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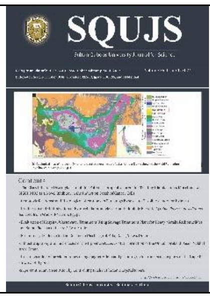

Supercontinuum Generation by Controlling Pitch in Photonic Crystal Fibers

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ABSTRACT: The influence of varying the distance between air holes (pitch) on the geography of solitone propagation through a photonic crystal fiber has been tested. The study depends on the Split-Step Fourier method and the results quantified using MATLAB. The first-order solitone was tested with the change in pitch, and it was found that there is a clear decay in the amplitude of the resulting pulse with an increase in pitch. When increasing the pitch in the case of second-order solitons, it was noticed that the pulse would split into multiple-order solitons down to higher-order solitons with the increase in pitch. In the case of third-order solitons, solitonic fission leads to the supercontinuum generation with increasing the pitch, where the supercontinuum generation was reached in this way depending on a very small energy source compared to the high energies used to generate this type of spectrum by the previous methods. In this study, I observed that when the pitch values increased in the third-order soliton, this result led to the use of supercontinuum generation (ScG) which has many applications such as medical and industrial applications and has an important role in modern communication systems.

Keywords: Photonic Crystal Fiber, Split-Step Fourier, Soliton Pulse, Pitch, Supercontinuum Generation.

توليد التوسع الطيفي الفائق من خلال التحكم بالمسافة بين الفجوات في الياف البلورة الفوتونية

محمد سالم جاسم الطائي

الملخص: تم اختبار تأثير اختلاف المسافة بين ثقوب الهواء على جغرافية انتشار السوليتون من خلال ألياف البلورة الفوتونية ، وتعتمد الدراسة على طريقة الخطوة المنقسمة لفورييه والنتائج التي تم التوصل إليها باستخدام برنامج ماتلاب تم اختبار السوليتون من الدرجة الأولى مع التغيير في المسافة بين الفجوات الهوائية ، حيث وجد أن هناك اضمحلالا واضحًا في سعة النبضة الناتجة مع زيادة المسافة. بينما في حالة السوليتونات من الدرجة الثانية ، لوحظ أن النبضة ستنقسم إلى سوليتونات متعددة الترتيب وصولاً إلى السوليتونات ذات الترتيب الأعلى مع زيادة المسافة بين الفجوات الهوائية ، بينما في حالة السوليتونات من الدرجة الثالثة ، يؤدي الانشطار السوليتوني إلى توليد التوسع الطيفي الفائق مع زيادة المسافة بين الفجوات ، حيث تم الوصول إلى التوسع الطيفي الفائق بهذه الطريقة اعتمادًا على مصدر طاقة صغير جدًا مقارنةً بالطاقات العالية المعتمدة في توليد هذا النوع من الطيف بالطرق السابقة. في هذه الدراسة لوحظ عند زيادة قيم المسافة بين الفجوات التي تؤثر على السوليتون من الدرجة الثالثة ، يتم الحصول على التوسع الطيفي الفائق الذي له العديد من التطبيقات منها الطبية والصناعية ، وله دور مهم في أنظمة الاتصالات الحديثة.

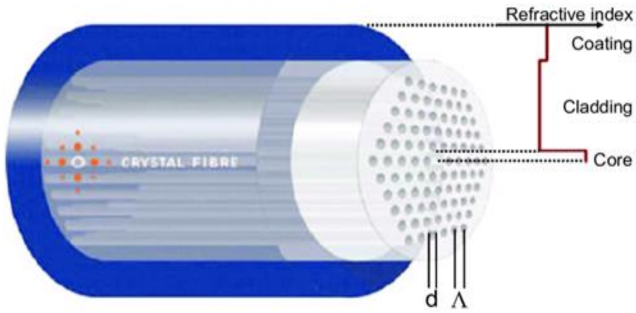
الكلمات المفتاحية: ألياف البلورة الفوتونية ،طريقة الخطوة المنفصلة لفورييه ، نبضة سوليتون، المسافة بين الفجوات الهوائية، التوسع الطيفي الفائق.

