Tunable Third Order Dispersion Compensator Using Nonlinearly Chirped Polymer Fiber Bragg Grating

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Abstract We propose a design method for tunable third-order dispersion compensation using nonlinearly chirped polymer fiber Bragg grating (FBG) made in fiber tapers. Simulation provides a very large dispersion tuning range from **-185.5** ps/nm^2 (at strain 0.1% and effective grating length, L_{eff}, of 3 cm) to **-0.62** ps/nm^2 (at strain 1%, L_{eff} = 1 cm).

Keywords: tapered fiber, nonlinearly chirped fiber Bragg grating, polymer optical fiber (POF), polymethylmethacrylate (PMMA), chirped fiber Bragg grating (CFBG), index modulation depth, effective length, and dispersion slope.

1. Introduction

Silica-based optical FBGs are important in optical signal processing, but they have the disadvantage of being difficult to tune. Now, researchers have developed POF Bragg gratings that can fulfill most of the functions of their silica counterparts, plus greater tunability [1].

Glass is relatively stiff material with large Young's modulus and a small thermal expansion coefficient, so that the Bragg wavelength of silica gratings can not be tuned easily by their mechanical or thermal methods.

In the early 1980s, scientists developed PMMA based POFs. These fibers have an attenuation round 150 dB/km; they freeze at temperatues below -20 ^oC and soften at temperatures higher than 120 ^oC. Thus, applications are confined to a protected environment. It has been found that the Young's modulus of POF is about 30 times less than that of silica which translates to a mechanical tunability for polymer-based Bragg gratings that is about 30 times longer than a Bragg grating in silica fibers.

Chirped Bragg gratings play an important role in dispersion compensation [2]. Chirp can be introduced into a grating by using temperature gradient, strain gradient, a refractive index gradient or by varying the period of the grating. One of chirping techniques is based on a cladding tapered fiber. Because the fiber has a non uniform diameter, an applied tension results in a strain gradient and consequently a non-uniform Bragg wavelength along the grating.

In this paper, a nonlinearly chirped (POF) is used in third order dispersion compensation.

2. Operational Principle

2.1 Reflectivity of polymer FBG

We now introduce the analysis of Bragg gratings fabricated in etched fibers [2]. Consider a uniform grating in an optical fiber of radius r. If the fiber is subjected to a tension, F, a change $\Delta\lambda_B$ (z) in the Bragg wavelength, λ_{Bo}, is obtained according to [3]

$$\frac{\Delta\lambda_B(z)}{\lambda_{Bo}} = (1-\mathrm{P}_e)\frac{F}{\pi E r^2} \quad , \qquad (1)$$

where E is Young's modulus of the polymer material (~3.1×10^9 for PMMA), P_e is the effective photoelastic constant of the fiber (~ 0.04 for PMMA).

If the grating is written in a fiber with non uniform diameter, different parts of the grating will have different Bragg wavelengths. The chirp function *f(z/L)* and fiber profile radius *r(z)* are related as to each other as follows [3]:

$$r(z) = \frac{r(0)r(L)}{[(r(0)^2 - r(L)^2)f(z/L) + r(L)^2]^{0.5}} ,(2)$$

where r(0), r(z) and r(L) are, respectively, the fiber core radius at z = 0.0 , z and L, with L the grating length.

If f(z/L) =z/L, this produces a linear chirp, represented by

$$\lambda_B(z/L) = \lambda_B(0) + \Delta\lambda_B(z/L), \quad (3)$$

where $\Delta\lambda_B$ is the total chirp of the Bragg wavelength and $\lambda_B(0)$ is its value at z = 0.0.

Then, the Bragg wavelength distribution of this chirped grating is λ_B (z), given by

$$\lambda_B(z) = \lambda_B(o) + \Delta\lambda_B f(z). \quad (4)$$

To simulate the output reflectivity of a CFBG, one considers the scattering method [2]. Suppose an arbitrary grating is divided into N short sections in which the grating is assumed to be uniform. Each section is considered to be a two–port network characterized by a length L_i, an index n_i, a period Λ_i and a coupling coefficient k_i. This can be described by the transmission matrix T^i which can be defined as [2]

$$\begin{bmatrix} b_i^{(2)} \\ a_i^{(2)} \end{bmatrix} = \begin{pmatrix} T_{11}{}^i & T_{12}{}^i \\ T_{21}{}^i & T_{22}{}^i \end{pmatrix} \begin{bmatrix} a_i^{(1)} \\ b_i^{(1)} \end{bmatrix}, \quad (5)$$

where $a_i^{(1)}$ and $b_i^{(1)}$ are, respectively, the input signal and output signal at port (1) and $a_i^{(2)}$ and $b_i^{(2)}$ are the corresponding signals at port (2).

