Optical design of flattened single mode optical fiber utilizing temperature dependence refractive indices of different materials

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Abstract

In this paper, flattened fibers based on step index single mode optical fiber has been modeled and designated considering the environmental temperature effect on the dispersion behavior of the fiber. The used model depends mainly on the thermal variation of the fiber core and cladding refractive index. Two materials have been used (Alumino-silicate and Vygor glass) as a core or cladding with temperature dependent refractive index over the range (-100 ºC to +100 ºC). The results show that the wavelength of zero total dispersion of the flattened fibers has a deviation of (0.215) nm/ºC.

تصميم بصري لليف بصري مسطح ذي نمط احادي بتغيير معامل الانكسار لمواد مختلفة اعتماداً على درجة الحرارة

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الخلاصة

تم في هذا البحث نمذجة و تصميم الالياف المتسطحة المرتكزة على اساس الليف البصري الخطوي و الاخذ بنظر الاعتبار تأثير درجة حرارة المحيط على سلوك التشتت لليف. يعتمد النموذج المستخدم بالاساس على تغير درجة الحرارة على معامل انكسار كل من القلب و القشرة. تم استخدام مادتين (*Alumino-silicate and Vygor glass*) كقلب وقشرة بمعاملات معتمدة على تغيير درجة الحرارة ضمن المدى (100- الى 100) درجة مئوية. أظهرت النتائج ان الطول الموجي للتشتت الصفري الكلي للالياف المتسطحة ينحرف بمقدار (0.215) نانومتر لكل درجة مئوية.

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1. Introduction

The optical fiber communication is the basic and appropriate alternative for high speed data transmission nowadays. It is apparent that the transmission performances are manipulated and optimized by controlling the optical and geometrical parameters in the fiber structures. As a result, any undesired variation in the fiber structure parameters, can perturb the transference performances. The refractive index variation as function of temperature is an important feature in the optical fibers. This factor determines the temperature characteristics of an optical fiber transmission system. Gosh, et al. [1] studied the temperature dependence of the Sellmeier coefficients which are necessary to optimize the optical design parameters of the optical fiber transmission system. Kovacevic, et al. [2] proposed an analytical expression for describing the thermal variation of the polymer optical fiber and his study covered the temperature range from (-60ºC to 100ºC). El Shirbeeny, et al [3] designated a shifted zero dispersion fiber for temperature dependent Sellmeier coefficients of the core material refractive index only.

In this paper, a design of flattened fiber based on single mode optical fiber considering the temperature dependent for both core and cladding materials for wide range of temperature (-100 ^{o}C to +100 ^{o}C) are modeled and investigated using Evolutionary algorithm optimization.

2. Temperature dependence refractive index

The wavelength-dependent Sellmeier equation for refractive index of the core and cladding materials is of the form [1, 2, and 3].

$$ n = A + \frac{B\lambda^2}{\lambda^2 - C} + \frac{D\lambda^2}{\lambda^2 - E} \quad\text{...} (1) $$

(λ is the wavelength in um, while both *B* and *D* in um^{-2}, *C* and *E* in um^2, *n* and *A* are unitless), where the last term accounts for the decrease in refractive indices due to lattice absorption, the first and second terms represent, respectively, the contribution to refractive indices due to higher energy and lower energy gaps of electronic absorption [3].

The Sellmeier coefficients (A, B, C, D and E) for Alumino-silicate and Vygor glass had been studied as function of temperature over the whole range of wavelength (800-1700 nm) as shown in Table (1) [1].

Table (1): Sellmeier coefficients with temperature effect. (*T* in °C) [1].

Sellmeier coefficient	Material (2) Alumino-silicate	Material (3) Vygor glass
A	$1.41294+24.95380 \times 10^{-6}$	$1.27409+45.70720 \times 10^{-6}$
B	$0.950465-0.11466 \times 10^{-5}$	$0.827657-1.47194 \times 10^{-5}$
C	$0.0132143+12.2470 \times 10^{-7}$	$0.0106179+12.3590 \times 10^{-7}$
D	$0.90443+11.60740 \times 10^{-7}$	$0.93839+12.58560 \times 10^{-7}$
E	100.0	100.0

The refractive index of both materials plays an important effect for choosing the proper one to be a core or cladding material due to the condition $n_{core} > n_{cladding}$.

