A theoretical study of soliton in photonic crystal fibers

Z. S. Abdul-Hussain and H. A. Sultan

Department of Physics, College of Education for Pure Sciences, University of Basrah, Basrah, Iraq
hassabd67@yahoo.com

Abstract: In this work the photonic crystals parameters, holes diameters, hole- hole spacing and number of holes on the optical fibers was studied. The study showed that the soliton which is depends on the dispersion and the refractive indices of the optical fiber are strongly affected by the photonic crystal parameters. the group velocity parameter was calculated for different values of holes diameters and hole- hole spacing.

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Introduction:

Photonic crystal fibers (PCFs) are new optical fibers made with internal a periodic structure by drilling air holes with a periodic arrangement in the substrate material. Then removing the central holes or fill it with another material to form defects in the arrangement to make the core of the PCF, while the outer structure plays the role of the clad of the PCF. The optical signal can propagate along the fiber in the defects of its crystal structure. The properties of the photonic crystal make new optical fibers properties not found in the classical fibers [1-4].

Choosing appropriate photonic crystal parameters, it can produce unique properties impossible to achieve in classical fibers, this makes PCFs very flexible and expand the range of their applications [5-7].

It is possible to control the dispersion, effective refractive index, and the nonlinearity of PCFs by changing the photonic crystal parameters (hole-hole spacing (lattice pitch), hole shape and diameter, the refractive index of the glass, number of holes and type of lattice).

When optical pulse passes through a fiber it suffers a distortion, where it expanded in time, this phenomenon called dispersion, this situation is the most advantage of optical fibers. If the dispersion is canceled the pulse propagate without changing its shape (Soliton). The main condition to achieve soliton waves is the nonlinear effects in the fiber must balance the dispersion effect. The nonlinearity and the group velocity dispersion (GVD) can be controlled by the photonic crystal parameters [8-10].

In this work, we studied the effect of the PCFs parameters (hole – hole spacing, number of holes and hole diameter) on the temporal soliton waves along the fiber.

Method:

The propagation of a short light pulse in PCFs is governed by the Nonlinear Schrodinger Equation (NLSE) given by [11-13]:

$$\frac{\partial A}{\partial z} + i\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2} + \frac{\alpha}{2}A = i\gamma|A|^2 A \qquad (1),$$

Where A(r, z) is the pulse envelope, α is fiber losses, β_2 is the second-order dispersion factor, γ is the nonlinear parameter given by [11 13]:

$$\gamma = \frac{2\pi n_2}{\lambda A_{eff}} \qquad (2),$$

where n_2 is the nonlinear refractive index, λ is the wavelength, and A_{eff} is the effective area of the fiber core.

This type of equation can be solved efficiently using the split step Fourier method (SSFM) [11-13], where the PCF length is divided into N cells, each cell while will divided into two parts, the first is for the linear term of the NLSE, and the second is for the nonlinear one. Then eq. (1) gives:

$$\frac{\partial A}{\partial z} = (L + N)\ A \qquad (3),$$

Where, L=$-\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2}$ is the linear operator, and N= $i\gamma|A|^2$ is the nonlinear one.

The solution of eq. (3) from z to z+h will be:

$$A(z,t) = \exp[h(L + N)]\,A(z,t) \qquad (4)$$

Using the FFT and invers of FFT technique, the pulse amplitude (A) will be calculated at each cell, as the first cell corresponding to the initial conditions. The whole procedure was calculated using Matlab software.

Results and discussion:

Nonlinear Schrodinger equation (1) was solved using SSFM and MATLAB to study the effect of three photonic crystals parameters on the PCFs properties. Each time one of them changed within a certain range, while the others were fixed as shown in table (1).

Table (1): Photonic crystals parameters used in the study.

Parameter	Range	Fixed value
Hole diameter (d) (μm)	0.3-0.7	0.3
Pitch (Λ) (μm)	(1-5)*d	0.5
Number of holes (N)	5-11	7

The PCFs dispersion and n_{eff} were found to be functions to the pitch as shown on the left offigure (1), it is clear that n_{eff} of the core decreases with increasing the wavelength and the pitch. In the same manner the PCF dispersion curve affected also, figure (1) (right), it shows the dispersion curve as a function to the wavelength and pitch, where the curve is growing towards the high values.

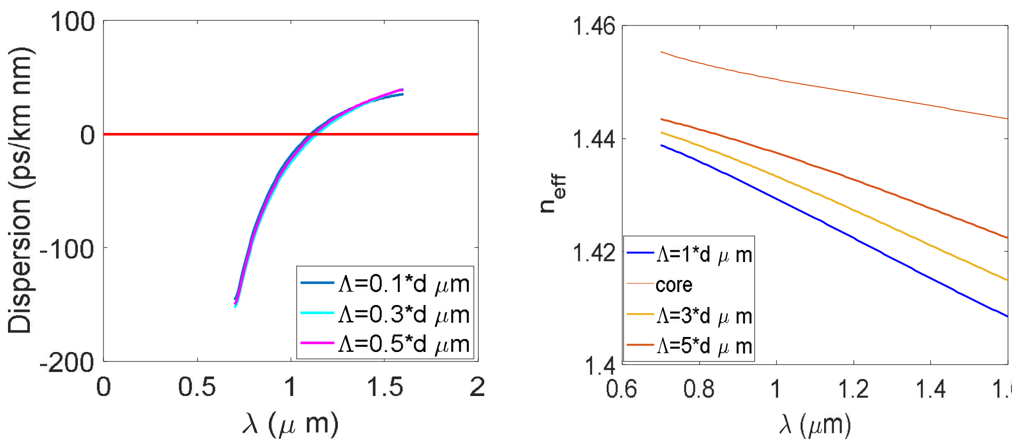

Figure (1): The dispersion curves (left), and n_{eff}(right), changes with wavelength at d=0.3 um, N=5.

