Theoretical Measuring for Negative Chromatic Dispersion Curves of Photonic Crystal Fiber by Gaussian Function

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ABSTRACT

Negative dispersion curves in a typical type of high negative chromatic dispersion photonic crystal fiber(PCF) have been investigated in this paper. The depended class of (PCF) has double-core structure (core-region: which has inner core and outer core) with a honeycomb photonic lattice in the cladding region.

Negative dispersion curves deviated from core-region of this type of fibers will be investigated. The investigation has depended an estimation process using an approximation function to create a mathematical model that enables us to measure negative dispersion curves. The influence of inner-core parameters (d_{core} d_1 and d_2) on dispersion curves has been investigated by varying the values of these parameters. Negative dispersion curves that were introduced by a previous study using finite-difference frequency-domain (FDFD)method for this class of(PCFs) are directly included in this work in order to measure matching ratio with our results.

Gaussian approximation function has been considered to estimate our mathematical model.

Keywords: Photonic crystal fiber, Theoretical model, Negative chromatic dispersion, Gaussian function.

1.Introduction

Photonic Crystal Fiber (PCF) can provide characteristics that ordinary optical fibers do not exhibit. Such as single-mode operation from the UV to IR with large mode-field diameters [1], highly nonlinear 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. Applications for photonic crystal fibers includes spectroscopy, metrology[5], biomedicine[6,7], imaging, telecommunications, industrial machining, and military [7,8] and the list keeps growing as the technology becomes mainstream. In transmission optical fiber, chromatic dispersion is one of the primary impediments. One of the best approaches to minimize the penalty of chromatic dispersion is to use dispersion compensating fibers which have negative chromatic dispersion that is used to periodically balance the positive chromatic dispersion from the G.652 optical fibers [9,10]. In designing chromatic dispersion compensation optical fiber, one must use an asymmetrical dual-concentric-core structure that can propagate two super -modes. This dual-core is widely used in design of the dispersion compensation fibers [11,12]. So another way to alter the dispersion is changing the core size and the refractive indices of the material of core and cladding. The presence of dispersion leads to signal degradation in optical fibers for telecommunications because of the varying delay in arrival time[13 ,14]. In this paper there is an approach to measure the optical dispersion curves for a specific type of PCF guiding light by conventional higher-index core modified by the presence of air-holes with a honeycomb array in the cladding region.

2. Cross-section structure of the PCF

Our mathematical model is proposed for a high negative chromatic dispersion PCF structure that is shown in Fig.1. Its composed of a circular air-holes in the cladding arranged in a honeycomb array with lattice constant L, where L is the center to center space between two nearest air-holes in the cladding region, while the diameter of the air-hole in the cladding is denoted by d3. The diameter of the circular germanium doped region in the core is dcore and the diameters of the 1st and 2nd ring air-holes around the core are denoted by d1 and d2, respectively. The circular doped region forms the inner core of the fiber while the outer core is formed between the 2nd ring air-holes and the cladding region by deleting some air-holes as shown in Fig.1. (This structure characteristic can make the inner mode and outer mode of the super- mode coupled and subsequently negative chromatic dispersion can be achieved)[15].

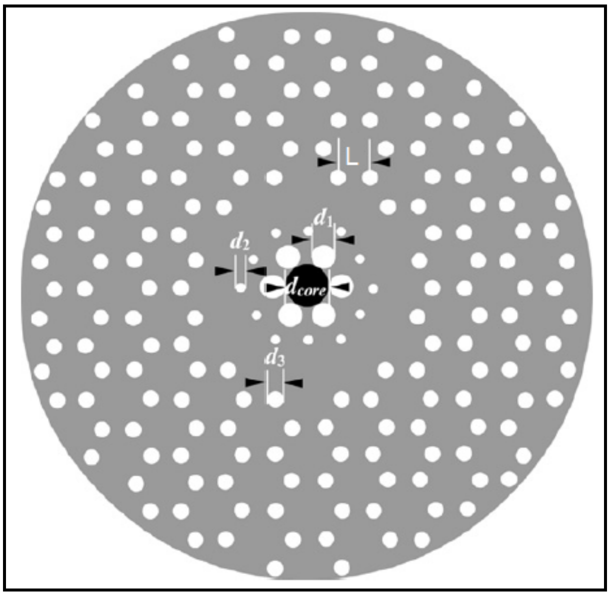

Figure 1: A cross-section structure of the PCF[16].

3. Design of the optimized structure parameters.

In a study introduced by the school of information and communication engineering at university of Guilin[16], the property of super-mode in high negative chromatic dispersion in this type of optical fiber has been investigated using finite-difference frequency-domain (FDFD) method with uniaxial anisotropic perfectly matched layers. The super-mode field profile is shown in Fig.2 and its at a wavelength in the range of 1.55µm. The cross-section parameters were as follows [16]:

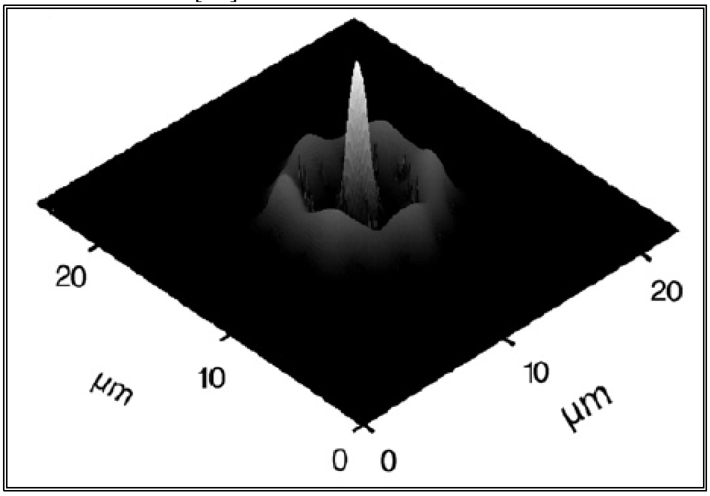

Figure2: Super-mode field profile at 1.55µm of wavelength[16].