The transmission matrix of the whole system is then

$$T = \prod_{i=1}^{N} T^i = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}, \quad (6)$$

where:

$$T_{11}{}^i = S_{21}{}^i - S_{22}{}^i S_{11}{}^i / S_{12}{}^i; \quad (7\text{-a})$$

$$T_{12}{}^i = S_{22}{}^i / S_{12}{}^i; \quad (7\text{-b})$$

$$T_{21}{}^i = -S_{11}{}^i / S_{12}{}^i; \quad (7\text{-c})$$

and

$$T_{22}{}^i = 1/S_{12}^i, \quad (7\text{-d})$$

where S_{kk} is the reflection coefficient at port K and S_{kl} the transmitted signals between ports K and L. These coefficients are defined as [2]:

$$S_{11} = S_{22} = k\frac{\exp(-\mu l) - \exp(\mu l)}{(\mu - j\Delta\beta)\exp(-\mu l) + (\mu + j\Delta\beta)\exp(\mu l)}, \quad (8\text{-a})$$

and

$$S_{12} = S_{21} = k\frac{(2\mu)}{(\mu - j\Delta\beta)\exp(-\mu l) + (\mu + j\Delta\beta)\exp(\mu l)}. \quad (8\text{-b})$$

where:

$$\mu^2 = |k|^2 - \Delta\beta^2, \quad (8\text{-c})$$

$$\Delta\beta = \beta - \frac{\pi}{\Lambda}, \quad (8\text{-d})$$

$$k = j\frac{\pi\Delta n}{\lambda_B}, \quad (8\text{-e})$$

$$\beta = \frac{2n_o\pi}{\lambda}, \quad (8\text{-f})$$

and

$$\lambda_B = 2n_{eff}\Lambda. \quad (8\text{-g})$$

where $\Delta\beta$ is the detuning parameter, k is the local coupling coefficient, Δn is the index modulation depth and l is length of each section.

Once the matrix T is determined, the reflection coefficient (ρ) can be obtained using [2]

$$\rho(\lambda) = \frac{-T_{21}}{T_{22}}. \quad (9)$$

Consequently, the reflectivity, R, can be obtained from the definition

$$R(\lambda) = |\rho|^2. \quad (10)$$

The refractive index of the core of the Bragg is given by [4]

$$n = n_o[1 + \Delta n(z)\cos\{\frac{2\pi}{\Lambda}z + \Phi(z)\}], \quad (11)$$

where Λ is the design period of the Bragg , $\Phi(z)$ is a slowly varying function of z that represents the chirp parameter, n_o is the average refractive index of the core, and $\Delta n(z)$ is the index modulation depth along the grating which is related to the apodization profile, h (z), by [5]

$$\Delta n(z) = \Delta n\ h(z). \quad (12)$$

In the present work, the apodization profiles used is the raised sine, given by [5]

$$h(z) = \sin^2(\frac{\pi z}{L}); \quad 0 \le z \le L , \quad (13)$$

2.2 Apodization parameter

The use of non constant value of Δn (apodized profile) implies a decrease in $\Delta n(z)$ at the grating ends that involves a reduction of the grating effective length. In order to maintain the bandwidth, it is necessary to increase the needed grating length by a factor $1/a_{eff}$,where [4]

$$a_{eff} = \frac{1}{k_o L}\int_0^L k(z)dz, \quad (14)$$

with

$$k_o = \pi \Delta n / \lambda_B , \qquad (15)$$

2. 3 Third order dispersion compensation

The CFBG bandwidth is assumed to be

$$\lambda_s \le \lambda \le \lambda_L \qquad (16)$$

where λ_s is the shortest wavelength (at the beginning of the grating) and λ_L is the longest wavelength (at the end of the grating).

The group delay of the optical fiber $\tau(\lambda)$ is expanded as a Taylor series around λ_o as [6]

$$D_1(\lambda) = \tau(\lambda) = \frac{1}{2}\tau^{(2)}(\lambda_o)(\lambda - \lambda_o)^2 , \qquad (17)$$

where, λ_o is the zero dispersion wavelength and $\tau^{(2)}(\lambda_o)$ is constant for the typical optical fiber.

The group delay of a typical 100 km dispersion shifted fiber (DSF) is shown in Fig.1 [7].

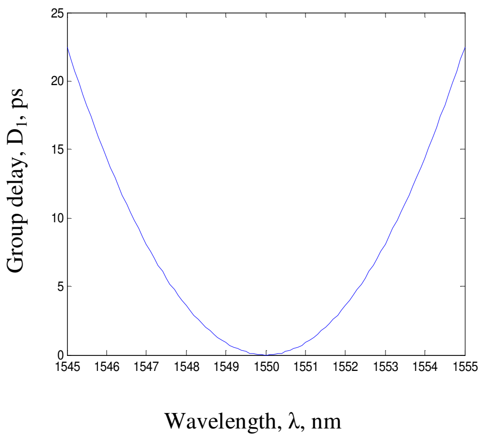

Fig.1 Group delay of a typical 100 km dispersion shifted optical fiber (DCF).

