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Using Lognormal Function to Measure Negative Chromatic Dispersion of Broadband Photonic Crystal Fiber

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ABSTRACT

Negative chromatic dispersion curves in a highly dispersive dual-concentric core pure silica photonic crystal fiber (PCF) have been investigated and measured. Our investigation depends on a simulation process for previous experimental results that were obtained by plane wave expansion (PWE) method. In the presented simulation process an approximation function will be considered to create a mathematical model that enables us to measure chromatic dispersion curves in this typical type of PC.The variations in the dispersion band-width that product as a function of lattice constant variation and air- holes diameters of lattice structure were carefully observed using Log normal approximation function. The obtained results by lognormal function match well with these obtained by PWE This work is devoted to supply fibers manufacturers with a précised model that can evaluate PCF performance by measuring negative dispersion and dispersion band-width theoretically and accurately.

Keywords: Chromatic dispersion, Photonic crystal fiber, lognormal function, Lattice structure parameters.

1. Introduction

Photonic Crystal Fiber (PCF) is a kind of optical fiber that uses photonic crystals to form the cladding around the core of the cable; photonic crystal is a low- loss dielectric medium constructed using a periodic array of microscopic air holes that run along the entire fiber length .With a highly structured cross-section of glass and air spaces (PCFs) also called micro -structured fibers, holey fibers and Bragg fibers, are the ultimate specialty fibers. Although (PCFs) have only recently become commercially available, many types are already available to support a rapidly growing range of applications because of the ability to confine light in hollow cores or with confinement characteristics not possible with conventional fibers such as single- mode operation from (UV)to (IR) with large mode- field diameters [1], highly nonlinearity performance for super continuum generation [2], numerical aperture (NA) values ranging from very low to about 0.9, optimized dispersion properties and air core guidance [3, 4] and among others. PCF is now finding applications in meteorology [5], biomedicine (bio-sensing) [6,7], imaging communications, industrial machining, military technology [7,8] and the list keeps growing as the technology becomes mainstream . In optical transmission fibers, chromatic dispersion is one of the primary impedance. And to minimize the penalty of chromatic dispersion, compensating fibers must be used in order to avoid excessive temporal broadening of ultra-short pulses and/or signal distortion because of the overlapping and interference processes between the neighbored broadened symbols of modulated signals particularly in cases with high data rates [9,10]. In designing chromatic dispersion compensating fibers an asymmetrical dual-concentric core structure must be used that can propagate two modes/ super modes. This dual-core is widely used in design of dispersion compensating fibers [11,12]. As a matter of fact advances in photonic crystal fiber technology promise to yield not only better ways to guide light but more efficient fiber lasers as well. In his paper a careful change for lattice structure parameter of PCF will be observed in order to create a specific model that can measure chromatic dispersion curves.

2. Cross-Section of the PCF.

Our mathematical model is devoted for a dual- concentric core PCF with a high negative dispersion coefficient and high broadband. A cross-section of the designed PCF is shown in figure(1), where d_1 denotes the diameter of first and second air-hole rings which form inner cladding region, d_2 denotes the diameter of third air-hole rings which form outer core region while d3 denotes the diameter of the rest of air-hole rings (fourth-tenth) which form the outer cladding region. The cross-section is with a lattice constant (A) where (A) is the center to center space between two nearest air-holes in the outer cladding region. The area at the center which is a pure silica doped region represents the inner core region of this PCF [13].This structure characteristics can make inner mode and outer mode of the super mode coupled and hence high negative chromatic dispersion can be achieved.