The diameter of the circular doped region in the fiber core d_{core}=2.10µm with a refractive index n_{core}=1.487, the optical lattice constant of the cladding L=1.50µm, the diameter of the air-hole in the cladding d_3=1.04µm, and the diameter of the 1st and 2nd ring air-holes around the inner core were 0.90µm, 0.40µm respectively. We can see that the super-mode has two modes that distributed in the inner fiber core and outer fiber core. In order to obtain high negative chromatic dispersion, one must control the wave-guide dispersion through a careful designing for the structure parameters [11,12,17]. The mentioned study introduced dispersion curves versus wavelength with a presence of specific values of structure parameters in this type of PCF. Figures (3),(4)and(5) represent the negative dispersion curves with presence of specific values of d_{core} , d_1, and d_2 (core region parameters) respectively. In the next step of our research a mathematical model for chromatic dispersion of core region parameters of the proposed PCF will be investigated. The exact definition of dispersion equation is expressed as : $D = -\frac{\lambda}{C}\frac{d^2\, Re\,(n_{eff})}{d\lambda^2}$

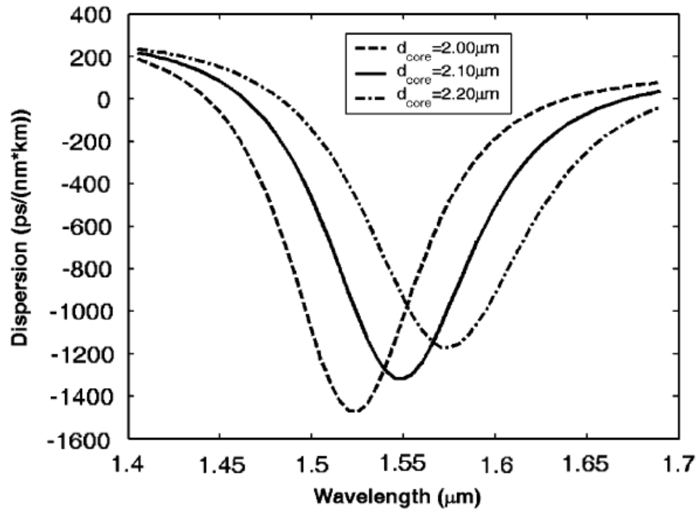

Figure3: The negative dispersion curves with different d_{core} [16].

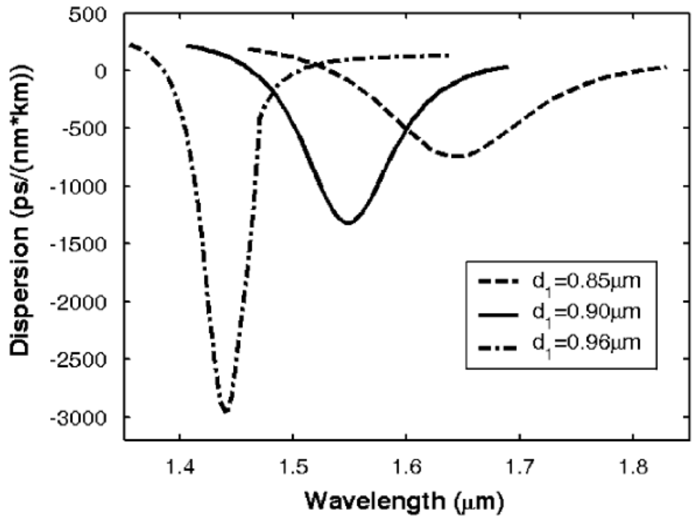

Figure4: The negative dispersion curves with different d_1 [16].

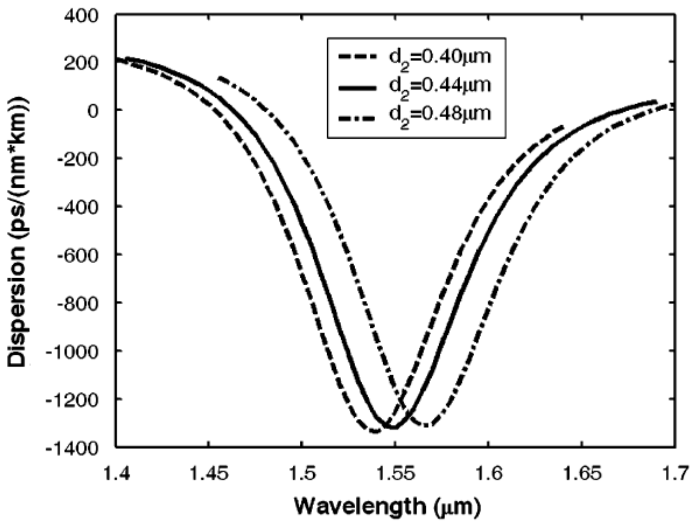

Figure 5: The negative dispersion curves with different d_2 [16].

