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A NOVEL DESIGN METHODOLOGY OF MULTICLAD SINGLE MODE OPTICAL FIBER FOR BROADBAND OPTICAL NETWORKS

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Abstract—In this paper two multi-clad RI- and RII-type optical fiber structures for small dispersion and dispersion slope as well as large bandwidth are considered and novel design strategy for this purpose is presented. The suggested design method uses the Differential Evolution (DE) approach. We put absolute value of dispersion factor as fitness function in differential evolution method. This algorithm successfully introduces a special fiber including so small dispersion and dispersion slope in the predefined wavelength duration. Also, the proposed method can set zero dispersion wavelengths with high accuracy compared other traditional methods. The designed dispersion-shifted RI single-mode fiber has the bandwidth of 600 nm and the max amount of 1.36 (ps/km/nm) in that duration which is an ideal result.

1. INTRODUCTION

Optical fiber communication is interesting method for realization of high speed data transmission. Optical fiber is physical media for optical signal propagation and has two basic problems must be considered in data transmission. Optical loss and dispersion are these physical drawbacks of the fiber. Optical amplifiers can be used for compensation of all loss occurred in propagation through fiber. Semiconductor optical amplifiers (SOA), erbium doped fiber amplifiers (EDFA) and Si-Nc EDFA are used for loss compensation. Dispersion in optical fiber limits bit rate of data transmission. For compensation of dispersion there are different methods. Dispersion compensators generally can be used and after a limited fiber length signal can be refreshed. But all of these methods have limited success and finally after some kilometers of fiber length repeaters are required. Dispersion management of fiber optic is important task in modern optical communication especially for multi-wavelength data transmission in wavelength division multiplexing (WDM) or dense wavelength division multiplexing (DWDM). So, suitable refractive index profile of fiber including small dispersion and dispersion slope is requested. Especially dispersion flattened structures for modern multi-wavelength communications highly interested.

For this purpose there are some interesting reported papers, which we are going to review some of them and present their limitations for the proposed purposes.

As a first and interesting work, we can point out to paper presented by Varshney et al. [1]. In this paper an optical flat fiber was presented to minimize dispersion and dispersion slope. In this design, core radius, effective area and carrier wavelength are $1\,\mu$m, $56.1\,\mu m^2$ and $1.55\,\mu$m respectively, which are used and according to their calculation, dispersion duration within [1530–1610] μm and dispersion slope at $1.55\,\mu$m are 2.7–3.4 ps/km.nm and 0.01 ps/km.nm^2 respectively. The presented paper introduces 80 nm bandwidth that is small for today DWDM applications. Also, the reported dispersion is enough high for high-speed data transmission. Finally, the presented work includes only C and L bands for data transmission.

A second work reported by Tian et al. [2] that discuss about increasing of the effective area for RI and RII triple-clad fibers. This paper reported 4.5 ps/km.nm for dispersion within [1540–1620] μm wavelength duration. Also, for this design, dispersion slope reported about 0.006 ps/km.nm within [1540–1620] μm wavelength duration. The proposed design has small bandwidth for DWDM applications and also high dispersion in this duration. The calculated dispersion slope in this paper is not so small for high-speed data transmission.

There are other papers presented to minimize dispersion and shift to requested values [3–6]. In these works dispersion calculation, minimization and shifting were discussed. The obtained results don't satisfactory. Also, in [5] there are very interesting methods presented for dispersion compensation and management.

Also, general information about physical mediums carrying information especially for coaxial and optical fibers including capabilities and limitations can be found in [7, 8].

So, the presented optical fibers don't have very interesting parameters to communicate high performance that satisfy today requested demands.

For fiber design optimization methods using GA [9–13] can be used to find out optimum values for each structure especially as an example for RII triple-clad optical fibers. In this case there are 6 optical and geometrical parameters, which must be determined for optimum operation. In this GA approach 50 initial individuals are considered and with increase of the individuals better situation can be obtained. Detail of GA technique applied to this problem will be discussed in the subsequent sections. For doing this work, one can be used the Transfer Matrix Method (TMM) [14, 15] developed in cylindrical coordinate for evaluation of the modal analysis of the proposed structure. In evaluation of this technique some interesting especial functions are used [16]. In the developed technique, it was proposed some interesting fitness functions to minimize the pulse broadening factor [17] (small dispersion as well as dispersion slope) and maximize the bandwidth (wavelength duration between zeros of the dispersion curve) as well as dispersion be lower than a threshold. Also, in these situations nonlinear effects can limit the propagation performance that discussed something about in [18–31].

Also, different aspects of modal analysis, pulse propagation through nonlinear fiber and design of dispersion compensation in different structures were done [32–46].

Thus in this paper, we try to present a new design methodology based on Differential Evolution (DE) optimization approach. The proposed method illustrates efficient design methodology and so interesting features can be obtained.

Organization of the paper is as follows.

In Section 2 mathematical principles for description of dispersion is presented. In this Section RI- and RII-type optical fibers are studied. Design strategy is discussed in Section 3. Simulation results and discussion is illustrated in Section 4. Finally the paper ends with a short conclusion.