Differentiating (17) with respect to λ gives the chromatic dispersion; second order, D_2 and third order (dispersion slope), D_3 as:

$$D_2(\lambda) = \frac{dD_1}{d\lambda} = \tau^{(2)}(\lambda_o)(\lambda - \lambda_o) , \qquad (18)$$

and

$$D_3(\lambda) = \frac{dD_2}{d\lambda} = \tau^{(2)}(\lambda_o). \qquad (19)$$

Therefore, FBG dispersion, and dispersion slope must be

$$D_{2FG}(\lambda) = -D_2(\lambda)L_F = -\tau^{(2)}(\lambda_o)(\lambda - \lambda_o)L_F , \qquad (20)$$

and

$$D_{3FG}(\lambda) = -D_3(\lambda)L_F = -\tau^{(2)}(\lambda_o)L_F , \; , \qquad (21)$$

where L_F is the length of typical fiber to be compensated.

2.3.1 Case of $\lambda_o < \lambda_s$

Which means that λ_o is shorter than the bandwidth of the FBG. The dispersion of the optical fiber is positive. So, the dispersion of the FBG is needed to be negative.

The chirped POF couples with light on the longer wavelength side and the group delay of the Bragg is given by

$$\tau(\lambda) = D_1(\lambda) = \frac{2 n_{eff} a_{eff}}{c}(L - z) , \qquad (22)$$

where, n_{eff} is the effective value of the refractive index of PMMA(~1.48), c is the velocity of light in free space, z is distance from the shorter wavelength side.

The wavelength as a function of distance z is given by [6]

$$\lambda_B(z) = \lambda_o + \sqrt{\left[(\lambda_L - \lambda_o)^2 - \left[(\lambda_L - \lambda_o)^2 - (\lambda_s - \lambda_o)^2 \right](1 - \frac{z}{L}) \right]} . \qquad (23)$$

Then

$$(1 - \frac{z}{L}) = -\frac{(\lambda_B(z) - \lambda_o)^2 - (\lambda_L - \lambda_o)^2}{(\lambda_L - \lambda_o)^2 - (\lambda_s - \lambda_o)^2} . \qquad (24)$$

Then, one can express the group delay as

$$\tau(\lambda) = -\frac{2 n_{eff} L_{eff}}{c} \frac{(\lambda_B(z) - \lambda_o)^2 - (\lambda_L - \lambda_o)^2}{(\lambda_L - \lambda_o)^2 - (\lambda_s - \lambda_o)^2} . \qquad (25)$$

Therefore, the grating and dispersion slope can be expressed as

$$D_{2FG}(\lambda) = -\frac{4 n_{eff} L_{eff} (\lambda_B(z) - \lambda_o)}{c[(\lambda_L - \lambda_o)^2 - (\lambda_s - \lambda_o)^2]} , \qquad (26)$$

and

$$D_{3FG}(\lambda) = -\frac{4n_{eff}L_{eff}}{c[(\lambda_L - \lambda_o)^2 - (\lambda_s - \lambda_o)^2]}. \qquad (27)$$

2.3.2 Case of $\lambda_o > \lambda_L$

Which means that λ_o is longer than the bandwidth of the FBG. The dispersion of the optical fiber is negative and dispersion of the FBG is positive. The chirped POF couples with light on the shorter wavelength side and the group delay of the Bragg is given by:

$$\tau(\lambda) = D_{1FG}(\lambda) = \frac{2n_{eff}a_{eff}}{c}(z). \qquad (28)$$

The Bragg wavelength as a function of distance z is given by [6]

$$\lambda_B(z) = \lambda_o - \sqrt{\left[(\lambda_s - \lambda_o)^2 - \left[(\lambda_s - \lambda_o)^2 - (\lambda_L - \lambda_o)^2\right](\frac{z}{L})\right]}, \qquad (29)$$

Then

$$\frac{z}{L} = -\frac{(\lambda_B(z) - \lambda_o)^2 - (\lambda_s - \lambda_o)^2}{(\lambda_s - \lambda_o)^2 - (\lambda_L - \lambda_o)^2}. \qquad (30)$$

Therefore, the group delay can be expressed as

$$\tau(\lambda) = -\frac{2n_{eff}L_{eff}}{c}\frac{(\lambda_B(z) - \lambda_o)^2 - (\lambda_s - \lambda_o)^2}{(\lambda_s - \lambda_o)^2 - (\lambda_L - \lambda_o)^2}, \qquad (31)$$

And the grating dispersion and dispersion slope, respectively, as

$$D_{2FG}(\lambda) = -\frac{4n_{eff}L_{eff}}{c}\frac{(\lambda_B(z) - \lambda_o)}{(\lambda_s - \lambda_o)^2 - (\lambda_L - \lambda_o)^2}, \qquad (32)$$

and

$$D_{3FG}(\lambda) = -\frac{4n_{eff}L_{eff}}{c[(\lambda_s - \lambda_o)^2 - (\lambda_L - \lambda_o)^2]}. \qquad (33)$$