4. Results and discussion :

In this part of our theoretical work a mathematical model will be estimated in order to observe the influence of d_{core} ,d_1 and d_2 variation on negative dispersion curves. It has been found that the best fitting function (has a good matching with the previous measured negative dispersion curves) is Gaussian function, given by:

$$Y = -a + b \exp[-0.5[(x - c)/d]^2] \quad (1)$$

Where Y denotes negative dispersion in (ps/(nm.km)), x denotes wavelength in (nm) and a,b,c&d represent parameters of Gaussian function, these parameters depend on d_{core} ,d_1 and d_2 (vary with the variation of d_{core} , d_1, and d_2), where, parameter-a denotes a shift factor, parameter-b denotes the amplitude of the curve, parameter-c is the position of the peak centre of curve, while parameter-d is the standard deviation.

4.1 Negative dispersion curves with d_{core} variation :

By varying the value of d_{core} , different values of a,b,c,&d are obtained. Table (1) shows these values.

Table 1. Values of Parameters a,b,c and at different d_{core}.

Parameter	d_{core}=2.0µm	d_{core}=2.10µm	d_{core}=2.20µm
r^2	0.990103	0.983416	0.985058
a	41.16067055	74.46223723	153.7713320
b	-1459.72900	-1332.92848	-1264.66886
c	1.525115029	1.551003642	1.576971218
d	0.034218181	0.038802573	0.045547372

Where r2 represents the correlation factor between measured and fitting negative curves. Figs.(6, 7,8,&9) denote the relation between each parameter and different values of dcore .The relation is represented by the equation above each figure. Fig. (10) represents comparing between original data (OD) of negative dispersion curves obtained by (FDFD)method and our simulated data (SD) by Gaussian function.

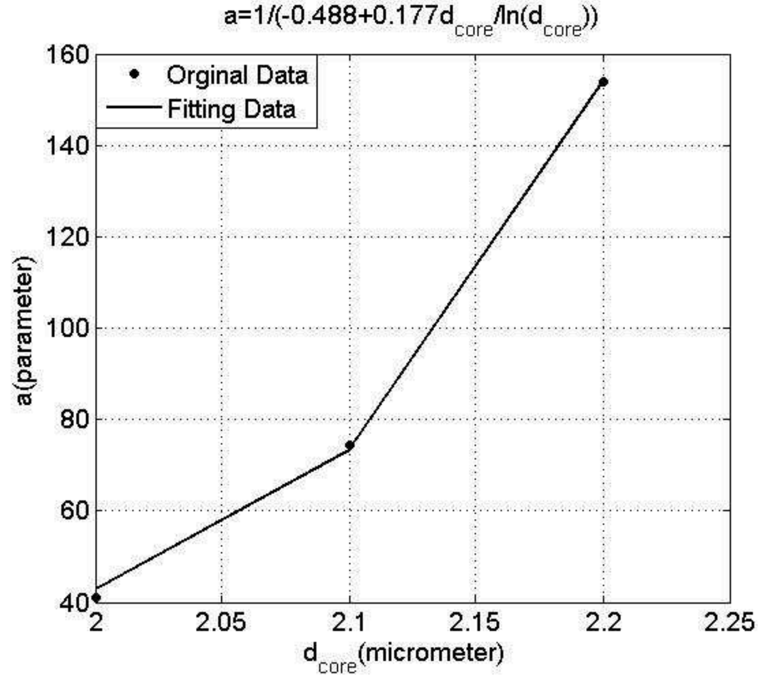

Figure 6: Relation between parameter-a and d_{core}.

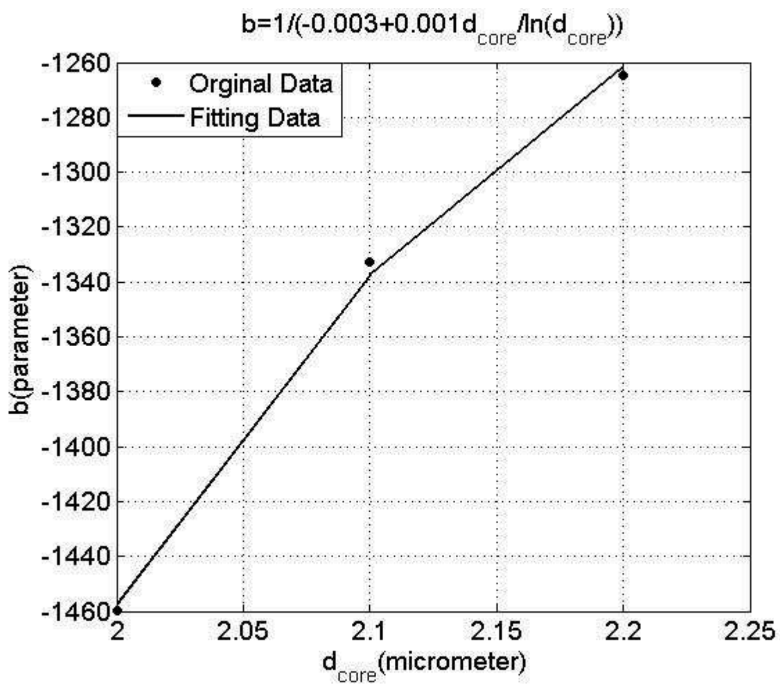

Figure7: Relation between parameter-b and d_{core}.