2. MATHEMATICAL FORMULATION

The mathematical background for description of the suggested structures is introduced in this section. The index of refraction profiles of RI- and RII-type fiber structures are shown in Fig. 1. In the proposed structures (RI and RII) the wave vector corresponding to guided waves are divided into two and one regions respectively. These regions are shown in Fig. 1.

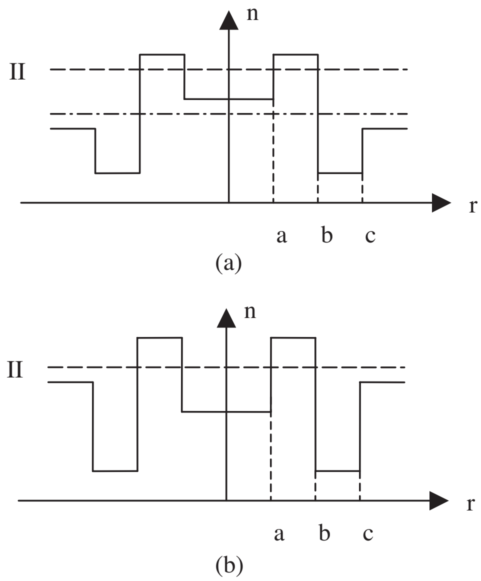

Figure 1. Refractive Index Profiles of RI- and RII-type Single mode triple clad optical fibers, (a) RI, (b) RII.

According to the wave equation for electromagnetic fields the following equation can be expressed.

$$\nabla^2 \begin{pmatrix} \vec{E} \\ \vec{H} \end{pmatrix} + k_0^2 n^2(r) \begin{pmatrix} \vec{E} \\ \vec{H} \end{pmatrix} = 0 \tag{1}$$

Under LP approximation and using the boundary conditions of electromagnetic fields we can obtain the characteristic equations of these fibers as Eq. (2) and Eq. (3).

$$\begin{vmatrix} J_m(k_1 a) & -J_m(k_2 a) & -Y_m(k_2 a) & 0 & 0 & 0 \\ 0 & J_m(k_2 b) & Y_m(k_2 b) & -I_m(\gamma_3 b) & -K_m(\gamma_3 b) & 0 \\ 0 & 0 & 0 & I_m(\gamma_3 c) & K_m(\gamma_3 c) & -K_m(\gamma_4 c) \\ \kappa_1 a J_m'(\kappa_1 a) & -k_2 a J_m'(k_2 a) & -k_2 a Y_m'(k_2 a) & 0 & 0 & 0 \\ 0 & k_2 b J_m'(k_2 b) & k_2 b Y_m'(k_2 b) & -\gamma_3 b I_m'(\gamma_3 b) & -\gamma_3 b K_m'(\gamma_3 b) & 0 \\ 0 & 0 & 0 & \gamma_3 c I_m'(\gamma_3 c) & \gamma_3 c K_m'(\gamma_3 c) & -\gamma_4 c K_m'(\gamma_4 c) \end{vmatrix}$$
$$= 0$$

$$(n_4 < n_e < n_1,\ RI) \tag{2}$$

$$\begin{vmatrix} I_m(\gamma_1 a) & -J_m(\kappa_2 a) & -Y_m(\kappa_2 a) & 0 & 0 & 0 \\ 0 & J_m(\kappa_2 b) & Y_m(\kappa_2 b) & -I_m(\gamma_3 b) & -K_m(\gamma_3 b) & 0 \\ 0 & 0 & 0 & I_m(\gamma_3 c) & K_m(\gamma_3 c) & -K_m(\gamma_4 c) \\ \gamma_1 a I'_m(\gamma_1 a) & -\kappa_2 a J'_m(\kappa_2 a) & -\kappa_2 a Y'_m(\kappa_2 a) & 0 & 0 & 0 \\ 0 & \gamma_2 b J'_m(\kappa_2 b) & \kappa_2 b Y'_m(\kappa_2 b) & -\gamma_3 b I'_m(\gamma_3 b) & -\gamma_3 b K'_m(\gamma_3 b) & 0 \\ 0 & 0 & 0 & \gamma_3 c I'_m(\gamma_3 c) & \gamma_3 c K'_m(\gamma_3 c) & -\gamma_4 c K'_m(\gamma_4 c) \end{vmatrix}$$
$$= 0,$$

$$(n_1 < n_e < n_2, RI), (n_4 < n_e < n_2, RII) \tag{3}$$

where J_m, Y_m, I_m and K_m are Bessel and modified Bessel functions. The parameters used in these relations are given as follow.

$$\gamma_i = \left(\beta^2 - n_i^2 k_0^2\right)^{\frac{1}{2}}, \quad \kappa_i = \left(n_i^2 k_0^2 - \beta^2\right)^{\frac{1}{2}}. \tag{4}$$

In these relations n_i is the refractive index of the ith layer of the RII profile. The optical parameters are defined as

$$P = \frac{b}{c}, \quad Q = \frac{a}{c}, \tag{5}$$

Also geometrical parameters defined as follow.

$$R_1 = \frac{n_1 - n_3}{n_3 - n_2}, \quad R_2 = \frac{n_2 - n_4}{n_3 - n_2}, \quad \Delta = \frac{n_1 - n_4}{n_4}. \tag{6}$$