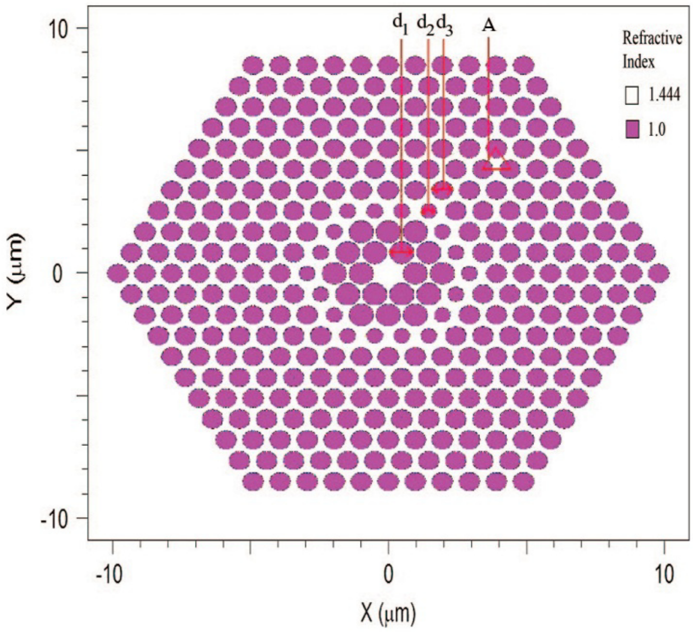

Fig.1 : Cross-section structure of proposed PCF [13].

3. Design of the Optimized Lattice Structure Parameters.

In a study introduced by the Microelectronic Research Centre, Department of Electrical and Computer Engineering at Texas University, Austin, the property of super-mode in this type of dual-concentric PCF has been investigated using the fully vectorial plane wave expansion (PWE) method [13]. Figure (2) represents super mode profile at 1.56 µm as a phase-match wavelength. Lattice structure parameters must be carefully chosen in order to control wave-guide dispersion and hence high negative dispersion can be obtained. This type of PCF can provide high negative chromatic dispersion coefficient of about -9500 (ps/nm.Km) with a full width at half maximum (FWHM) in the range of 55µm. This result was obtained after using several trail values for each of lattice structure parameters. Lattice constant (period) (A) were chosen to have the values (A= 0.98, 1.10, 1.30)µm. Figure(3a) represents negative chromatic dispersion curves at different values of (A). In this type of PCF lattice constant plays a vital role in achieving broadband operation along with a very high negative dispersion values, so by designing a structure with a very small value of A, very high dispersion-bandwidth can be obtained. However it becomes difficult to control the diameter of air-holes over such small dimensions. So the lattice constant value 0.98µm has been chosen to be investigated with different values of air-hole diameters (d_1, d_2, and d_3).Figures (3b, c, d) represent negative chromatic dispersion curves with different values of d_1/A, d_2/A, and d_3/A respectively [13]. In our research we shall try to estimate a mathematical model using a suitable function that enables us to measure negative dispersion curves in this type of PCF in a theoretical way.

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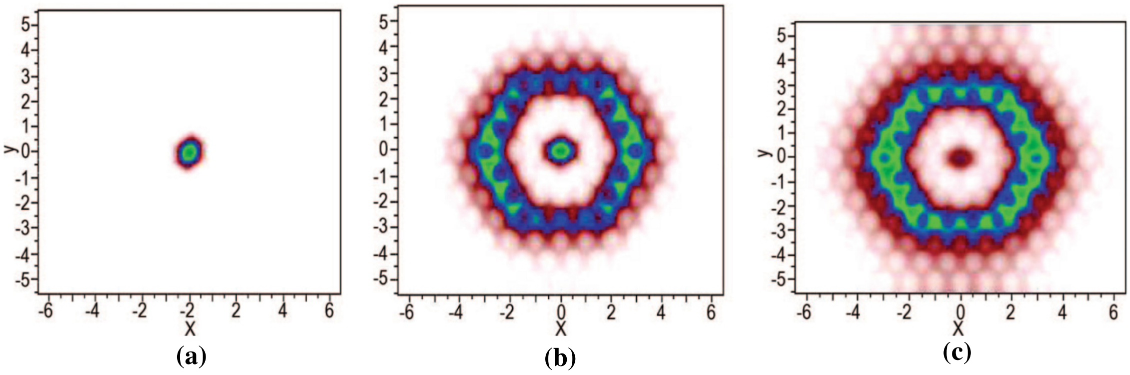


Fig. (2): Mode profile at (a) $A<A_P$(b) $A = A_P$ (c) $A > A_P$ (A_P is the phase-match wavelength =1.56μm) [13].