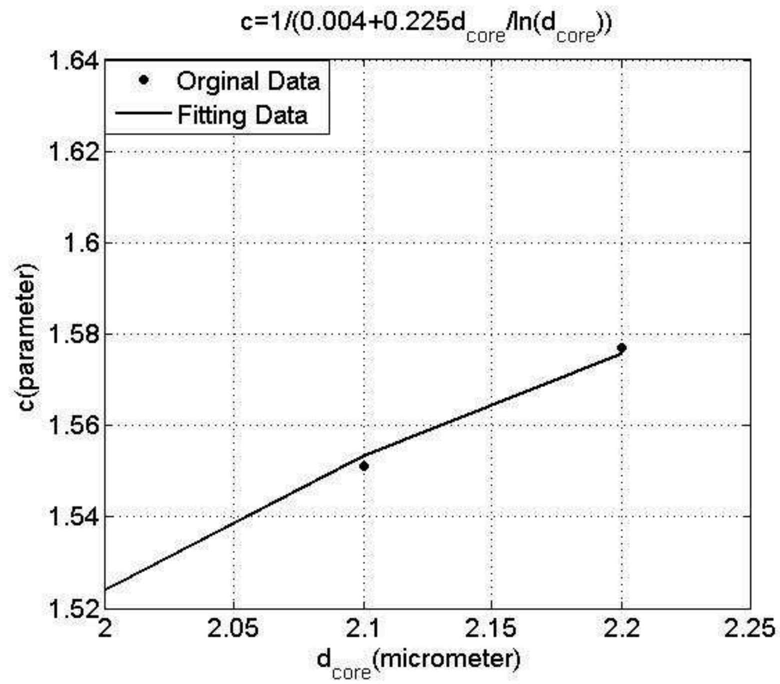

Figure 8: Relation between parameter-c and d_{core}.

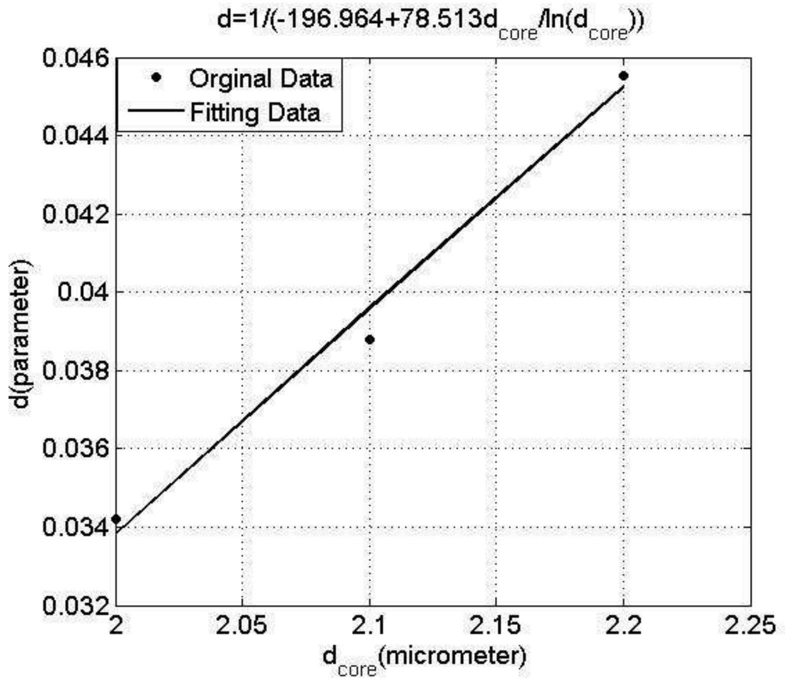

Figure 9: Relation between parameter-d and d_{core}.

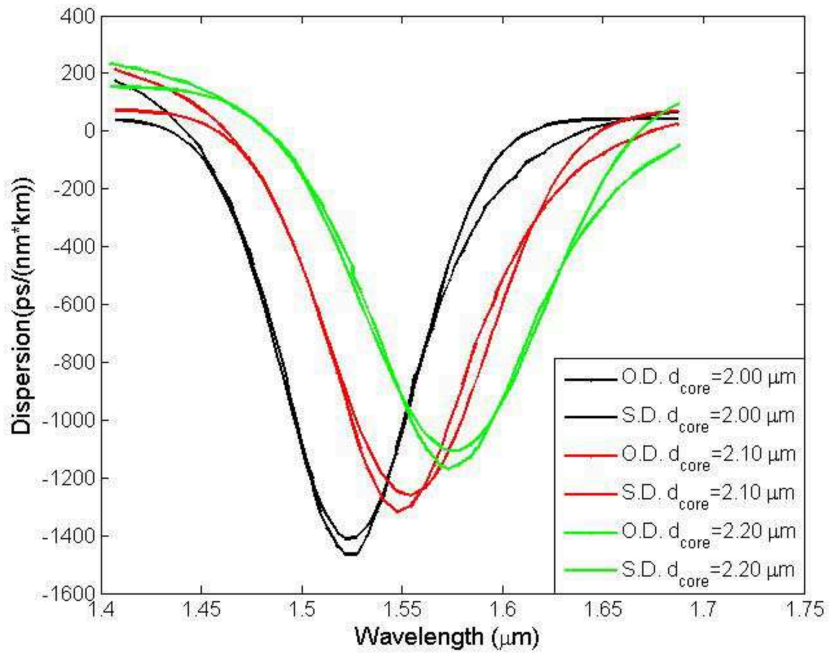

Figure 10:The original data (OD)and simulated data (SD).