For RII fibers the normalized frequency is introduced also by:

$$V = k_0 a \sqrt{n_2^2 - n_4^2}, \tag{7}$$

and the normalized propagation constant is defined as follow.

$$B = \frac{\left(\frac{\beta}{k_0}\right)^2 - n_4^2}{n_2^2 - n_4^2}. \tag{8}$$

In the following, in order to calculate the dispersion and dispersion slope in the proposed structures, the total dispersion (D) and the dispersion slope (S), which include waveguide and material dispersion are given in Eq. (9) and Eq. (10), respectively,

$$D = -\frac{\lambda}{c}\frac{d^2 n_4}{d\lambda^2}\left[1 + \Delta\frac{d(VB)}{dV}\right] - \frac{N_4}{c}\frac{\Delta}{\lambda}V\frac{d^2(VB)}{dV^2} \tag{9}$$

$$\begin{aligned} S \;=\; & -\frac{\lambda}{c}\frac{d^3 n_4}{d\lambda^3}\left[1+\Delta\frac{d(VB)}{dV}\right]-\frac{1}{c}\frac{d^2 n_4}{d\lambda^2}\left[1+\Delta\frac{d(VB)}{dV}\right] \\ & +\frac{N_4}{c}\left(\frac{\Delta}{\lambda^2}\right)V^2\frac{d^3(VB)}{dV^3}+2\frac{N_4}{c}\frac{\Delta}{\lambda^2}V\frac{d^2(VB)}{dV^2} \\ & +2\frac{\Delta}{c}\frac{d^2 n_4}{d\lambda^2}V\frac{d^2(VB)}{dV^2}, \end{aligned} \tag{10}$$

where c and $N_4 = d(k_0 n_4)/dk_0$ are speed of light in free space and the group index of outer clad respectively. In simulation results for evaluation of the dispersion characteristics, we assumed $m = 0$ for calculation of determinants appeared in Eq. (2) [3, 4].

It is necessary to gain $d(VB)/dV$, $V[d^2(VB)/dV^2]$ and $V^2[d^3(VB)/dV^3]$ relations to complete the calculation of Eqs. (9) and (10). To achieve these terms basic relations appeared in Eqs. (2), and (3) should be used and results are given in Eqs. (11)–(14) considering Eqs. (7) and (8).

$$U \;=\; a\sqrt{k_0^2 n_2^2-\beta^2} \tag{11}$$

$$\frac{d(VB)}{dV} \;=\; 1+\left(\frac{U}{V}\right)^2\left[1-2\left(\frac{V}{U}\right)\frac{dU}{dV}\right] \tag{12}$$

$$V\frac{d^2(VB)}{dV^2} \;=\; -2\left(\frac{dU}{dV}-\frac{U}{V}\right)^2-2U\frac{d^2U}{dV^2}, \tag{13}$$

$$\begin{aligned} V^2\frac{d^3(VB)}{dV^3} \;=\; & 6\left(\frac{dU}{dV}-\frac{U}{V}\right)-2U_3V\frac{d^3U}{dV^3} \\ & -6V\frac{d^2U}{dV^2}\left(\frac{dU}{dV}-\frac{U}{V}\right). \end{aligned} \tag{14}$$

Another parameter that we pay attention on and should calculate is dispersion length. Dispersion length is the lengths that after passing that the pulse width of the unchriped input pulse broaden to as $\sqrt{2}$ times as input pulse width. This parameter can be calculated by using Eq. (15).

$$L_D = \frac{t_i^2}{|\beta_2|}, \tag{15}$$

where t_i and β_2 are the full wave at half-maximum of intensity distribution at input of the fiber and the group velocity dispersion.

3. DESIGN STRATEGY

As it was mentioned, our goal of optimization is to obtain an especial specification (optical and geometrical parameters) for optical fiber in which the obtained parameters support dispersion and dispersion slope in the possible minimum level in broad wavelength duration. The dispersion and slope are directly related to the structure of the optical fiber such as the diameter and refractive index of different layers in the fiber. We can include all of these specifications in optical (a, P, Q) and geometrical parameters (R_1, R_2, Δ) and just work with them. The optimization technique in this paper is based on Differential Evolution (DE). DE is a successful method to obtain our goals. The obtained results of this method are better than reported results and our obtained results of other methods such as GA (genetic algorithm). Firs we a shortly introduce DE method and then explain our strategy to design purpose fibers.

Differential Evolution (DE) is a stochastic nonlinear optimization algorithm that is introduced by Storn and Price in 1996. In this algorithm a population of solution vectors is successively updated by addition, subtraction, and component swapping, until the population converges, hopefully to the optimum. In this algorithm there isn't any derivation. There are few parameters to been set so it make this algorithm simply to use. In other word, this method is a simple and apparently very reliable method. DE method is started with randomly chosen solution vectors. For each i in (1, ... , NP), form a 'mutant vector'. Mutant vector is a variable vector. NP is the number of population members in other hand the size of population. DE confirmed the mutant vector as bellow:

$$v_i = x_{r1} + F \cdot (x_{r2} - x_{r3}), \tag{16}$$

where $r1$, $r2$ and $r3$ are three mutually distinct randomly drawn indices from (1, ... , NP) and also distinct from i, and $0 < F \leq 2$. the structure of this method is shown in Fig. 2.