3. Material dispersion

Material dispersion is caused by variations of refractive index of the fiber material with respect to wavelength. Since the group velocity is function of refractive index, the spectral components of any given signal will travel at different speeds causing deformation of the pulse [4]. The material chromatic dispersion (M_D) can be written through the wavelength and temperature dependence of the core refractive index (n_{co}) as [5]:

$$M_D(\lambda, T) = -\frac{\lambda}{c}\frac{d^2 n_{co}}{d\lambda^2}$$ .... (2)

4. Waveguide dispersion

Waveguide dispersion occurs because different spectral components of pulse travel with different velocities by the fundamental mode of the fiber. It is as a result of axial propagation

constant β being a function of wavelength due to the existence of one or more boundaries in the structure of the fiber. Without such boundaries, the fiber reduces to a homogeneous medium, the fundamental mode becomes a uniform plane-wave, and the waveguide dispersion effect is eliminated. The waveguide dispersion $W_D(\lambda, T)$ can be obtained by using Maxwell's equations for optical fiber [5,6]:

$$W_D(\lambda, T) = -\frac{(n_2 - n_1)}{c\lambda}\left(V\frac{d^2(bV)}{dV^2}\right) \quad\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(3)}$$

Where:

$$V\frac{d^2(bV)}{dV^2} = \frac{2U^2H}{V^2W^2}\left\{[3W^2 - 2H(W^2 - U^2)] + W[W^2 + U^2H]\left[H-1\left[\frac{K_{\ell-1}(W) + K_{\ell+1}(W)}{K_\ell}\right]\right]\right\} \quad\dots\dots \text{(4)}$$

$$H = \frac{K_\ell^2(W)}{K_{\ell-1}(W) + K_{\ell+1}(W)} \quad\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(5)}$$

$$b = \frac{\frac{\beta^2}{K_o^2} - n_2^2}{n_1^2 - n_2^2} \quad\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(6)}$$

$$U = a(K_o^2 n_1^2 - \beta^2)^{\frac{1}{2}}, \quad W = a(\beta^2 - K_o^2 n_2^2)^{\frac{1}{2}} \quad\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(7)}$$

The normalized waveguide parameter V is define as $V = (U^2 + W^2)^{\frac{1}{2}}$

K is the modified Bessel function, β is the propagation constant

The total dispersion parameter, D_T, is expressed as:

$$D_T = M_D + W_D \quad\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(8)}$$

Material and waveguide dispersion act together on the optical fiber pulse, so for some values of wavelengths, the waveguide dispersion being of opposite sign to that of the material dispersion. There exists, therefore, a wavelengths at which the total dispersion will vanish.

5. Minimization Using Evolutionary Algorithm

The evolutionary algorithms [7] are adaptive methods which may be used for optimization problems. It works with a population of individuals, each representing a possible solution to a

given problem. The highly fit individuals are given opportunities to reproduce by cross-over and mutation operation with other individuals in the population. This produces new individuals as offspring, which share some features taken from each parent.

The choice of fitness function is important in the optimization process, because this function is the connection between the physical problem and the optimization technique.

There are many fitness functions for optimization, the most used function is root mean square error [8]. The error between calculated dispersion and target dispersion is calculated using the following equation:

$$ MF = \sum_{i=1}^{N} \frac{\left(DT_i - DT_o\right)^2}{N} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (9)} $$

Where (DT_i , DT_0) are the designing (resulting) total dispersion and the target total dispersion, respectively. (*N*) is the number of wavelengths points through the whole spectrum.

Thus the basic purpose of the minimization is to obtain minimum value for the total merit function (*MF*) that can achieve minimum total dispersion.

6. Results and Discussions

The temperature dependent Sellmeier coefficients have been calculated for both optical fiber glasses materials within operating temperature (-100 to 100 ^{o}C) and wavelength range (1200 to 1700 nm).