4.2 Negative dispersion curves with d_1 variation :

By varying values of d_1, different values of parameters a,b,c,&d are obtained. Table (2) shows these values.

Table 2. Values of Parameters a,b,c and d at different d_1.

Parameter	**d_1= 0.40µm**	**d_1= 0.44µm**	**d_1= 0.48µm**
r^2	0.987284	0.985077	0.990108
a	110.8813605	86.15186394	90.89848462
b	-834.188267	-1379.28751	-3008.39083
c	1.650276554	1.549679802	1.438640201
d	0.062572445	0.038517249	0.018369354

Where, r^2 denotes the correlation factor between measured and fitting curves. Figs (11,12,13&14) represent relation between each parameter and different values of d_1. The relation is represented by the equation above each figure. Fig.(15) represents comparing between (OD) of negative dispersion curves obtained by (FDFD) method and our (SD) by Gaussian function.

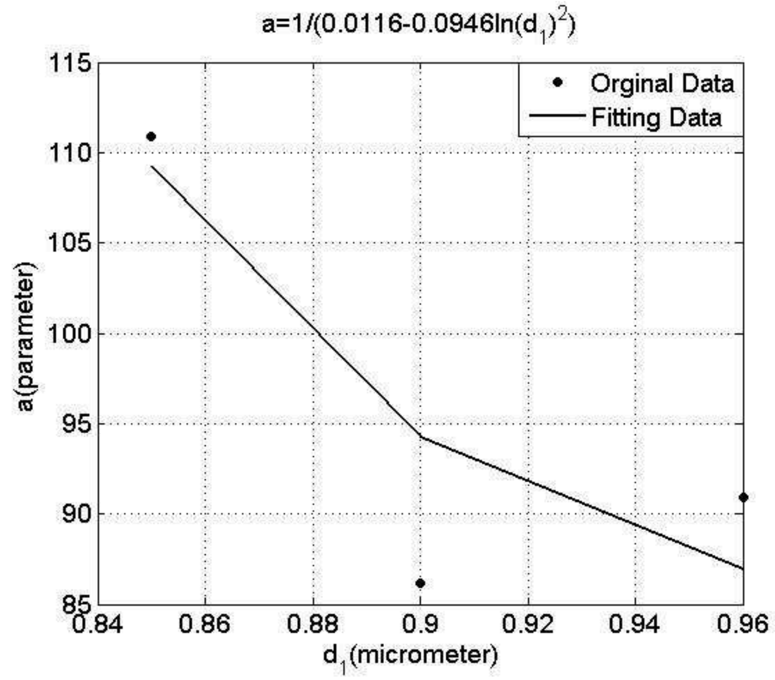

Figure 11: Relation between parameter-a and d_1.

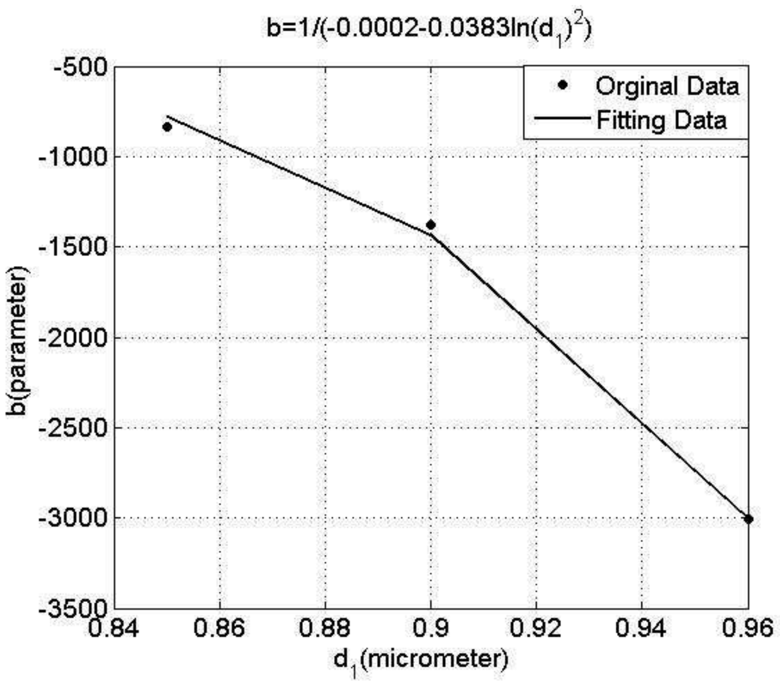

Figure12: Relation between parameter-b and d_1.

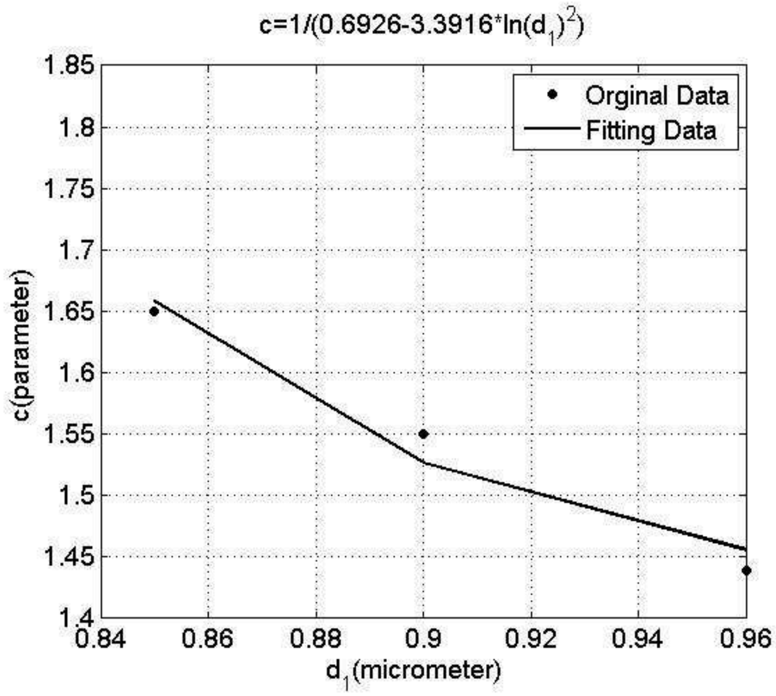

Figure13: represents relation between parameter-c and d_1.