Now we have some mutant and initial population that we should select better individuals for next generation. For this purpose we introduce a parameter by the name of crossover (CR), which determined the amount of crossover (amount of changes in next generation in compare of present generation) that we want to happen in the next generation. CR can be selected as a number between [0–1]. We crossover v_i and x_i to form the trial vectors by the name of u_i. For each component of vector, DE draw a random number in U [0, 1], that is called rand$_j$. CR here is like a cut-off parameter. If rand$_j \leq CR$ then DE choose $u_{ij} = v_{ij}$, and in the other case DE choose x_{ij} as u_{ij}.

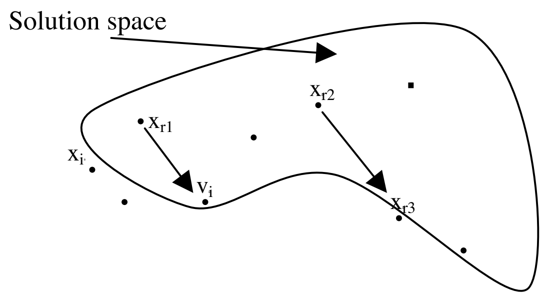

Figure 2. How confirmed the mutant vector.

To ensure at leas some crossover is occurred, one component of u_j is selected a random to be included in v_i. For example, maybe we have

$$\begin{aligned} x_i &= (x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5}) \\ v_i &= (v_{i1}, v_{i2}, v_{i3}, v_{i4}, v_{i5}) \\ u_i &= (v_{i1}, x_{i2}, x_{i3}, x_{i4}, v_{i5}) \end{aligned}$$

The next step is selection. If objective value COST (u_i) is lower than COST (x_i), then u_i replace x_i in the next generation. Otherwise, DE keeps x_i.

We can say that DE is the only algorithm which consistently found the optimal solution and often with fewer evaluations of functions than the other methods. The are some reasons that DE method is a good method. One of this reason is using simple subtraction to generate random direction to produce new generation. The other reason is more variation in population that led to more varied search over solution space. We can also select size and direction of changing next generation by Δ, that is $(x_{r2} - x_{r3})$. DE has some parameters that help us to variation the algorithm as we want. We can use the best vector instead of random in x_{r1}, and also we can use more vectors for more variation instead of single difference, for example $(x_{r2} - x_{r3} + x_{r4} - x_{r5})$.

Now we pay to the strategy of our design. First we introduce a function as cost function that this function is a important factor in optimization. Indeed all the algorithm is optimization of this function that we should select it so that can obtain our goals. In this studying we select absolute dispersion as cost function. The numbers of parameters are six, optical and geometrical parameters, we select the amount of CR as 0.8 to done more crossovers in DE and increasing the space of searching parameters. One important factor in the results of running DE is initial population, that we can select it in to ways. First can be randomly selected or if we the approximate define of the solution, we can use the related parameters as initial population. In the second way we can obtain better results in a shorter time. Here we first randomly change the parameters and put the better results in the initial population.

4. SIMULATION RESULTS

According to the presented formulism and structure in Section 2, in this section the simulated results are illustrated to evaluate usefulness of the introduced idea. In the first step, we optimize the proposed fiber structure using DE algorithm considering sum of absolute dispersion factor in the wavelength duration of [1.5–1.6] um as cost function. Optimized parameters in this case including optical and geometrical using DE method are given in Table 1. By using Eq. (9) and Eq. (10) we can calculate the dispersion and dispersion slope factors illustrated in Fig. 3 and 4. It is shown that dispersion flattened profile can be obtained for both RI- and RII-type fibers. Also, the case is better for RI- than RII-type structures. For dispersion slope the case is same too.

Table 1. The optical and geometrical parameters resulted by running DE in the wavelength range of [1.5–1.6] um.

parameters	RI	RII
a (e-6)	2.5062105	2.6059178
$P = b/c$	0.6460655	0.6837144
$Q = a/c$	0.4083225	0.3729432
$R1$	3.2018295	1.6854434
$R2$	0.8493893	−0.0757139
Δ (e-3)	3.3335338	3.001958

As we see in Fig. 3 the amount of Dispersion for the RII structure, in the range of wavelengths [1.5–1.6] um changes from −1.388 (Ps/km/nm) to 0.064 (Ps/km/nm). Also the maximum amount of dispersion in the RI structure is −0.2058 (Ps/km/nm) in the wavelength of 1.5 um and the amount of dispersion at 1.6 um is −0.02788 (Ps/km/nm). So, we can obtain small dispersion in the whole duration [1.5–1.6] um. Some important features of the dispersion profile are extracted and shown in Table 2. As it is shown in Fig. 3, we have some wavelengths that have zero dispersion which are named these zero dispersion wavelengths. Here, we introduce bandwidth as