The optimum design consists of Alumino-silicate and Vygor glass as core and cladding materials, respectively, with core radius (1.302 μm). Figures (1, 2 and 3) shows the total dispersion with varying core radius at temperatures (-100, 26 and 100 ^{o}C). The results shows that the sensitive effect of the core radius on the total dispersion as moving away from the optimum value. Also, it can be seen that at temperature (26 ^{o}C) the zero dispersion wavelengths occurs at (1361.7 and 1591.5 nm) with maximum total dispersion of (1.033 ps/nm/km) at wavelength (1465 nm).
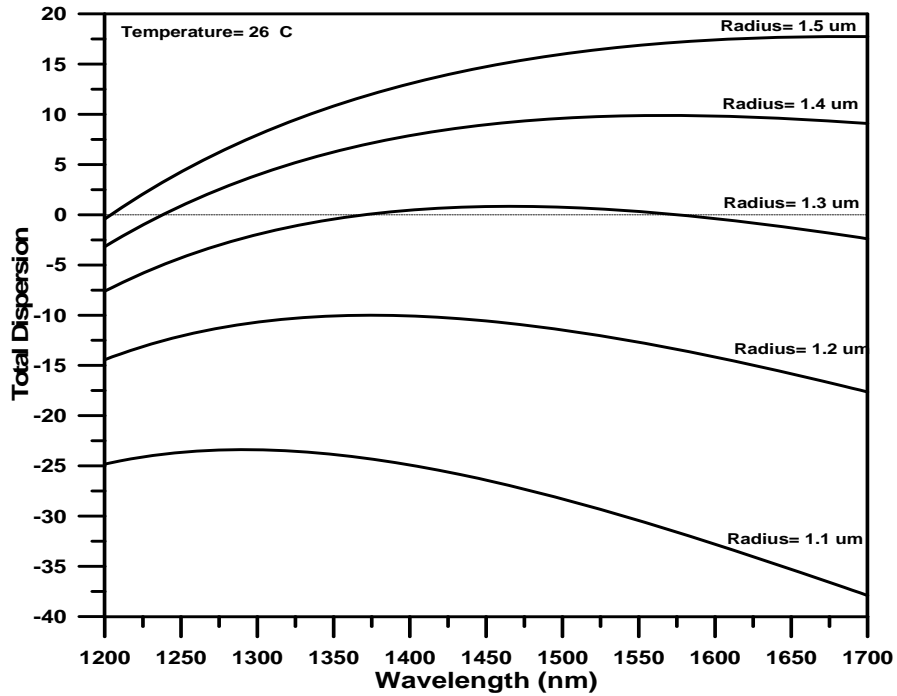
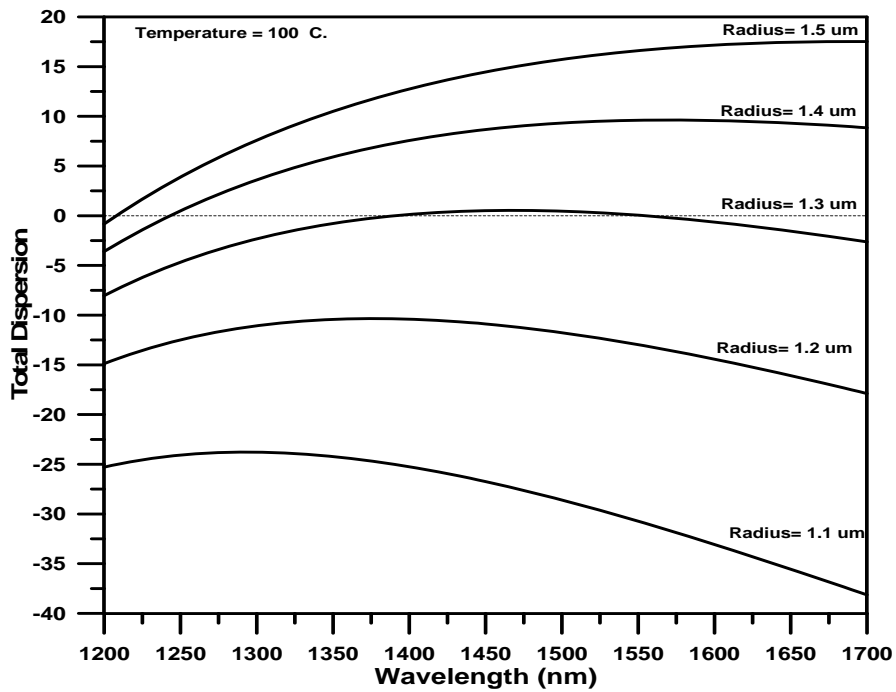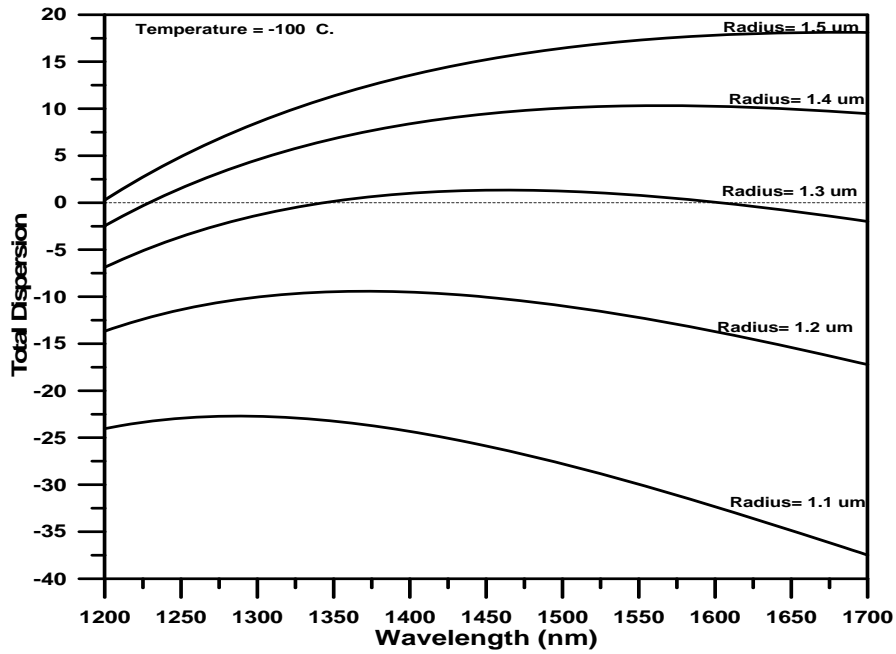**Figure (1): Total Dispersion at room temperature as function of core radius.**