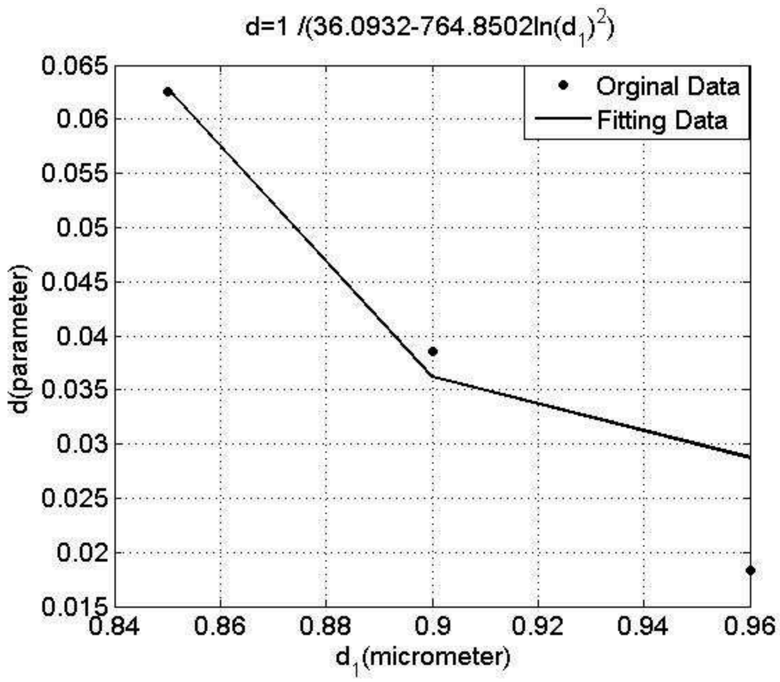

Figure 14: Relation between parameter-d and d_1.

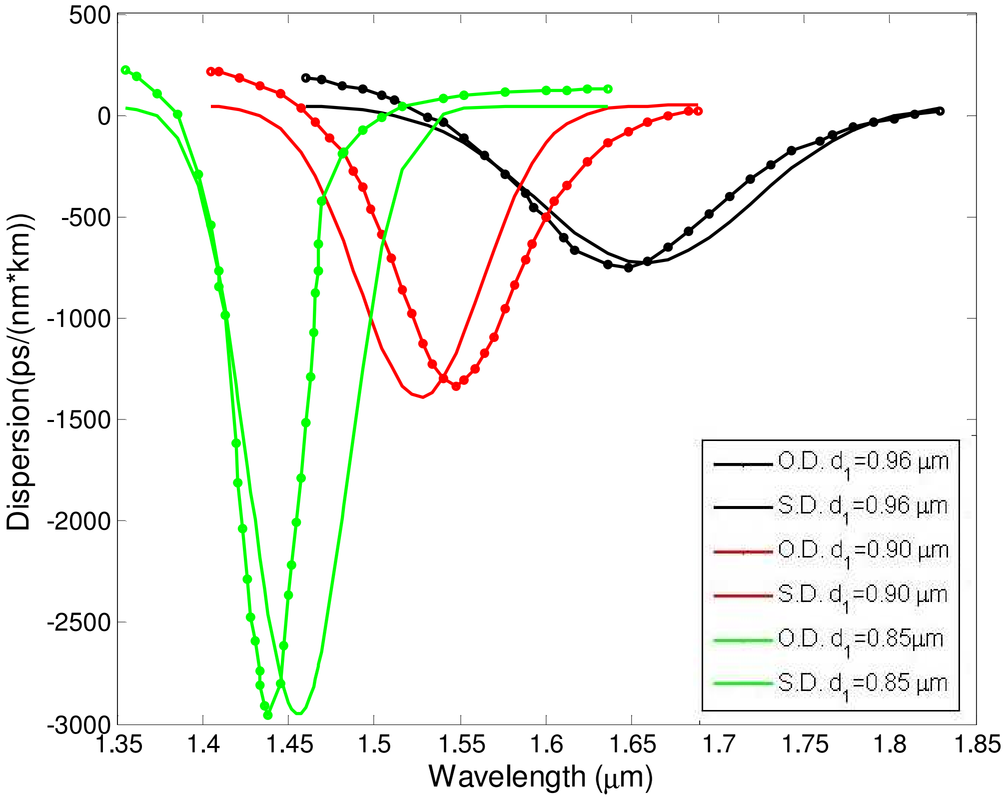

Figure 15: The original data (OD) and simulated data (SD).

4.3 Negative dispersion curves with d_2 variation:

As in the 1st and 2nd part of our theoretical work, table (3) represents (a,b,c&d) values at different values of d_2. (r2) represents correlation factor.