1. Introduction

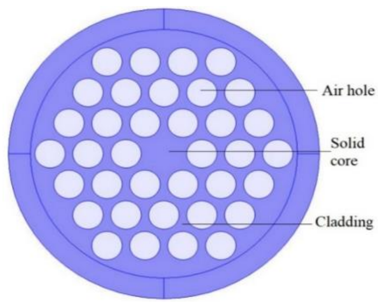
A solid-core photonic crystal fiber is defined as a fiber with a silica backdrop and air holes in the cladding area. The core is engineered to have a high refractive index compared to the cladding, and laser light is guided through the fiber in the same manner that it is guided in traditional fibers, through a modified total internal reflection process [1]. This structure allows a PCF to be built with better properties than a traditional optical fiber. These characteristics include an indefinite single module, controllable dispersion qualities, and a high nonlinear factor [2]. Because of these characteristics, PCF's can be used as optical amplifiers, fiber lasers, super continuum generation, and for all-optical wavelength transfer, among other applications [3]. The PCF's nonlinear properties can be improved by achieving a limited effective mode region [4]. The PCF nonlinearity can be improved by a few degrees by decreasing the effective mode region. As the nonlinear coefficient is increased, the fiber becomes a perfect candidate for optical applications, and the detection of nonlinear effects becomes possible at the shortest fiber lengths [5-7]. It is therefore possible to achieve a well-guided mode that is limited to a narrow region by varying the sizes of the air-holes within the cladding region. PCFs are used in parametric amplifiers as nonlinear mediums[8]. By appropriately adjusting the air-hole diameters, one may construct an appropriate mode area that results in the required nonlinearity [9-10]. Optical parametric amplifiers in fiber are used in a variety of applications, including signal processors, converters of optical wavelength, and line amplifiers. To assure manufacturing, a new PCF with a radius suitable for airholes (d=0.5)μm was designed with low dispersion, high nonlinearity, decreased confinement loss, and improved mode region characteristics. The PCF structure, which has a wide range of applications in optical communications, was created using a modelling methodology specific to this study. The propagation of the first, second and third-order solitones was controlled by controlling the distance between the air holes (Λ).

2. Photonic Crystal Fibers (PCFs)

This form of PCF is made up of a patrol system of air holes rings with a solid core in the middle that runs through the length of the fiber, as shown in Figure 1.



(a)



(b)

Figure 1. Solid-core PCF with microstructure cladding is the most prevalent design.

They are made of pure silica, and their aim is to lower the cladding's effective refractive index, resulting in a total internal reflection guidance system [11]. (Figure 1,a) illustrates the cross section of the solid core. (Figure 1,b) shows the variation in refractive index with radial size.

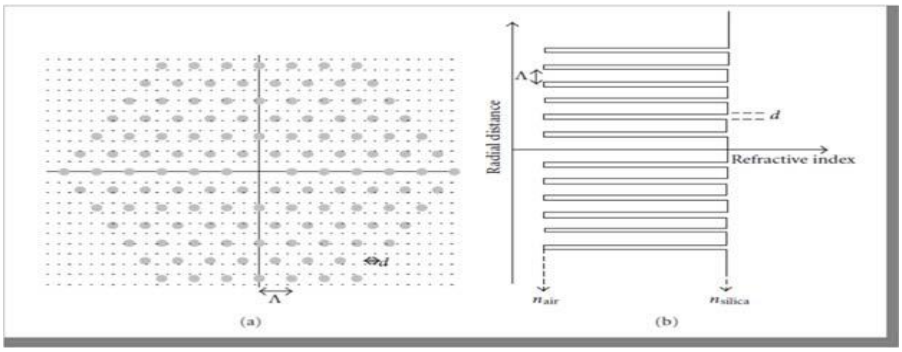


Figure 2. (a) Solid-core fiber cross-section and (b) refractive index profile [12].