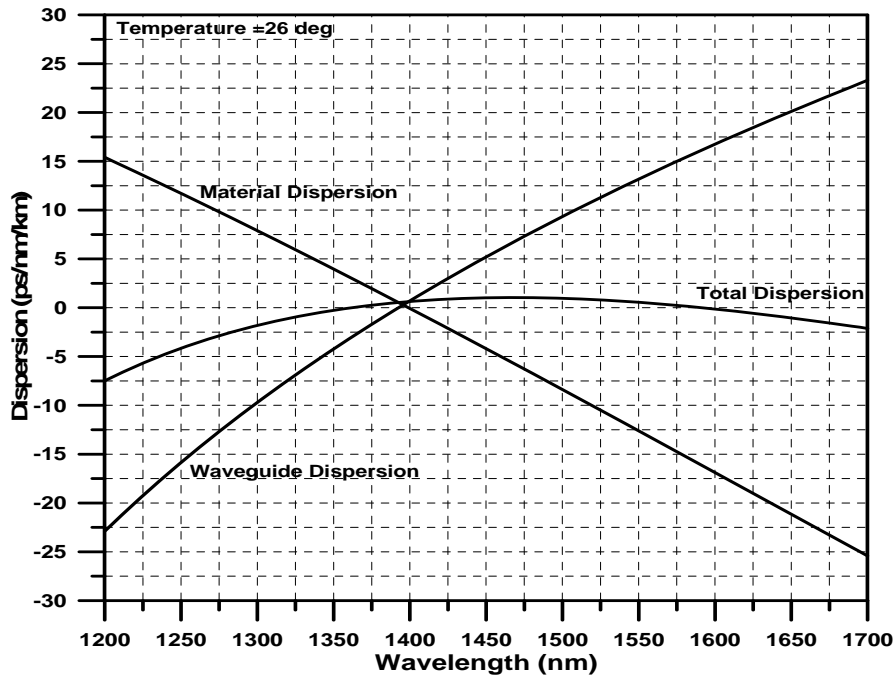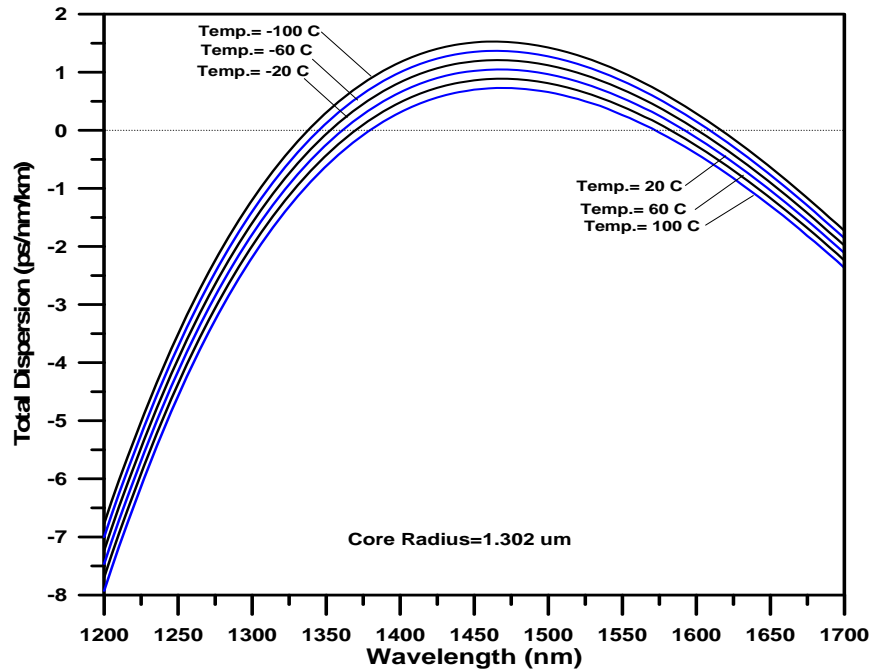**Figure (2): Total Dispersion at temperature (100 °C) as function of core radius.**