Table 3. Values of Parameters a,b,c and d_2.

Parameter	**d_2= 0.96µm**	**d_2= 0.90µm**	**d_2= 0.85µm**
r^2	0.994472	0.994491	0.998464
a	112.7388334	85.39005931	42.69311251
b	-1392.46070	-1353.71064	-1332.37094
c	1.541169435	1.551278763	1.569081807
d	0.039486036	0.038651960	0.036766659

Figs. (16,17,18&19) denote relation between each parameter and d_2, while Fig.20 represents comparing between (OD) of negative dispersion curves obtained by (FDFD) method and our (SD) by Gaussian function.

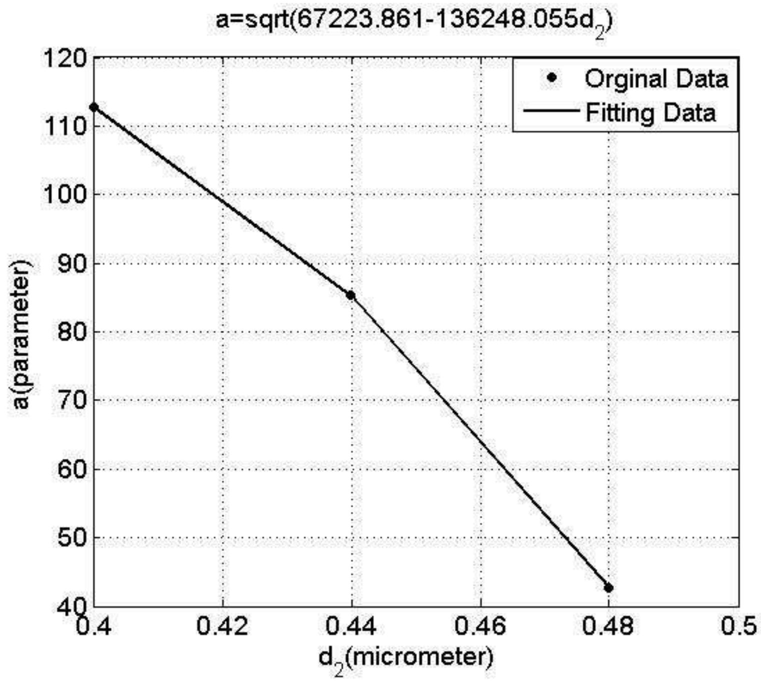

Figure 16: Relation between parameter-a and d_2.

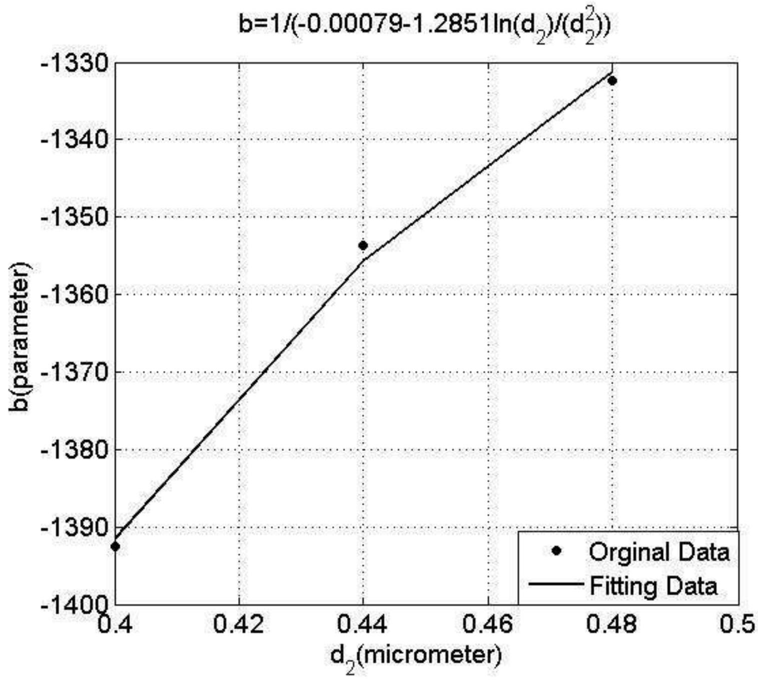

Figure17: Relation between parameter-b and d_2.

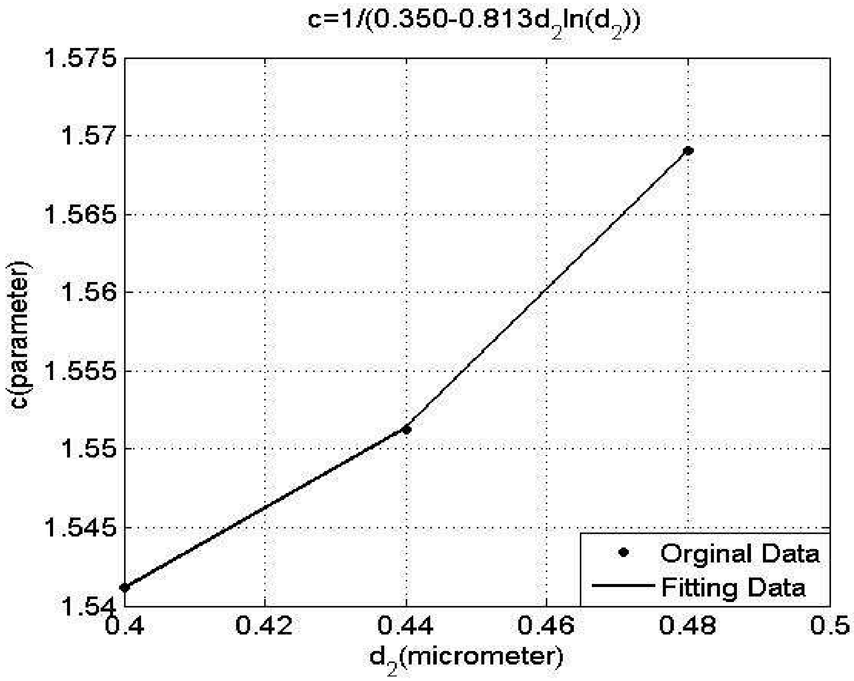

Figure 18: Relation between parameter-c and d_2.