One of the most appealing features of PCFs is their ability to remain single-moded over a broad wavelength range, unlike ordinary single-mode fibers, which become multi-moded for wavelengths under their single-mode cut-off wavelength. PCFs with this benefit are known as Endlessly Single-Mode (ESM) – PCFs [13]. The cladding's limited air-filling fraction is needed for a low index-contrast equivalent waveguide, which is required for single-mode operation. At lower wavelengths, the effective index of the cladding would be similar to the refractive index of the silica. This property would reduce the wavelength and maintain the single-mode over a broad wavelength range [14]. The improved optical guiding conditions ensure that PCFs are ideal for the desired application through the following effects:

A-Effective Area A_{eff}

The light carrying region is commonly referred to as the effective mode area. Electric-field (E) propagation occurs within the core for the fundamental propagating mode; as a result, the effective mode region (EMA) of a PCF can be calculated using equation 1[15].

$$A_{eff} = \frac{\left(\int\int |E_t|^2 dxdy\right)^2}{\int\int |E_t|^4 dxdy)} \quad (1)$$

B-**Non Linear effect (γ)**

The nonlinear effects would be worthwhile with a high optical power density supplied by a limited effective field. The effective region and even the nonlinear coefficient of the PCF background material in relation to the operating wavelength are all directly related to the nonlinear effectiveness or nonlinearity. Equation 2 can be used to look at the nonlinear effect [15].

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

C-Material Dispersion

Since the phase index fiber model is made of pure silica glass, the material dispersion (in the core region) can be approximated using the Sellmeier principle. The wavelength dependency of a material's refractive index is caused by the interaction of the optical mode with ions, gases, or electrons in the material. The dispersion of the materials is determined by equation 3 [16].

$$D = -\frac{\lambda}{c}\frac{d^2n}{d\lambda^2} \quad (3)$$

In this study, the main parameter was the pulse that takes the form of sech^2 pulses, which is known as soliton.

3. Soliton In Photonic Crystal Fibers

The interesting phenomenon of optical solitons, which are solitary optical waves that spread in a particle-like manner over long distances, has been the subject of intensive research in recent decades owing to its critical position in ground-breaking applications such as mode-locking [17], frequency combs [18-19], and supercontinuum generation [20, 21], among others [22-24]. One of the specific challenges is the interaction of a laser pulse with a nonlinear photonic crystal. Many papers deal with (i) building an all-optical switcher based on this relationship, (ii) light translation on photonic crystal defects, and (iii) photonic crystal use in different laser systems [25]. The main aim of this study is to investigate in depth the relationship between soliton formation and parameters, as well as to discover a method for regulating soliton parameters and soliton displacement in photonic crystals. The (NLSE) governs pulse propagation within a waveguide [26]. Mathematically, it is expressed as equation 4 [27]:

$$i\,\frac{\partial A(z,t)}{\partial Z} = \frac{i\alpha}{2}A(z,t) + \frac{\beta_2}{2}\frac{\partial^2 A(z,t)}{\partial T^2} - \gamma\,|\,A(z,t)\,|^2\,A(z,t) \quad (4)$$

Where $A\,(z,t)$ denotes the slowly varying pulse envelop amplitude, β_2 = 2nd- order dispersion, α= losses of fiber, γ = effect of nonlinearity. The effects of fiber losses, nonlinearity, and dispersion on pulses transmitting through the fibers are described by the three components on the right side of equation (4). Depending on the incoming pulse characteristics - peak intensity (Po=1) watt and starting width (To=1) ps, dispersive or nonlinear effects prevail along the fiber. The dispersion length (L_D) and nonlinear length (L_N) values of the fiber over which dispersive or nonlinear effects are relevant for pulse evolution are used to determine length scaling. based on equations 5 and 6 [28, 29].

$$L_D = \frac{T_\circ^2}{|\beta_2|} \quad (5)$$

$$L_{NL} = \frac{1}{\gamma\beta_\circ} \quad (6)$$

The split-step Fourier method (SSFM) is used to perform the numerical simulations. Abnormality is suspected in the dispersion (β_2 = - 3) ps^2km^{-1} , furthermore, there are no losses. (α = 0) $dBkm^{-1}$. nonlinear effects (γ= 1)$W^{-1}Km^{-1}$, where the parameters for the photonic crystal fibers are the distance between holes (d=0.5) μm, wavelength (λ=1.55) nm, number of air-holes (n=8), and diameter of the air hole (Λ=1.2,1.8,2)μm. The results are reached using the MATLAB program.