2.3.3 Case of $\lambda_s < \lambda_o < \lambda_L$

When $\lambda_s < \lambda_o < \lambda_l$, λ_o included in the operation bandwidth. As $D_{2FG}(\lambda) < 0$ for $\lambda > \lambda_o$ and $D_{2FG}(\lambda) > 0$ for $\lambda < \lambda_o$, $D_{2FG}(\lambda)$ can be separated into two or three functions which can be realized by two or three gratings:

i) when $D_{2FG1}(\lambda) < 0$, grating 1 couples light on the longer wavelength side. Hence

$$\lambda_B(z) = \lambda_{Bo} + \sqrt{\left[(\lambda_L - \lambda_{Bo})^2 - \left[(\lambda_L - \lambda_{Bo})^2 - (\lambda_s - \lambda_{Bo})^2\right](1 - \frac{z}{L})\right]}, \qquad (34)$$

where, λ_{Bo} is the Bragg wavelength of the uniform Bragg grating (=1550 nm in all previous cases).

Now

$$\tau(\lambda) = -\frac{2n_{eff}L_{eff}}{c}\left[\frac{(\lambda_B(z) - \lambda_{Bo})^2 - (\lambda_L - \lambda_{Bo})^2}{(\lambda_L - \lambda_{Bo})^2 - (\lambda_s - \lambda_{Bo})^2}\right], \qquad (35)$$

$$D_{2FG}(\lambda) = -\frac{4n_{eff}L_{eff}}{c}\left[\frac{(\lambda_B(z) - \lambda_{Bo})}{(\lambda_L - \lambda_{Bo})^2 - (\lambda_s - \lambda_{Bo})^2}\right], \qquad (36)$$

$$D_{3FG}(\lambda) = -\frac{4n_{eff}L_{eff}}{c[(\lambda_L - \lambda_{Bo})^2 - (\lambda_s - \lambda_{Bo})^2]} \qquad (37)$$

As $D_{2FG1}(\lambda) > 0$, the second grating couples light on the shorter wavelength side. The wavelength as a function of distance z is given by [6]

$$\lambda_B(z) = \lambda_s + (\lambda_L - \lambda_s)[1 - \sqrt{(1 - \frac{z}{L})}]. \qquad (38)$$

Hence

$$\tau(\lambda) = \frac{2n_{eff}L_{eff}}{c}[1 - (1 - \frac{\lambda_B(z) - \lambda_s}{\lambda_L - \lambda_s})^2], \qquad (39)$$

$$D_{2FG}(\lambda) = \frac{4n_{eff}L_{eff}}{c}[(1 - \frac{\lambda_B(z) - \lambda_s}{\lambda_L - \lambda_s})(\frac{1}{\lambda_L - \lambda_s})], \qquad (40)$$

and

$$D_{3FG}(\lambda) = -\frac{4n_{eff}L_{eff}}{c(\lambda_L - \lambda_s)^2}. \qquad (41)$$

The third grating has linear chirp. If the third FBG has positive dispersion ($D_{2FG3}>0$), then it couples light on the shorter wavelength side, and $\lambda_B(z)$ can be expressed as

$$\lambda_B(z) = \lambda_s + (\lambda_L - \lambda_s)\frac{z}{L}. \qquad (42)$$

Therefore

$$\tau(\lambda) = \frac{2n_{eff} L_{eff}}{c} [\frac{\lambda_B(z) - \lambda_s}{(\lambda_L - \lambda_s)}], \quad (43)$$

$$D_{2FG}(\lambda) = \frac{4n_{eff} L_{eff}}{c(\lambda_L - \lambda_s)}, \quad (44)$$

$$D_{3FG}(\lambda) = 0. \quad (45)$$

But, if the third FBG has negative dispersion (D_{2FG3}<0), then it couples light on the longer wavelength side, and Bragg wavelength is given by

$$\lambda_B(z) = \lambda_s + (\lambda_L - \lambda_s)(1 - \frac{z}{L}). \quad (46)$$

Therefore

$$\tau(\lambda) = \frac{2n_{eff} L_{eff}}{c} [1 - \frac{\lambda_B(z) - \lambda_s}{(\lambda_L - \lambda_s)}], \quad (47)$$

$$D_{2FG}(\lambda) = -\frac{4n_{eff} L_{eff}}{c(\lambda_L - \lambda_s)}, \quad (48)$$

and

$$D_{3FG}(\lambda) = 0. \quad (49)$$

2.4 Radius Profile

For the Bragg wavelength of (23) and (34), and by considering $\lambda_o = \lambda_{Bo}$, one can deduce the radius profile as

$$r(z) = \frac{r(L)r(o)}{\sqrt[4]{r(o)^4 - [(r(o)^4 - r(L)^4](1 - z/L)}}. \quad (50)$$