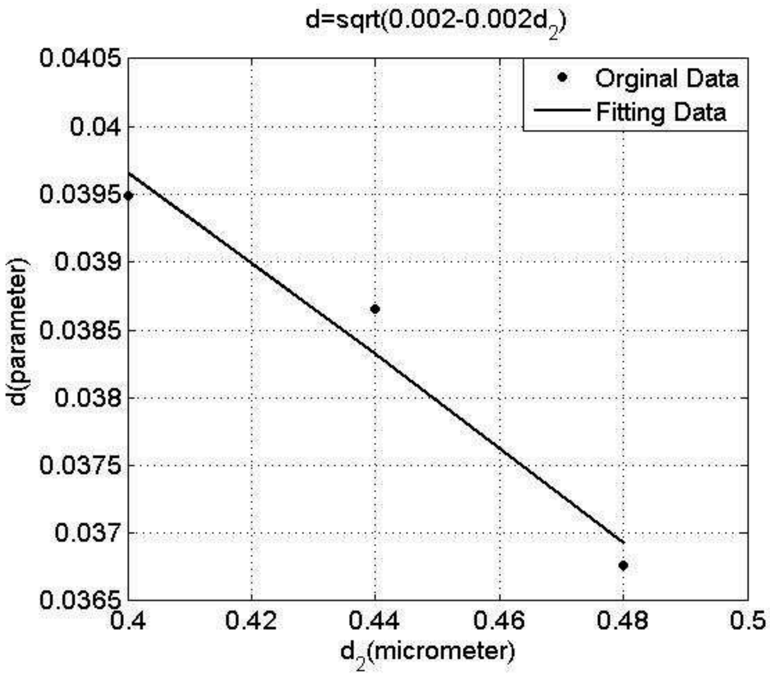

Figure19: represents relation between parameter-d and d_2.

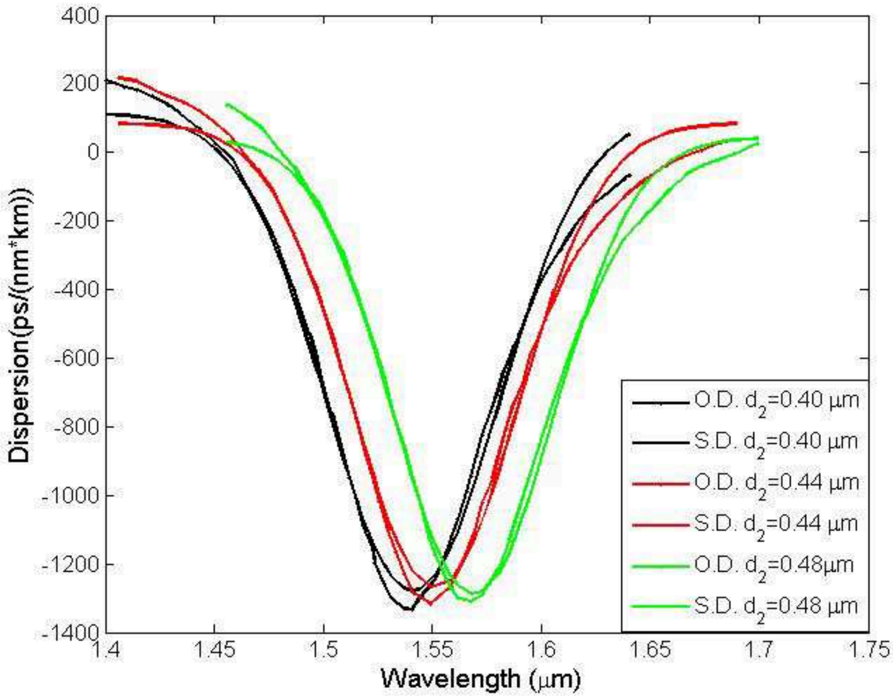

Figure 20: The original data (OD) and simulated data (SD).

5. Conclusions

According to our results, it has been found that Gaussian approximation function has a high matching / fitting ratio with the results of the negative dispersion curves obtained by Finite-Difference frequency--Domain method that was introduced by a previous study for the same type of (PCF) (which has inner and outer-core region with a honey-comb lattice structure in cladding region). In our simulation process, parameters a,b,c and d have been considered as functions of core region parameters (d_{core} , $d_1$and d_2)

By using Gaussian approximation function, correlation factor (r^2) comparing with (FDFD)method is in the range of (0.98-0.99) ,this indicates the accuracy of our mathematical model, so by this suggested sample of simulation, negative dispersion curves in this tpyp of (PCF) can be determined directly in a theoretical way. Other approximation functions can also be depended to estimate the theoretical model but correlation factor will not be the same as far to our knowledge.

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