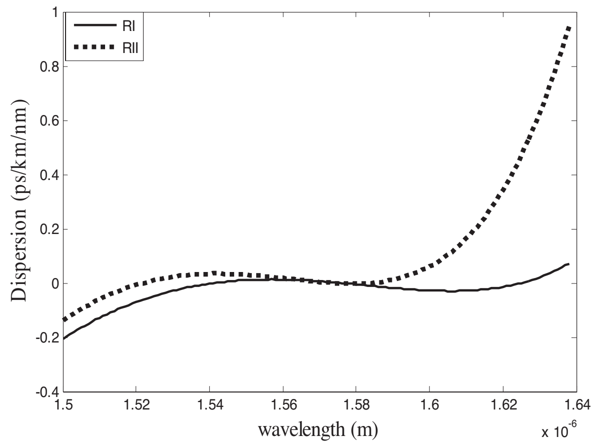

Figure 3. Dispersion vs. wavelength for parameters presented in Table 1.

distance between first and last zero dispersion points.

In Fig. 4 dispersion slope versus wavelength is illustrated for RI- and RII-type fibers. It is shown that for given wavelength duration dispersion slope for RII-type is smaller than RI-type.

Another important parameter in fiber optic which is named dispersion length is shown in Fig. 5 for both introduced fiber structures. It is observed that the dispersion length for RII-type fiber is so larger than the RI-type fiber.

By increasing the wavelength region into [1.3–1.8] um and applying DE algorithm considering results of pervious step as initial population, we obtain optical and geometrical parameters that are shown in Table 3. The calculated dispersion and dispersion slope curves are shown in Fig. 6 and in Fig. 7. The dispersion length factor is shown in Fig. 8 also.

As we see in Fig. 5 the amount of Dispersion for the RI

Table 2. Important specifications of the dispersion curves in Fig. 3.

Type of structure	Number of zero dispersion points	Max amount of dispersion between zeros	Bandwidth (um)
RI	2	0.029	102
RII	3	0.034	82

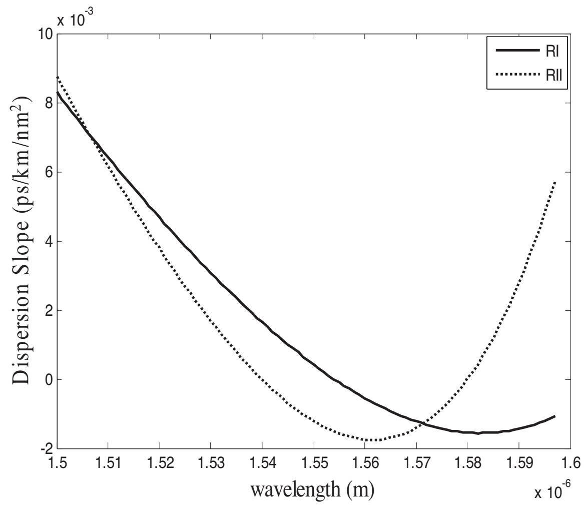

Figure 4. The dispersion slope curves of the resulted parameters in Table 1.

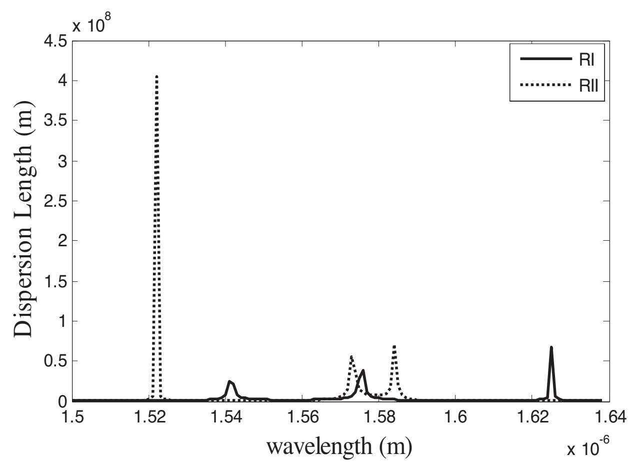

Figure 5. Dispersion length versus the obtained parameter in Table 1.

structure, in the range of wavelengths [1.5–1.6] um changes from −5.821 (Ps/km/nm) to 0.881 (Ps/km/nm) and for RII structure changes from −7.7 (Ps/km/nm) to 3.951 (Ps/km/nm). The important specifications of dispersion curves in Fig. 6 are shown in Table 4. As we see here by increasing the region of optimization we can increase bandwidth instead of increasing the amount of dispersion in that bandwidth. Here for the RI fibers we obtained the bandwidth of

Table 3. The optical and geometrical parameters resulted by running DE in the wavelength range of [1.3–1.8] um.

parameters	RI	RII
a (e-6)	2.7739835	2.2082040
$P = b/c$	0.67912806	0.7697095
$Q = a/c$	0.52502227	0.3734449
$R1$	3.4064929	2.3568334
$R2$	0.9635842	-0.05302923
Δ (e-3)	5.3887532	3.6657646

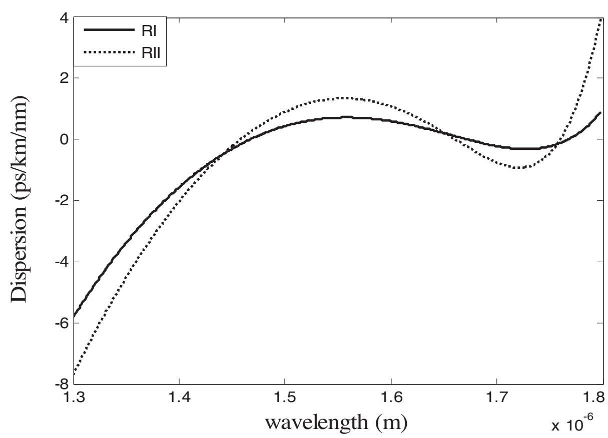

Figure 6. The dispersion curves of the resulted parameters in Table 3.