Similarly, for the Bragg wavelength of (29), (38), (42) and (46), the radius profile will, respectively, be

$$r(z) = \frac{r(L)r(o)}{\sqrt[4]{r(L)^4 - [(r(L)^4 - r(o)^4](z)}}, \quad (51)$$

$$r(z) = \frac{r(o)r(L)}{\sqrt{([r(o)^2 - r(L)^2][1 - \sqrt{1 - (z/L)}] + r(L)^2)}}, \quad (52)$$

$$r(z) = \frac{r(o)r(L)}{\sqrt{([r(o)^2 - r(L)^2][z/L] + r(L)^2)}}. \quad (53)$$

and

$$r(z) = \frac{r(o)r(L)}{\sqrt{([r(L)^2 - r(o)^2][1 - z/L] + r(o)^2)}}. \quad (54)$$

3. Results and Discussion

The described method is modeled through MATLAB to study the effect of different parameters on the grating reflectivity and fiber dispersion. In our work r(0) = 62.5 µm, and r(L) = 50 µm. The obtained results are discussed in the following sections.

3.1 Apodization parameter

The raised sine apodization profile is used. The apodization parameter a_{eff} is calculated for each needed profile radius and results are stated in Tables 1-3.

Strain %	a_{eff}
0.1	0.4994
0.2	0.4987
0.3	0.4981
0.4	0.4975
0.5	0.4969
0.6	0.4963
0.7	0.4956
0.8	0.4950
0.9	0.4944
1	0.4938

Table 1 Apodization parameter when profile radius in (50) or (51) is used.

Strain %	a_{eff}
0.1	0.4994
0.2	0.4989
0.3	0.4983
0.4	0.4978
0.5	0.4972
0.6	0.4966
0.7	0.4961
0.8	0.4955
0.9	0.4950
1	0.4944

Table 2 Apodization parameter when profile radius in (52) is used.

Strain %	a_{eff}
0.1	0.4994
0.2	0.4988
0.3	0.4982
0.4	0.4976
0.5	0.4969
0.6	0.4963
0.7	0.4957
0.8	0.4951
0.9	0.4945
1	0.4939

Table 3 Apodization parameter when profile radius in (53) or (54) is used.

3.2 Maximum reflectivity amplitude

3.2.1 Effect of grating strength

Consider for the uniform Bragg $\Delta L = L$, $\lambda = \lambda_B$. So, $\Delta\beta = 0$ and $\mu = k$ and one can conclude that, the maximum reflectivity, R_M, is

$$R_M = \tanh^2(\mu L) = \tanh^2(kL)\,. \qquad (55)$$

The maximum reflectivity versus the grating strength, kL, is shown in Fig.2.

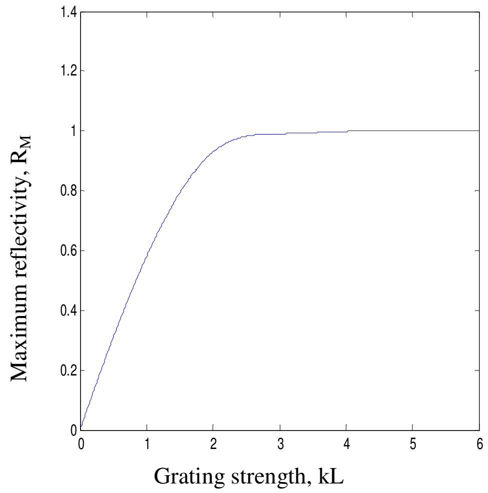

Fig.2 Maximum reflectivity versus grating strength, kL..

3.2.2 Effect of strain

Now, consider L=2 cm, $\Delta n = 2\times10^{-4}$, and λ_o=1550 nm with the raised sine profile. In the case of $\lambda_o < \lambda_s$, Fig. 3 shows the decrease of maximum reflectivity with the applied strain.

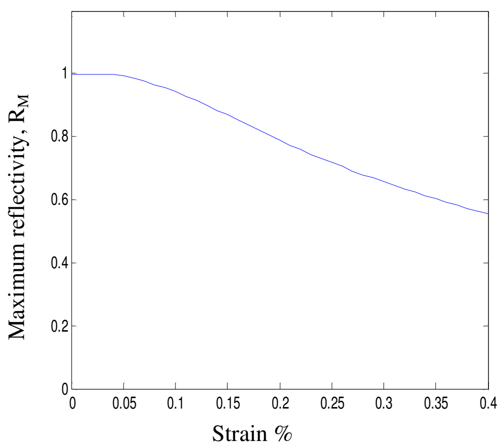

Fig. 3 Maximum reflectivity versus applied strain.

3.2.3 Effect of the grating length

Now we use $\Delta n = 6\times10^{-4}$, and the case $\lambda_o < \lambda_s$. The length of chirped APOF is changed, and the effect is studied for different values of strain. As in Fig. 4, at the same length, the maximum reflectivity decreases with strain because of the increase in the reflection band, (λ_L-λ_s) with the strain. At the same strain, the maximum reflectivity increases with grating length because the area under k(z) profile increases (and the integral of k(z) increases).