4. Simulation Results

The effect of the distance between air holes (Λ) on different-order solitons has now been studied and analyzed.

4.1 First-order soliton

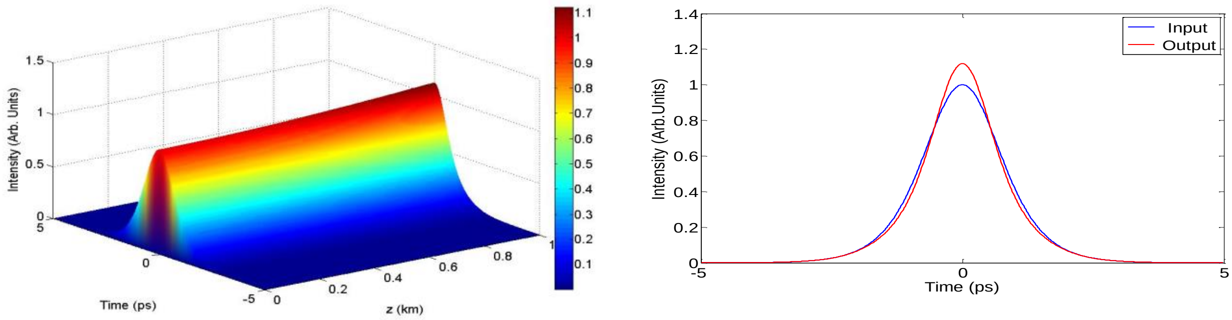
$Sech,$ pulses of the form are used, i.e, having the following form equation 7 [30].

$$A(0,t) = N\,Sech(t) \tag{7}$$

The order of the pulse is represented by N. When N=1 is used, just generate the first-order equation 8.

$$A(0,t) = \;Sech(t) \tag{8}$$

If the pulse has the form of a "Sech" and N = 1, it is referred to as the fundamental soliton, and Figure (3-a,b,c) below shows its propagation along the fiber. The distance between air holes (Λ) first-order solitone has been controlled as $\Lambda = (1.2, 1.8, 2)\mu m$. And the radius of the air holes is constant, equal to 0.5 μm As shown in the following results.



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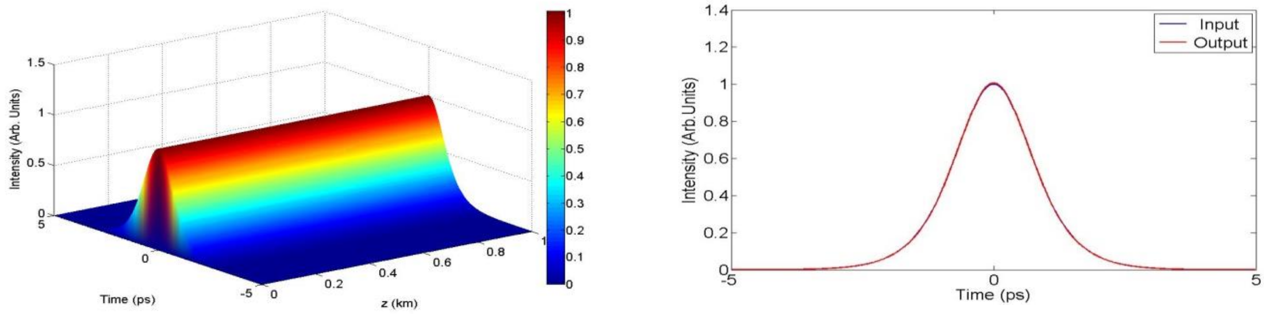