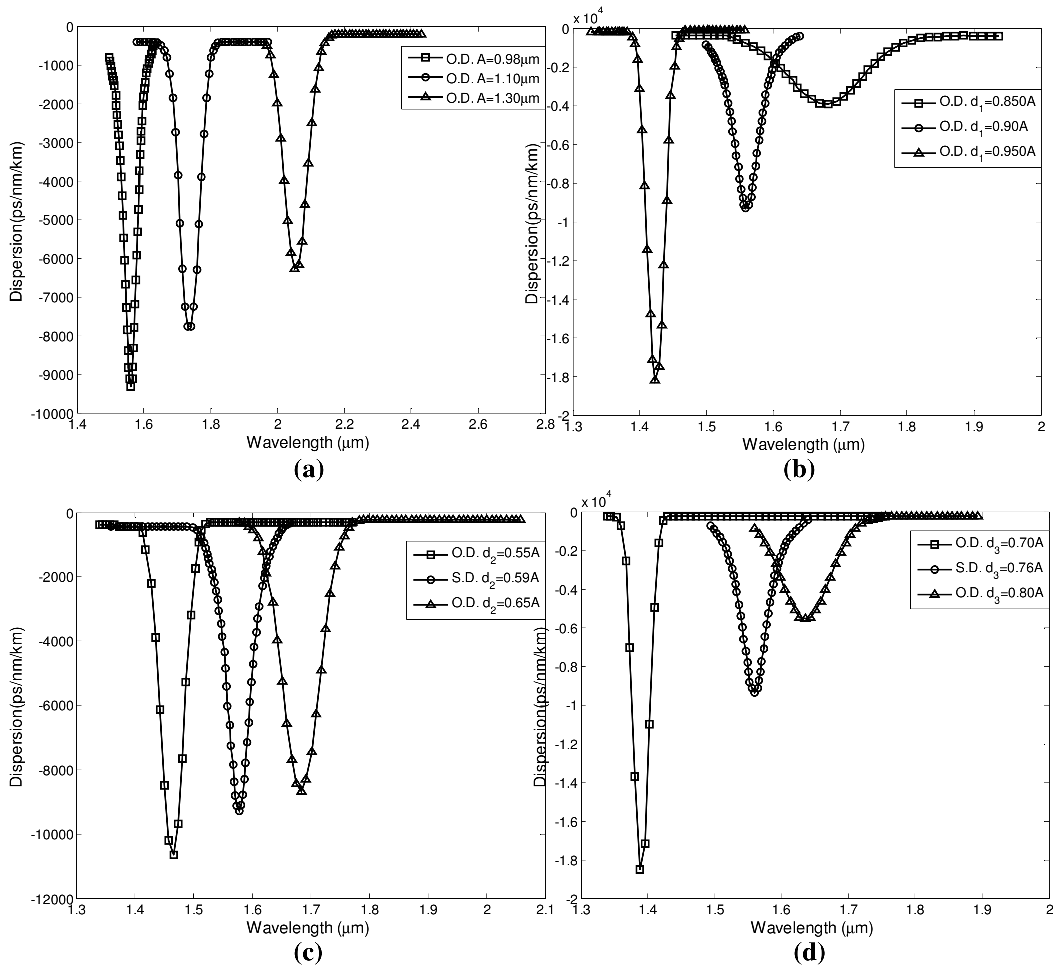


Fig.(3): Negative chromatic dispersion at different values of (a) A (b) d_1/A (c) d_2/A (d) d_3/A [13].

4. Results and Discussion

In this part of our theoretical work a mathematical model will be estimated in order to observe the influence of A, d1, d2 and d3 on negative dispersion curves. According to our investigation and after several trail functions, lognormalwere chosen to be the considered function to estimate the model. Lognormal function is given by:

$$y = a + b \exp[0.5 (\ln (x/c)/d)]2 \qquad (1)$$

Where, y denotes negative dispersion in (ps/nm/km), x denotes wavelength in (nm) and a,b,c and d represent the parameters of our function. These parameters will act as a function of lattice structure parameters (A, d_1, d_2, and

d_3), where, parameter-a represents a shift factor, b represents amplitude of the curve, c represents the position of peak center, while parameter-d is the standard deviation.