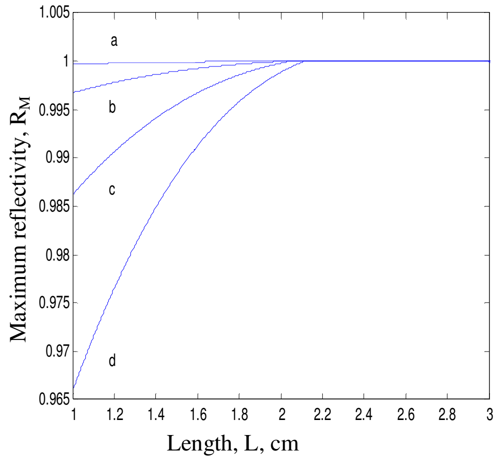

Fig. 4 Maximum reflectivity versus length under different strain values: (a) 0.1%; (b) 0.2%; (c) 0.3%; (d) 0.4%.

3.2.4 Effect of index modulation depth

Now, we use L = 4 cm, and the case $\lambda_o < \lambda_s$. Index modulation depth, Δn, of a chirped APOF is changed, and the effect is studied at different values of strain. As in Fig. 5, at the same value of Δn, the maximum reflectivity decreases with the strain as the reflection band, (λ_L-λ_s) increases with the strain. At the same strain, the maximum reflectivity increases with Δn because the area under k(z) profile increases.

3.2.5 Effect of L and Δn simultaneously

To have maximum reflectivity greater than 99 %, Fig. 6 shows the minimum value needed of the index modulation depth, Δn_{min} for each value of length, L. To have maximum reflectivity greater than 99 %, Fig. 7 shows the minimum value needed of length, L_{min} for each value of used index modulation depth, Δn.

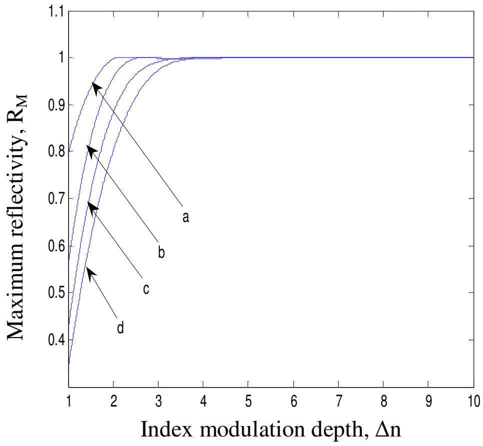

Fig. 5 Maximum reflectivity versus index modulation depth under different strain values: (a) 0.1%; (b) 0.2%; (c) 0.3%; (d) 0.4%.

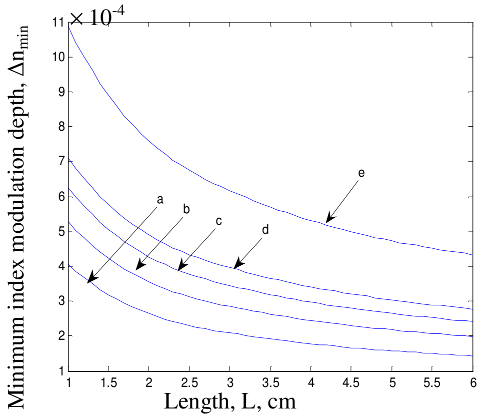

Fig. 6 Index modulation depth versus minimum length under different strain values: (a) 0.1%; (b) 0.2%; (c)0.3%; (d) 0.4%;(e) 1%.

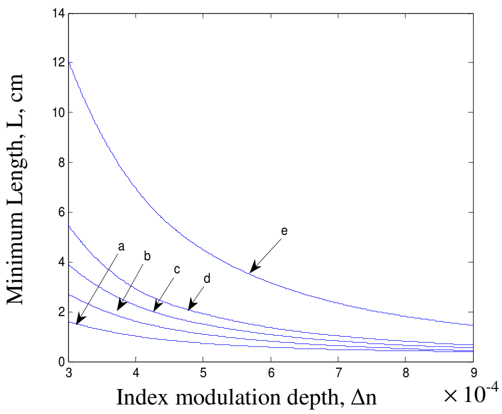

Fig. 7 Index modulation depth versus minimum length under different strain values: (a) 0.1%; (b) 0.2%; (c) 0.3%; (d) 0.4%;(e) 1%.

3.3 Design of third order dispersion compensator

Now, a proposal is suggested for dispersion slope compensation (third order dispersion compensation):

- The relationship between operating region and the zero dispersion wavelength is determined, so one can choose the suitable design of the third order equalizer. (Case (2.3.1), or case (2.3.2), or case (2.3.3).), and the proper profile radius.
- The bandwidth of the fiber Bragg grating is determined which must be equal to or greater than that of the operating bandwidth, so one can choose the suitable strain value, as the strain increases the bandwidth of FBG increases .
- Value of dispersion slope to be compensated determines the needed active length of the grating L_{eff}. and then the physical length of the L can be determined from the relation:

$$L = \frac{L_{eff}}{a_{eff}}. \tag{56}$$

- After obtaining the needed physical length, L, the minimum index modulation depth Δn_{min} is determined (to ensure that the maximum reflectivity is greater than 99 %.).