363 nm with maximum dispersion of 0.7219 (Ps/km/nm), notice that this amount is a very low dispersion for that obtained broad bandwidth, and for the RII fibers we obtained 363 nm bandwidth with maximum dispersion of 1.345 (Ps/km/nm) in that duration. Obtaining zero dispersion slopes in large wavelength duration that is very important factor for optical communication systems and is our main purpose which is illustrated in Fig. 7, especially for RI type fiber.

In another step according to the achieved results of previous steps, we increase the wavelength region of optimization to obtain large bandwidth. In this step, we set the region of optimization to [1.1–2] um, and run the DE algorithm with obtained results of pervious steps as initial population. The output results of DE are shown in

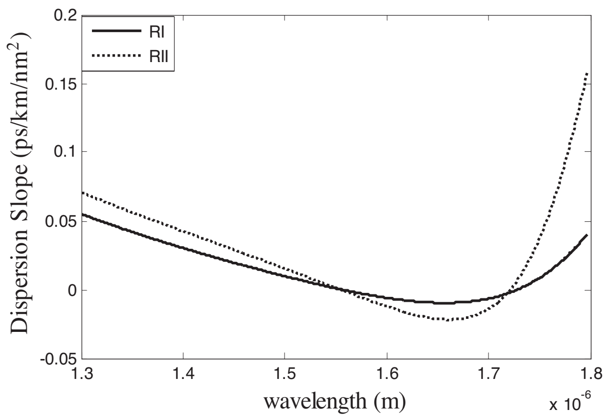

Figure 7. Dispersion slope vs. wavelength for parameters given in Table 3.

Table 5. Also, dispersion length is illustrated in Fig. 8. In this case also, the dispersion length for RI-type is smaller than RII-type case.

The calculated dispersion and dispersion slope with considering the parameters given in Table 5 are shown in Fig. 9 and Fig. 10. As we see in Fig. 9 the dispersion of optimized RI fiber changes from −22.5 (Ps/km/nm) to 4 (Ps/km/nm) in the wavelength duration of [1.1–2] um. The important factors of the illustrated dispersion factor is extracted and shown in Table 6.

Also, dispersion length is illustrated in Fig. 11. The achieved bandwidth in this step (running DE in the wavelengths of [1.1–2 um] with supposed cost function), for the RI fiber is about 600 nm with the maximum dispersion of 1.367 (Ps/km/nm), and for the RII fiber is about 620 nm with the maximum dispersion of 3.293 (Ps/km/nm) in that duration. The dispersion lengths of these fibers are shown in Fig. 11.

Table 4. Important specifications of the dispersion curves in Fig. 6.

Type of structure	Number of zero dispersion points	Max amount of dispersion between zeros	Bandwidth (nm)
RI	3	0.7219	363
RII	3	1.345	363

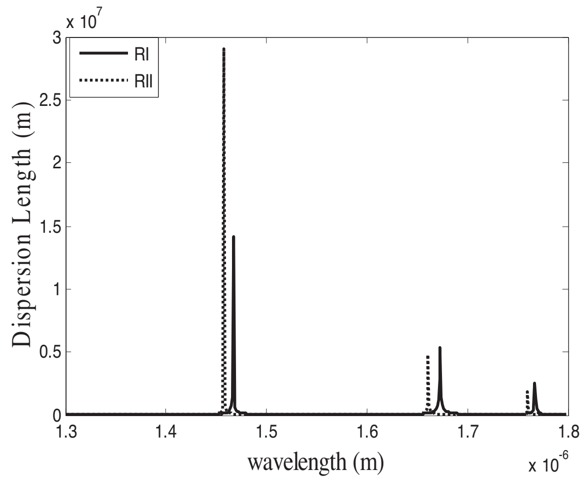

Figure 8. Dispersion length vs. wavelength for parameter given in Table 3.

To compare the difference between DE algorithm and other algorithms such as genetic algorithm, we execute both algorithms in same conditions, (same initial population, same amount of population size, number of population, crossover and extra), and show the resulted dispersion curve in Fig. 12.