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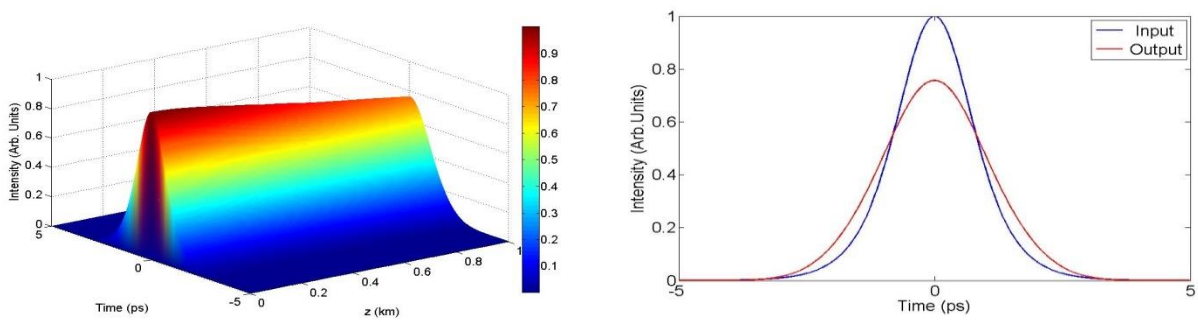


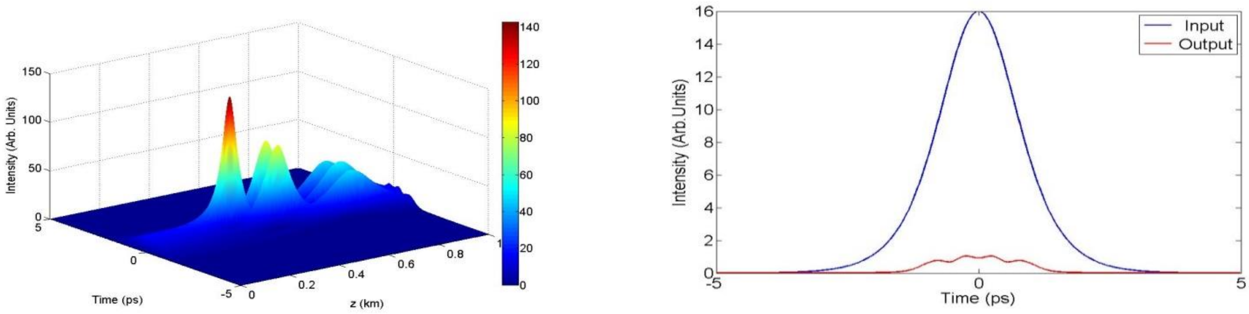
(c)

Figure 3. Shows the amplitude of the output pulse in three and two dimensions, first- order soliton, with different pitch $\Lambda = 1.2\mu m$, b- $\Lambda = 1.8\ \mu m$, c- $\Lambda = 2\ \mu m$.

Through the results of the change in the diameter of air holes in figure 2, it is clear that there is a decrease in the amplitude level of the outgoing pulse and that this decrease is gradually decreasing as the diameter of air holes increases. There is also a clear capsizing in the 3D pulse; rather than the widening at the end of the pulse appearing as the diameter of the holes increases, the expansion begins from the beginning of the pulse spread. The reason for this is that by increasing the diameter of the holes, the distance travelled by the light propagation through the fiber will lose part of its power, which leads to a decrease in the amplitude of the pulse coming out.

4.2 Second-Order Soliton

In the second order of soliton where N=2As in the 3D soliton, the pulse displays convexities and concavities with distance and time with the change in the diameter of air holes, and that increasing this same diameter of air holes has a clear influence on modifying the pulse strength, and that the output pulse steadily diminishes as the diameter of air holes increases, as seen in the 2D soliton. Figure 4 shows that.



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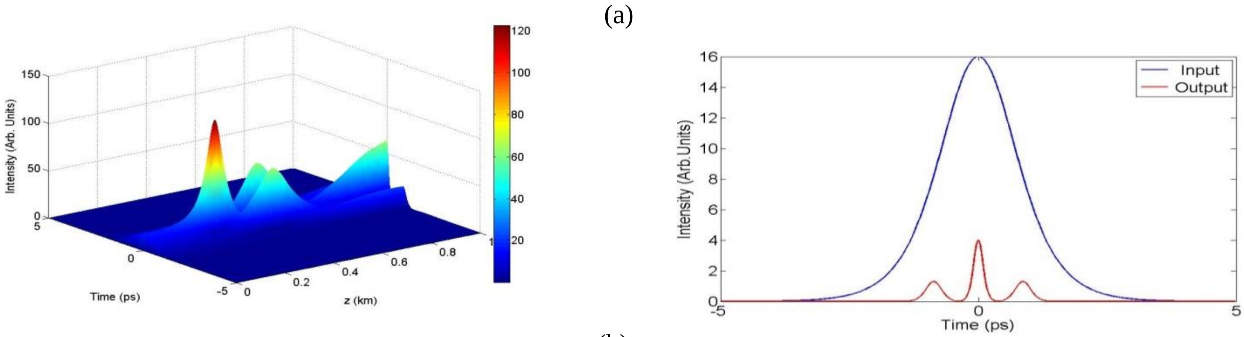