Our simulation of case (2.3.1) or case (2.3.2) provides a very large dispersion tuning range say from **-185.5** ps/nm^2 (at strain 0.1%, L_{eff} = 3 cm) to **-0.62** ps/nm^2 (at strain 1%, L_{eff} = 1 cm).

3.3.1 Design of case (2.3.3)

- The bandwidth of the FBG is determined which must be equal to or greater than that of the operating bandwidth, hence, one can choose the suitable strain value. The position of λ_o with respect to λ_s is determined. So, one can choose the suitable Bragg wavelength of the uniform grating λ_{Bo} which depends on the applied strain. The position of λ_o in the bandwidth is adjusted by the value of the Bragg wavelength of the uniform grating before applying strain. For all fibers, we have L_{1eff} = L_{2eff} = 2cm, L_{3eff} = 1 cm, strain = 0.3% and λ_{Bo} is displayed in Fig. 8. In graph (a), the longest wavelength λ_L = 1550 nm and λ_{Bo} = 1543.1 nm. In graph (b), shortest λ_s=1550 nm and λ_{Bo} = 1545.5 nm. In practical cases, λ_o can be chosen in any position in the bandwidth, from λ_s to λ_L.

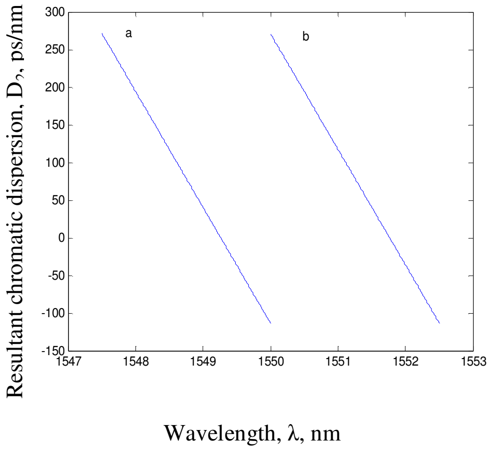

Fig. 8 The resultant dispersion: (a) λ_{Bo}= 1543.1 nm (b) λ_{Bo}= 1545.5 nm.

Figure 9 displays the needed wavelength of uniform Bragg grating, λ_{Bo} versus the shift of the zero dispersion wavelength, λ_o from the longest wavelength of the Bragg grating, λ_L. Strain value determines the grating bandwidth.

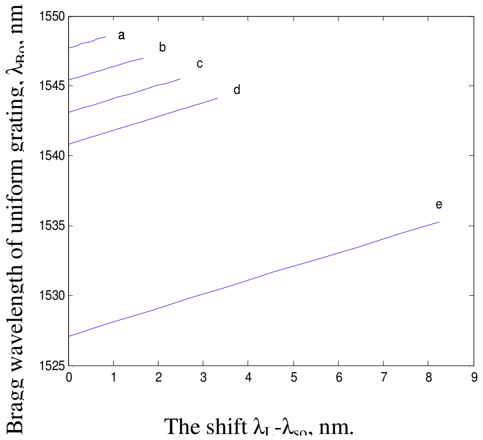

Fig. 9 The resultant dispersion :(a) λ_{Bo}= 1543.1 nm (b) λ_{Bo}= 1545.5 nm.

- Value of dispersion slope to be compensated determines the needed active length of the first and second gratings L_{eff}. Then, the physical length, L, can be determined from (56).
- The third grating adjusts the zero resultant dispersion to the zero dispersion wavelength position.
- Using the obtaining value of L, the minimum index modulation depth Δn_{min} is determined (to ensure that the maximum reflectivity is greater than 99 %.).

3.4 A design example

Consider a WDM system of 8 nm bandwidth (from 1546 to 1554 nm), and the third order dispersion of a dispersion shifted fiber, is 9 ps /nm^2 [7]. So, the design is as follows

- Case (2.3.3) is considered.
- To have a bandwidth of 8 nm, the needed strain is about 1% (8.37 nm) as shown in Fig. 10, and in this case we have a guard band of 0.37 nm.

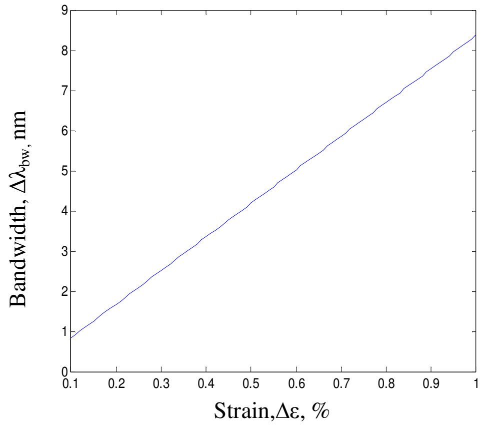

Fig. 10 Bandwidth versus strain.