Figure (3): Total Dispersion at temperature (-100 ^{o}C) as function of core radius.

Figure (4) shows the material, waveguide and total dispersion for this design, while Figure (5) shows the effect of temperature variation on the total dispersion value. With attention to the Fig.(5), it can be seen that the maximum total dispersion decreased with increasing temperature from (-100 ^{o}C to +100 ^{o}C) by the amount of 0.004 ps/nm/km for every degree of temperature .

Figure (4): The material, waveguide and total dispersion at core radius 1.308 μm

Figure (5): The total dispersion at core radius 1.308 µm for different temperatures.

The zero total dispersion for the flattened fiber occurs at two wavelengths, the first wavelengths increased with increasing temperature, while the second wavelengths decreased as temperature increased. For both cases the change in zero dispersion wavelengths with respect to the change in temperature $d\lambda/dT$ =0.215 nm/^{o}C. The operating width of wavelengths which represents the difference between the two zero total dispersion wavelengths decreased as the temperature increased.

7. Conclusions

The temperature dependence of the total dispersion has been obtained for two materials at various temperatures. It was found that the environmental temperature must be considered for the desired optical fiber design. Both material and waveguide dispersions have been computed, the best design has a core radius of (1.302 μm). The results show that the variation of the zero total dispersion on both sides of the flattened spectrum has a linear proportionality with temperature ($d\lambda/dT$ =0.215 nm/^{o}C) which is considered as large deviation with temperature.

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