice constant is less than 0.78µm, then its simulation result is same as Ge background material for both linear and nonlinear case.

So the above finding leads us to believe that one can optimize a 2D PCS for realizing different optical components. Though we have shown the action of beam splitter in this paper but other actions can be also realized by suitably optimizing the structure.

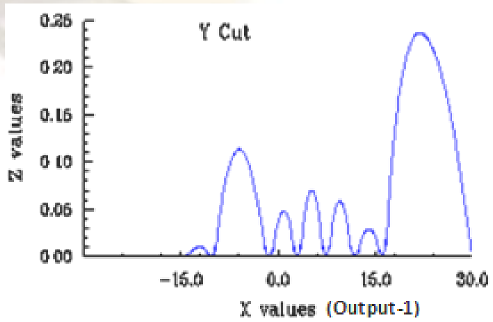

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Fig.2(a) multi beam splitter of hexagonal structure of linear SF57 (X-Z plane)

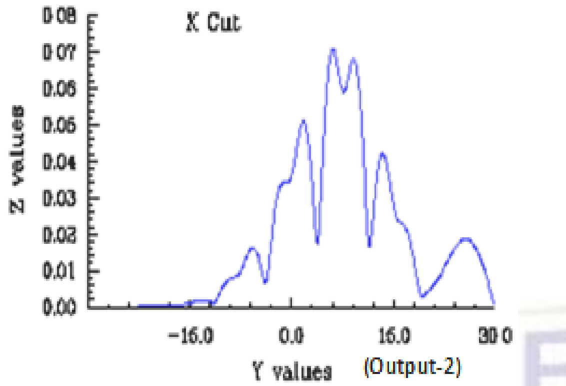

Fig.2 (b) multi direction beam splitter of hexagonal structure of linear SF57(Y-Z plane)

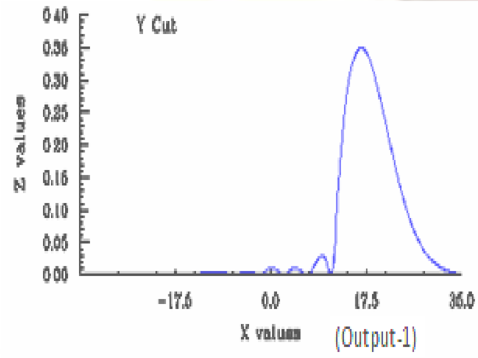

Fig.2(c) multi beam splitter of hexagonal structure of non linear SF57 (X-Z plane)

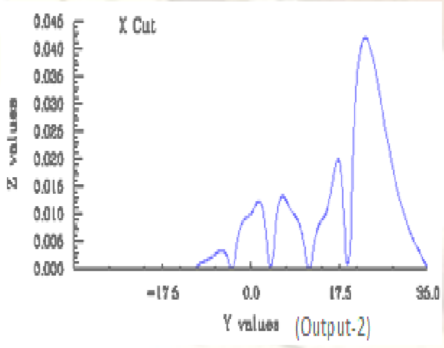

Fig.2 (d) multi direction beam splitter of hexagonal structure of linear SF57(Y-Z plane)

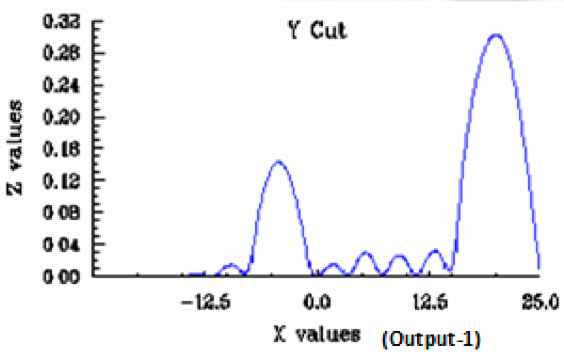

Fig.3 (a) Multi direction beam splitter of linear BK7 hexagonal structure (X-Z plane)

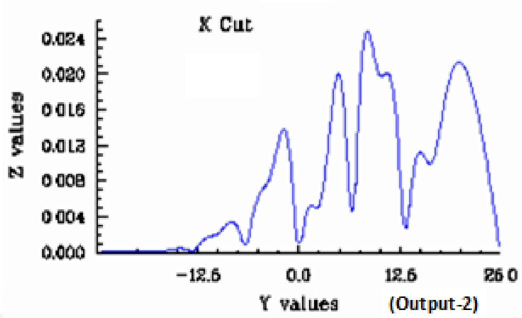

Fig.3 (b) Multi direction beam splitter of linear BK7 hexagonal structure (Y-Z plane)

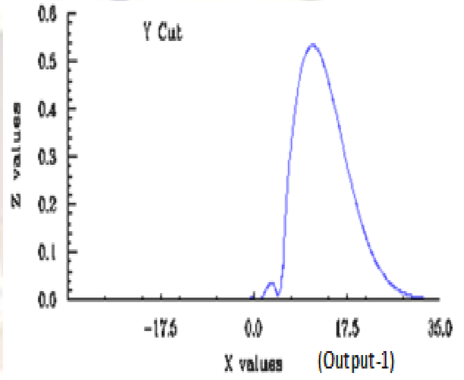

Fig.3 (c) Multi direction beam splitter of non linear BK7 hexagonal structure (X-Z plane)

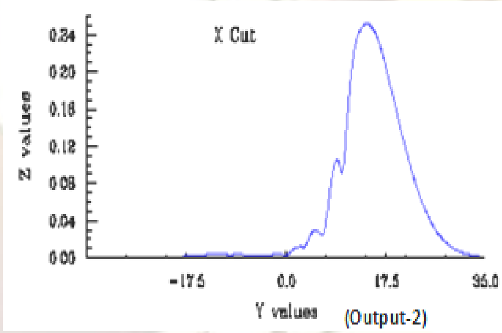

Fig.3 (d) Multi direction beam splitter of non linear BK7 hexagonal structure (Y-Z plane)

V. CONCLUSIONS:

. It is shown that by suitably optimizing the Hexagonal photonic crystal structure with respect to lattice constant and refractive index of background material, both splitting ratio as well as signal splits into different direction changes. Hexagonal photonic crystal structure can be used as a beam splitter.

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