- The shift of λ_o with respect to λ_L is 4 nm (1550-1546 nm). From Fig. 11, the needed Bragg wavelength of the uniform grating is 1531.2 nm.

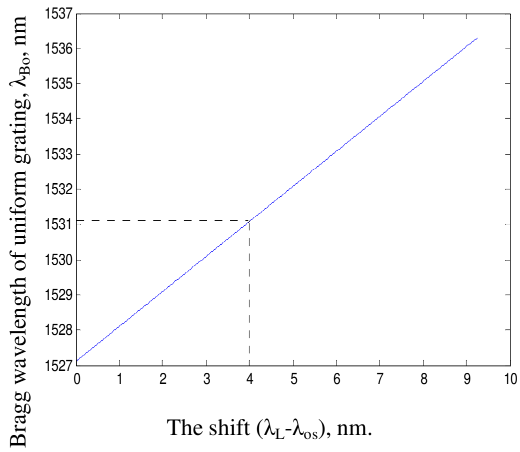

Fig. 11 Bragg wavelength of uniform grating versus the shift λ_L-λ_o for strain 1%.

- We need dispersion slope of value **-9 ps/nm^2**. From Fig. 12, the needed effective length of the first and second gratings is L_{eff} = 2.56 cm. By using Tables 1 and 2, the physical length of the first grating is (2.56/0.4938) = 5.184 cm, and of the second grating is (2.56/0.4944) = 5.18 cm.

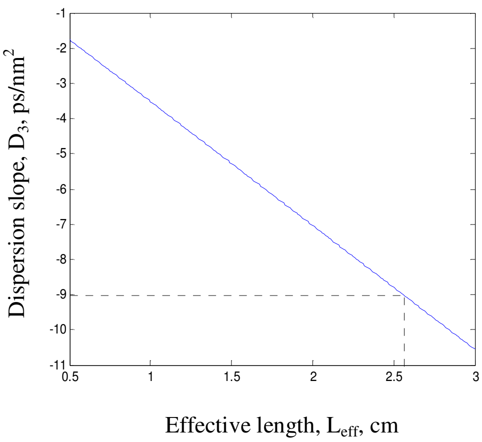

Fig. 12 Dispersion slope versus effective length for strain 1%.

From Fig. 13, the minimum index modulation depth of the first grating is 4.65×10^{-4} and of the second grating is 3.93×10^{-4}.

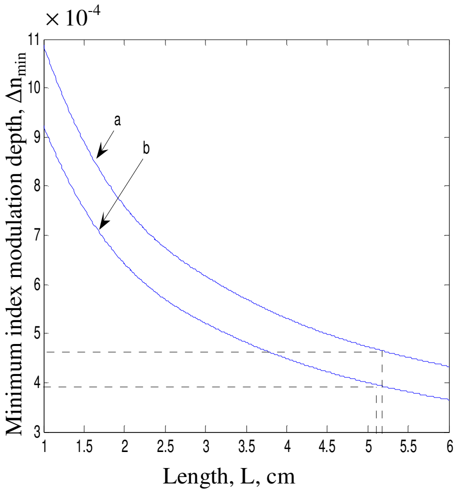

Fig. 13 Minimum index modulation depth needed to have maximum reflectivity greater than 99% at strain 1% for:(a) FBG_1; (b) FBG_2.

From Fig. 14, λ_o in the center of the band, so there is no need to the third grating. Also, the dispersion slope is ~ -9 ps/nm^2, which is the needed value to compensate the typical value of the fiber which is 9 ps/nm^2. This ensures the validity of the model.

4. Conclusion

A design of third order dispersion compensator using a polymer FBG is proposed. The obtained results demonstrate a very large dispersion slope tuning range, say from -185.5 ps/nm^2 (at strain 0.1%, L_{eff} = 3 cm) to -0.62 ps/nm^2 (at strain 1%, L_{eff} = 1 cm). The model is successfully applied to the third order dispersion equalizer of needed dispersion slope -9 ps/ nm^2 to compensate the typical value of the fiber.

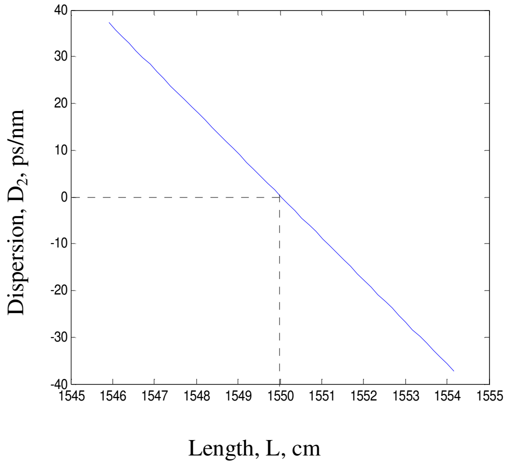

Fig. 14. The resultant dispersion versus wavelength.

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