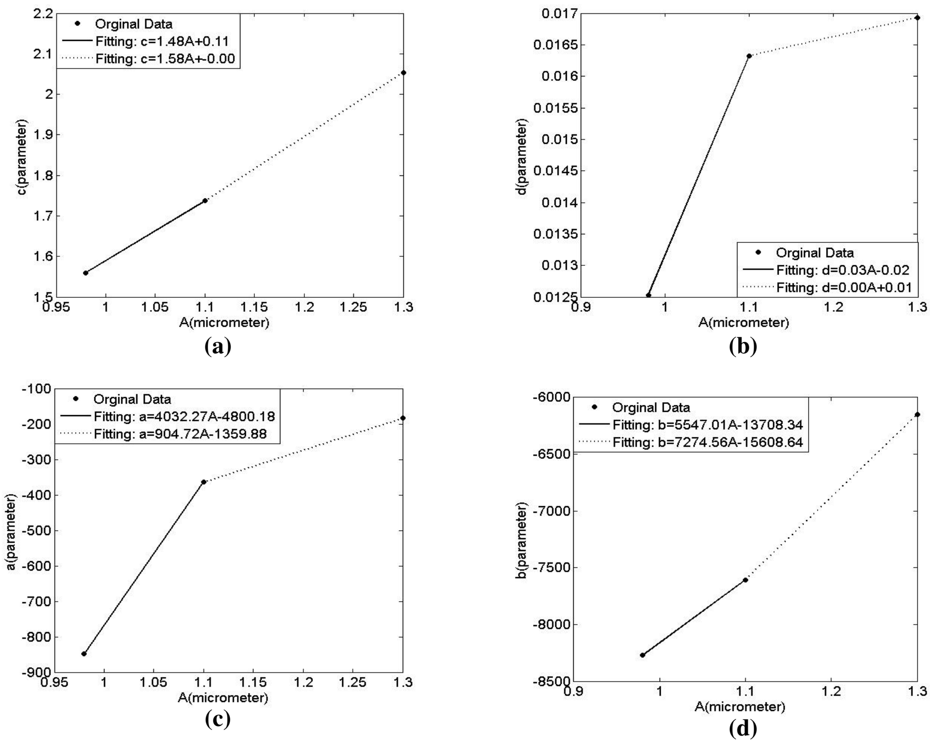
4.1 Negative Dispersion Curves at Different A :

By varying the values of lattice constant (A), several values of parameters a,b,c and d are obtained. Table (1) shows .

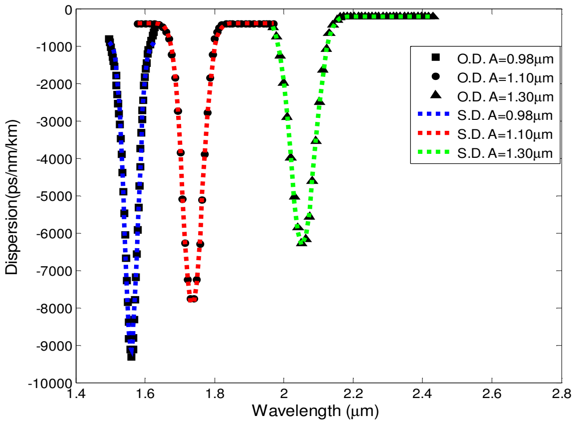
Table (1): Values of parameters a, b, c and d at different A.

Parameter	***A=0.98 μm***	***A=1.10 μm***	***A=1.30 μm***
r^2	0.992	0.998	0.999
a	-848.555	-364.683	-183.738
b	-8272.270	-7606.628	-6151.717
c	1.559	1.736	2.053
d	0.0125	0.016	0.016

These values, r^2 represents correlation factor between original data and our estimated data .Figs. (4a, b, c and d)) denote the relation between each parameter of our function and different values of (A). The relation is given by equation above/under each figure. Obtained negative dispersion curves are shown in fig.(5).



Figs.(4): Relation between each parameter and diameter A.