As it is observed in Fig. 12, the achieved dispersion curve using DE algorithm is so better than the other achieved from GA. The amount of dispersion for the DE result changes from [−5.821 0.88] (Ps/km/nm) whereas for the DE result changes from [−6.532 15.3] (Ps/km/nm) in

Table 5. The optical and geometrical parameters resulted by running DE in the wavelength range of [1.1–2] um.

parameters	RI	RII
a (e-6)	2.5694698	2.4904958
$P = b/c$	0.7638290	0.8957018
$Q = a/c$	0.5962377	0.3954816
$R1$	3.8535700	1.1701676
$R2$	0.8553986	−0.7135836
Δ (e-3)	8.5923193	8.7786587

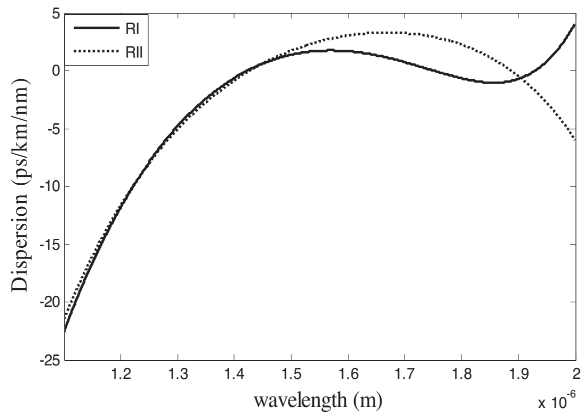

Figure 9. The dispersion curves of the resulted parameters in Table 5.

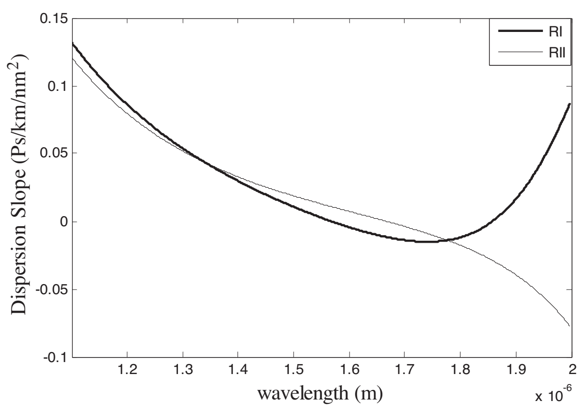

Figure 10. The dispersion slope curves of the resulted parameters in Table 5.

Table 6. Important specifications of the dispersion curves in Fig. 9.

Type of structure	Number of zero dispersion points	Max amount of dispersion between zeros	Bandwidth (um)
RI	3	1.367	601
RII	2	3.293	622

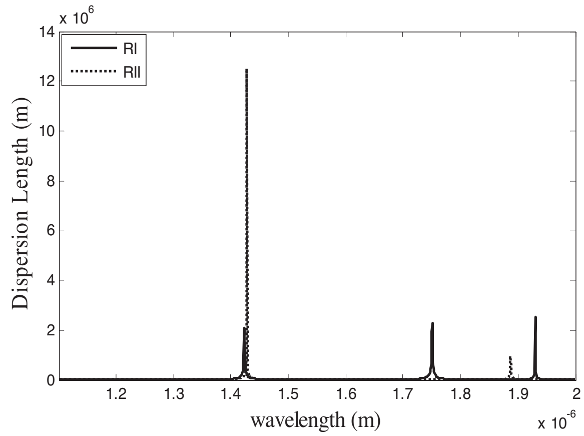

Figure 11. Dispersion length versus the obtained parameter in Table 5.

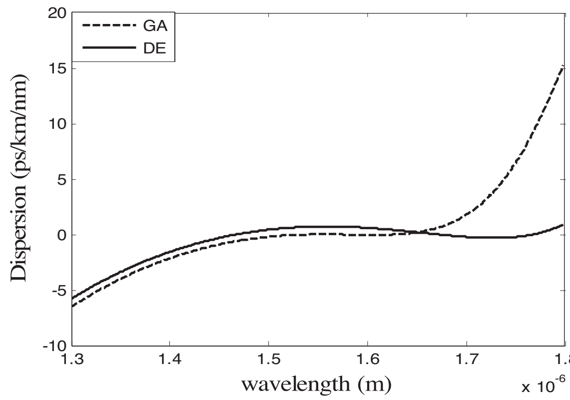

Figure 12. Comparison between dispersion curves resulted by running DE and GA.

the [1.3–1.8 um] wavelength duration. The dispersion curve of the DE is completely flattened in the optimization wavelength duration and the obtained bandwidth is about 360 nm whereas the obtained bandwidth of another one is about 100 nm.

This study provides not only broad band uniform dispersion curve, new type of dispersion-flattened fibers, but also new basic principle for design of desired dispersion curve by selecting the suitable GA and DE. For instance here is a study of obtaining the dispersion shifted fiber. In the dispersion shifted fibers we can set the zero

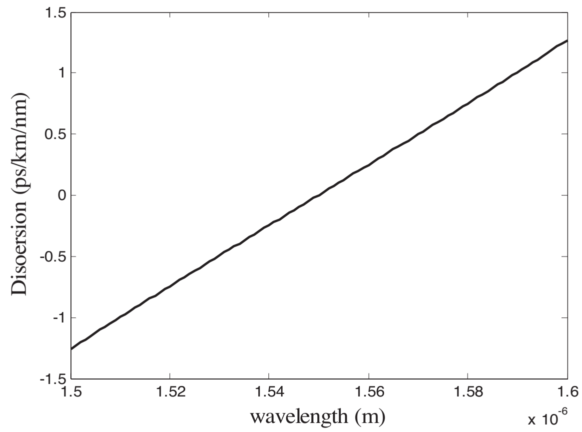

Figure 13. Dispersion length versus the obtained parameter in Table 7.