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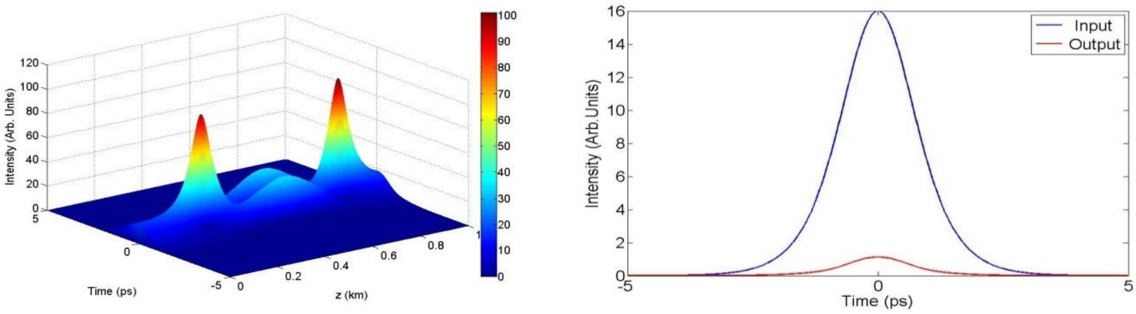

(c)

Figure 4. Explain the amplitude of the output pulse in three and two dimensions for a second order- soliton, with different pitch. a- a- Λ =1.2μm, b- Λ =1. 8 μm,c- Λ =2 μm.

The N=2 soliton spectral components are separated in time as a function of a perturbation introduced at Λ = (1.2, 1.8) μm. Since the perturbation lowers Λ=2 μm, only partial spectral re-compression appears. Optical pulses in a nonlinear and dispersive medium that show periodic oscillations in their temporal and spectral forms are classified as second- order. when only the pitch effect is considered, demonstrates the power evolution of pulse shapes. Within two soliton periods, the soliton decay can be seen.

4.3 Third – Order Soliton

When it comes to the third-order soliton, with N=3 the pulse exhibits bifurcations, showing the formation of a supercontinuum by soliton fission across time and distance with air-hole changes Λ = (1.2, 1.8, 2) μm, with increased pitch, the output strength steadily diminishes to the point of vanishing, as shown in Figure 5.