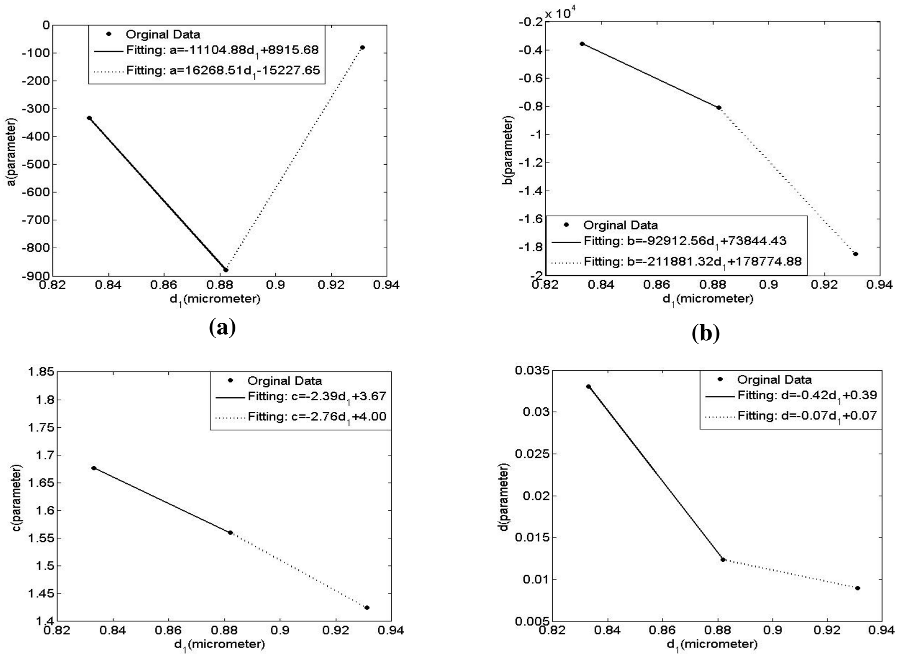
Figs.(5): Comparing between original dispersion curves (OD) measured by (PWE) method and simulated dispersion curves (SD) by Lognormal function at different A.

4.2 Negative dispersion curves at different d_1:

By varying the values of diameter d_1 and considering A to be 0.98µm, several values of parameters a, b, c and d can be obtained. Table (2) shows these values.Where, r2 represents correlation factor between original data and our estimated data. Figs. (6) represent the relation between each parameter and different values of air-hole diameter d_1. Obtained negative dispersion curves are shown in Fig.(7).

Table (2): Values of parameters a, b, c and d at different d_1

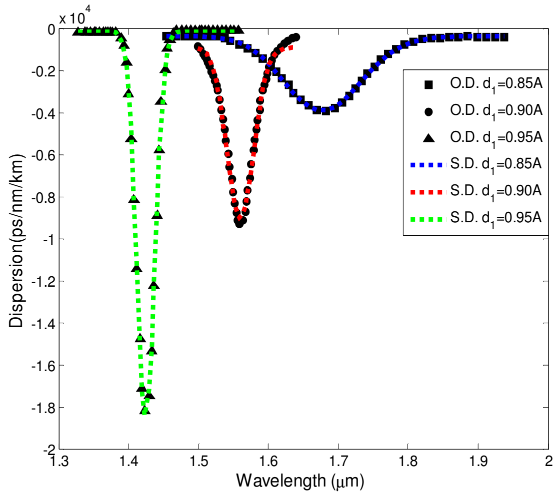
Parameter	*d_1=0.85A*	*d_1=0.90A*	*d_1=0.95A*
r^2	0.998	0.993	0.997
a	-334.682	-878.821	-81.664
b	-3551.730	-8104.445	-18486.630
c	1.676	1.559	1.424
d	0.0330	0.012	0.08



(a) (b)

(c) (d)