dispersion point to arbitrary wavelength. To obtain this purpose, we selected absolute dispersion in that wavelength as cost function and run the sufficient DE algorithm. In this simulation we like shift zero dispersion wavelength to 1.55 um which is interesting for optical communication. The output results of DE are given in Table 7, and the related dispersion curve is illustrated in Fig. 13. As we see in Fig. 13 the zero dispersion point is successfully shifted to 1.55 um and also the amounts of dispersion around this wavelength are equal with opposite signs (dispersion in 1.5 um is about -1.25 ps/km/nm and in 1.6 um is about $+1.25$ ps/km/nm).

For compare of other presented methods with DE approach, it is

Table 7. The optical and geometrical parameters resulted by running DE with absolute dispersion at 1.55 um as cost function.

parameters	RI
a, the radius of fist layer	2.6521187e-6
$P = b/c$	0.5640656
$Q = a/c$	0.4686066
$R1$	3.2062703
$R2$	1.3862477
Δ (e-3)	4.8630771

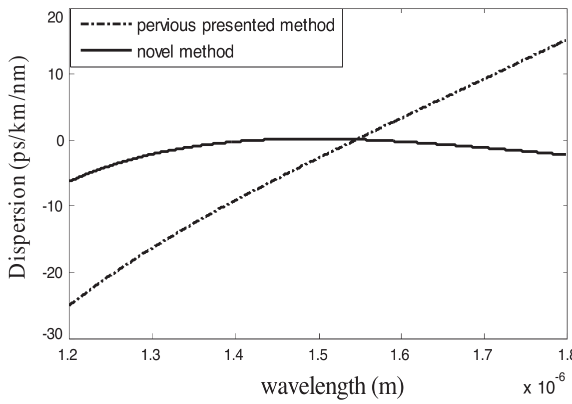

Figure 14. Compare between the dispersion curves of the best pervious method and the novel presented method.

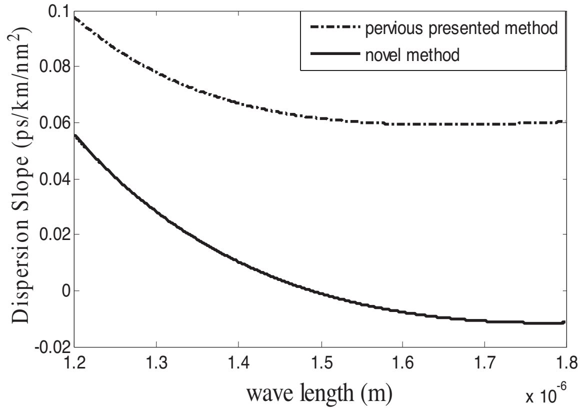

Figure 15. Compare between the dispersion slope curves of the best pervious method and the novel presented method.

necessary to compare the results obtained in this paper with the best reported results given in [8]. In that paper optimization is based on the weighted fitness function that is applied to genetic algorithm and the selected structures are MII type fibers. We do optimization using DE method and illustrate dispersion curve with pervious dispersion curve in Fig. 14.

The reported dispersion values for the pervious method is changed from -25 to 15 (Ps/km/nm), whereas for the novel method presented in this paper is changed from -6 to 0.2 and from 0.2 to -2 (Ps/km/nm), in the wavelength duration of [1.2–1.8] um.

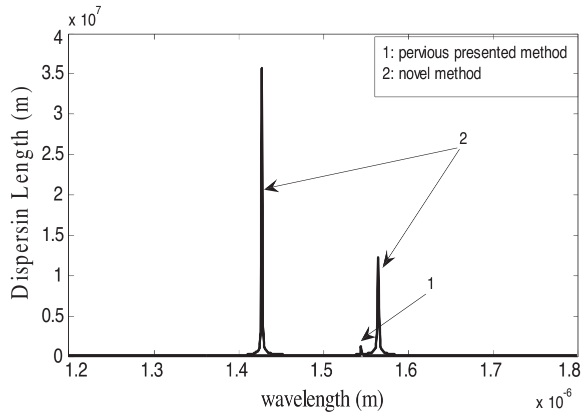

Figure 16. Compare between the dispersion lengths of the best pervious method and the novel presented method.

The dispersion slope for both methods is shown in Fig. 15. As we see, the maximum amount of dispersion slope for the first case is 0.1 (Ps/km/nm^2), whereas for the DE method is about 0.05 (Ps/km/nm^2).

The dispersion length is also calculated and illustrated in Fig. 16. The pervious method predicts one peak in the dispersion length curve and it is about 1270 km, whereas the situation for DE method is different and has two peaks around 35600 km and 12200 km.

In this section different aspects of single mode triple clad optical fiber design has been considered and evaluated. It was shown that the proposed DE method is efficient for fiber design.

5. CONCLUSION

In this paper single mode triple clad optical fiber design for dispersion flattened purpose has been studied. It is shown that DE optimization method is better than GA in this case. Also, we have been shown that 600 nm flat band in these structures can be obtained.

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