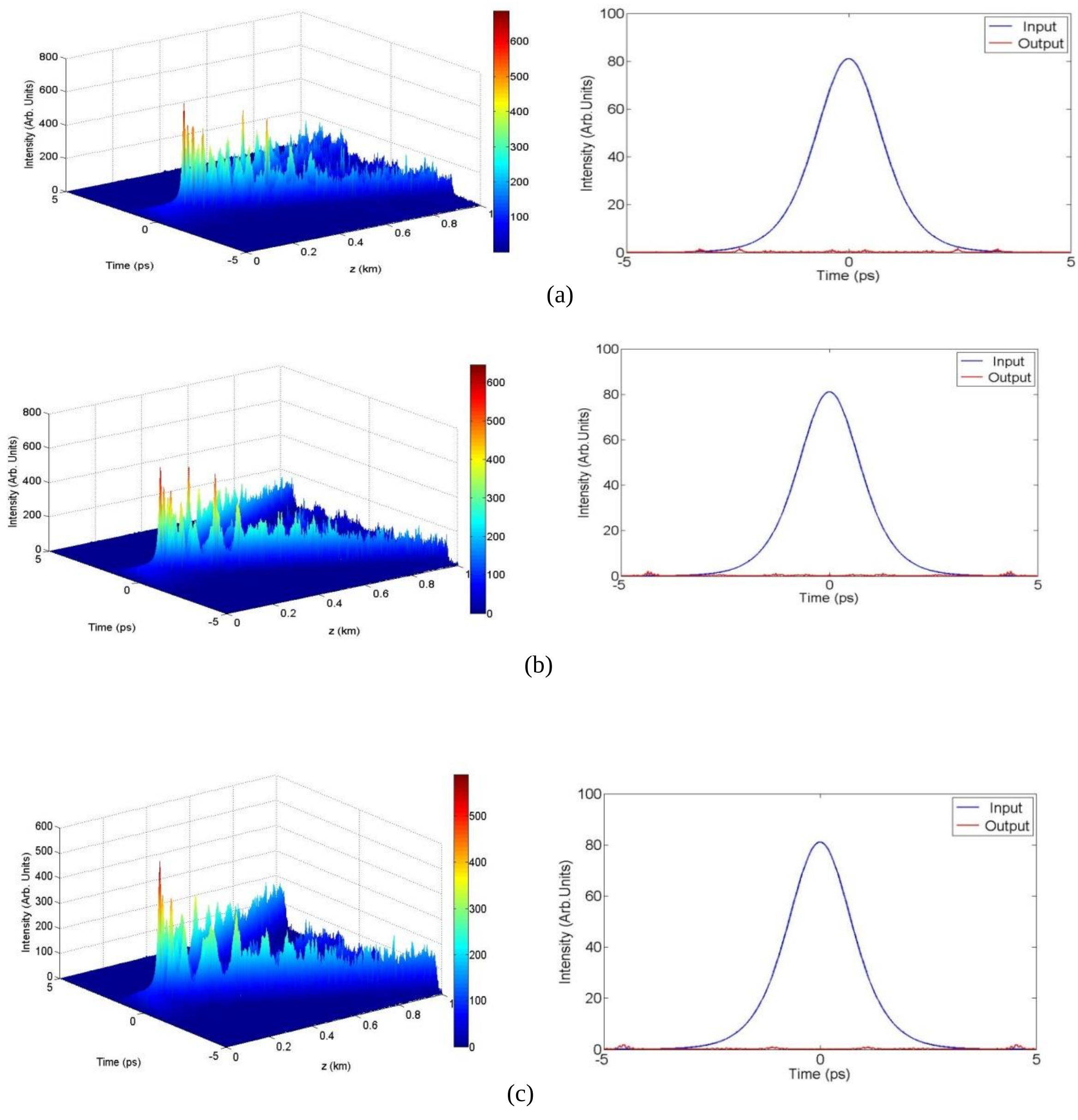

Figure 5. Explain the amplitude of the output pulse in three and two dimensions with different pitches.
a- a- Λ =1.2μm, b- Λ =1. 8 μm, c- Λ =2 μm.

Higher-order solitons are structurally unstable, according to one study, and a perturbation in the modified nonlinear Schrödinger equation (NLSE) can produce significant changes in the nonlinear dynamics of pulse amplitude. In figure 4 it can be observed that Positive chirp is produced by SPM, while negative chirp is produced by GVD (D>0). The amount of positive chirp created by SPM is greater than the amount of negative chirp generated by GVD due to the higher intensity; it cannot be cancelled out entirely. As a consequence, the pulse begins to chirp in a constructive manner.

4. Conclusions

The aim of this study was to look into the decay of various orders of soliton, which was caused by changing the distance between the air holes. To complete this mission, a systematic modelling effort for soliton propagation in photonic crystal fibers was undertaken. The split- phase Fourier approach was used to create a simulation tool (SSFM). It turns out that when soliton is in the first order, there is an inversion occur in the form of solitone, as well as a decrease in pulse intensity as the distance between air holes increases Λ=(1.2,1.8, 2) μm. In the case of second-order solitone, distortions appear when the distance between air holes is (Λ=1.2 and 1.8) μm, but the contours of the pulses appear with a decrease and regularity of the pulse of the output when Λ= 2 μm. When the distance between air holes changes in the case of the third-order solitone in the super continuum generation phenomenon, is clear as well as the chirps are evident as the distance between air holes increases and the intensity level of the pulse decreases. The main properties of this study are useful for nonlinear microscopy and spectroscopy applications.

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