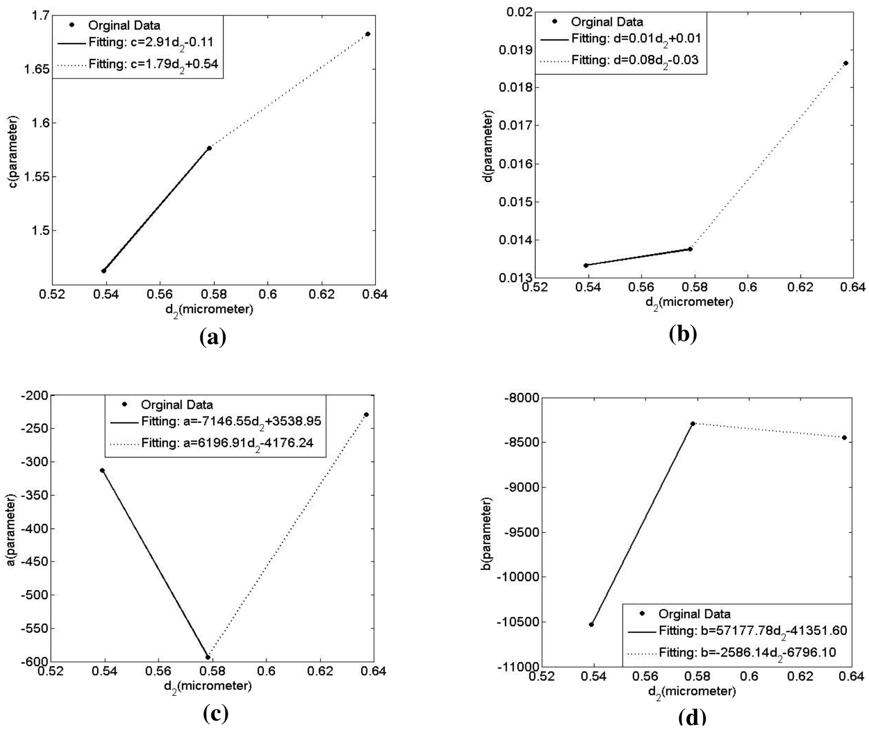
Figs.(6): Relation between each parameter and diameter d_1.



Figs.(7): Comparing between original dispersion curves (OD) measured by (PWE) method and simulated dispersion curves (SD) by Lognormal function at different d_1..

4.3 Negative dispersion curves at different d_2:

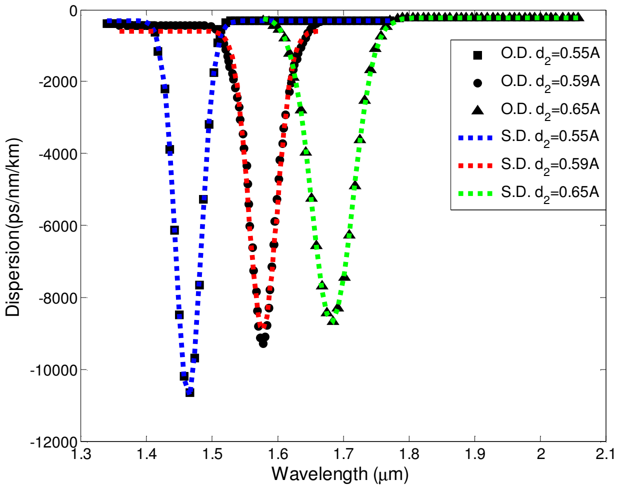
As in first and second analysis part specific values of d_2 will give us different values of parameters a, b, c and d. Table (3) shows these values. Figs.(8) show the relation between each parameter and d_2. A comparing for the obtained dispersion curves is shown in fig.(9).



Figs.(8): Relation between each parameter and diameter d_2.

Table (3): Values of parameters a, b, c and d at different d_2

Para-meter	***d_2=0.55A***	***d_2=0.59A***	***d_2=0.65A***
r^2	0.998	0.992	0.999
a	-313.040	-593.185	-228.807
b	-10532.776	-8291.407	-8443.472
c	1.462	1.576	1.682
d	0.013	0.0137	0.018