The solution was repeated for the effect of the hole diameter, and its effect on the PCF dispersion and n_{eff} was figured out in figure (2). It is clear that n_{eff} is decreasing more with increasing the wavelength and the hole diameter. The dispersion curve is shifted downward, the zero-dispersion wavelength enhanced toward shorter wavelength, with increasing the hole diameter.

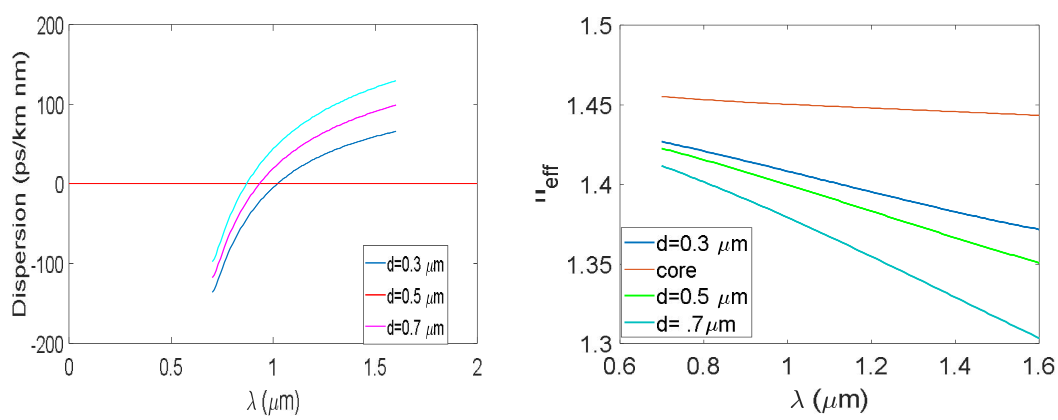

Figure (2): The dispersion curve and n_{eff} for different values of hole diameter.

For the effect of N, the solution shows that the effect of N is less than the effect of the pitch and the hole diameter as in figure (3), it can be seen that the changes in the dispersion curve and was a little.

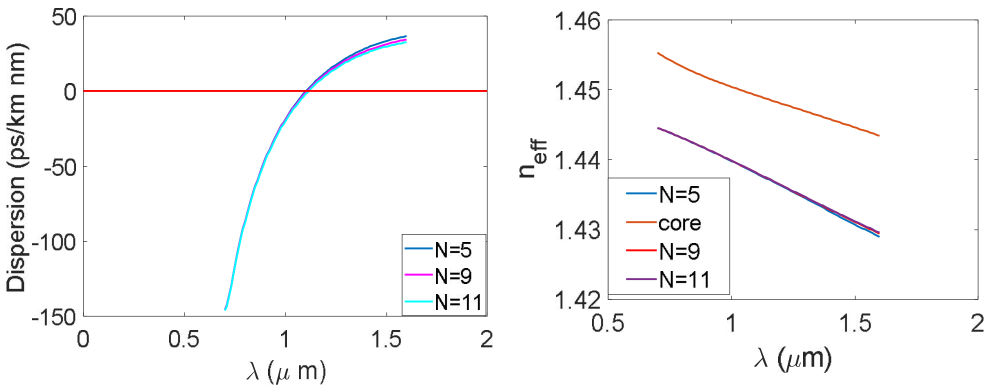

Figure (3): The dispersion curve and n_{reff} for different values of hole number.

As the dispersion being a function to the photonic crystal parameters, and the wavelength, the soliton appearance will also be affected. |The soliton wave dependent on the dispersion, the input pulse duration and its power were investigated as follows:

The dependent of β_2 on the hole diameter, are shown in figure (4), it is clear that β_2 strongly affected by d. In other hand Λ effect on β_2 are shown in figure (5), it can be seen that β_2 change is in opposite its change with the hole diameter, d.

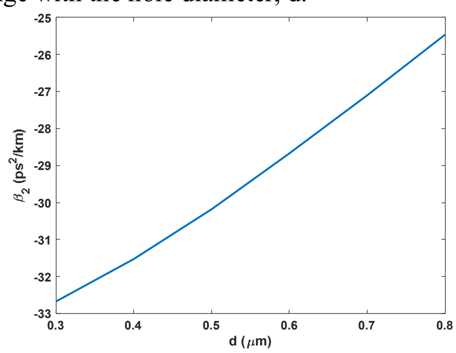

Figure (4): The relation between β_2 and the hole diameter, d.

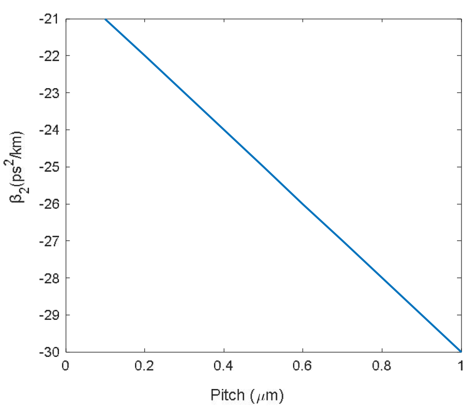

Figure (5): The relation between β_2 and the pitch, Λ.

Conclusions:

The soliton wave happen when a balance achieved between the dispersion and nonlinearities in PhCFs. the dispersion curve showed that it is depending on the PhC parameters, the hole diameter, hole- hole spacing, and number of holes, the refractive index of the core was found to be PhC parameters dependent also. β_2 showed strong dependent on the PhC parameters, the hole diameter and hole- hole spacing.

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