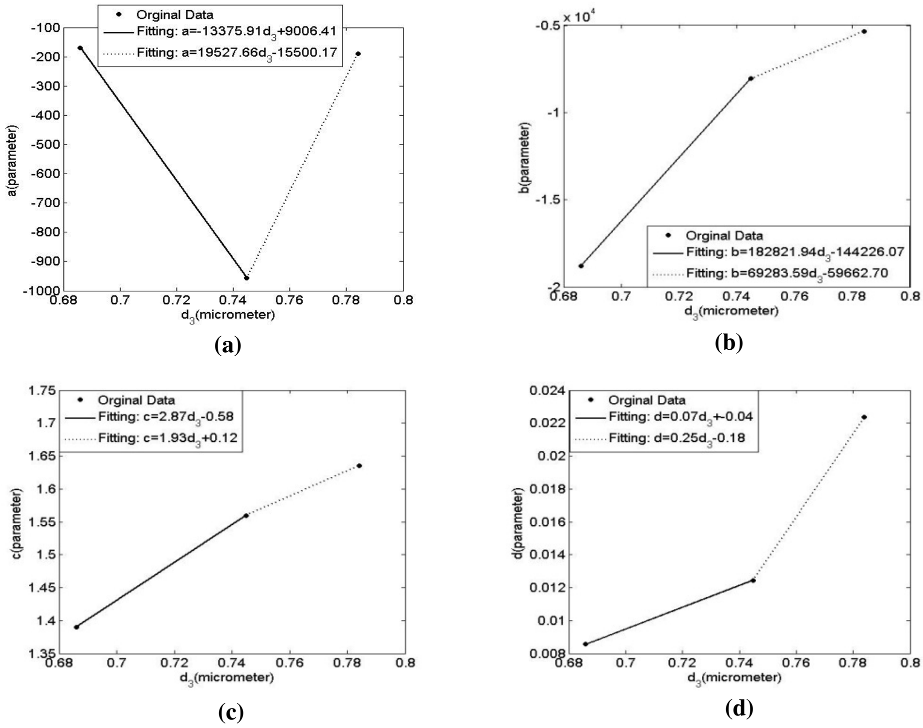
Figs.(9): Comparing between original dispersion curves (OD) measured by (PWE) method and simulated dispersion curves (SD) by Lognormal function at different d_2.

4.4 Negative dispersion curves at different d3

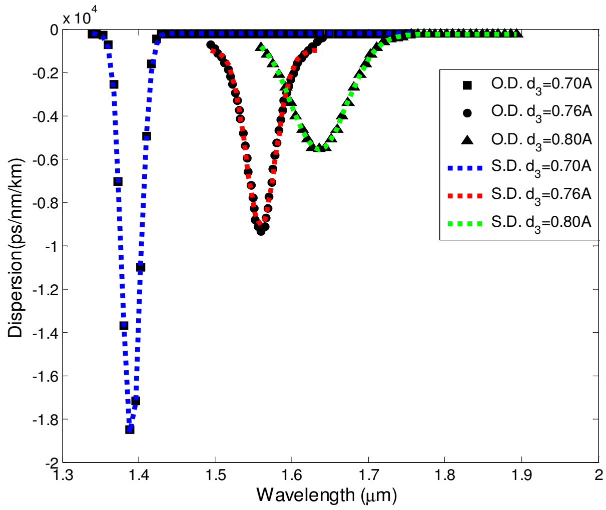
As in previous parts, several specific values of diameter d_3 will give us several values of parameters a, b, c and d as shown in table (4). The relation between each parameter and d_3 is shown in figs.(10). A comparing for dispersion curves is shown in fig.(11).

Table (4): Values of parameters a, b, c and d at different d_3

Para-meter	***d_3=0.70A***	***d_3=0.76A***	***d_3=0.80A***
r^2	0.999	0.993	0.999
a	-169.466	-955.970	0.999
b	-18810.217	-8060.287	-5344.370
c	1.390	1.559	1.635
d	0.008561585	0.012	0.022



Figs.(10): Relation between each parameter and diameter d_3



Figs.(11): Comparing between original dispersion curves (OD) measured by (PWE) method and simulated dispersion curves (SD) by Lognormal function at different d_3.

5. Results and Discussion

According to our results, negative chromatic dispersion curves measured by Lognormal function matches well with these measured by PWE method that was introduced by a previous study for the same type of PCF. This is obvious by observing high fitting ratio in comparing figures. The calculated correlation factor (r2) is almost close to one which indicates high accuracy. Lattice constant (A) plays a vital role in determining dispersion property and dispersion band-width. The considered approximation function can provide fibers manufacturers with a précised model that can evaluate the performance of this typical type of PCF by observing wave-guide dispersion through careful changes for lattice structure parameters in a theoretical way.

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