CONTRIBUTION TO THE MATHEMATICAL MODELING OF PARAMETERS INFLUENCING PHASE MASKS FOR IMPROVING THE PERFORMANCE OF BRAGG GRATINGS IN OPTICAL FIBER

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ABSTRACT

The ever-increasing demand for data quantity in telecommunications is pushing optical fiber technology to its limits. Improving the plane Bragg grating formula is the first step in this study. Then the objective is to find all the parameters affecting the optical performance of the phase masks, and consequently, of the Bragg gratings on optical fibers. This directed us to 4 results of parameters to survey: the length L of the grating, the difference in refractive index between the exposed and non-exposed part of the Bragg grating on optical fiber, the delay time and bandwidth of chirped networks and the apodization functions.
Thus, the study of each of these parameters allowed us to minimize and even effectively eliminate the oscillations in the delay time. Removing oscillations is one of the basic points for improving the Bragg grating which is the goal of our study.

Keyword: *fiber, dispersion, Bragg grating, transfer matrix, apodization*

1. THE OPTICAL FIBER NETWORK

1.1 Introduction

The Bragg grating are essential components in current optical telecommunications systems. These allows you to operate on different wavelengths then make them travel in the same optical fiber, and at that point extract them to find the original signal. In this journal, the optical characteristics of phase masks have been improved with the objective of highlighting the parameters governing the phases, and consequently, Bragg gratings on optical fibers. This will define the requirements of the manufacturing process for the phase mask. The objective of this study will therefore be to analyze each parameter influencing the Bragg grating so to improve the performance of phase masks. The improvement of these 4 parameters allows the perfection of the phase mask which is one of the key elements of the Optical fiber.

1.2 Phase Masks

The goal at this point is to estimate the values of the mask parameters necessary in order to obtain a good quality phase mask. The parameters in question are the depth "h", the period "Λ" and the ratio of the line width to the period "d" in the field of telecommunications, the target wavelength is 1550 nm. The Bragg relation makes it possible to relate the wavelength to be reflected and the period of the grating:

$$\lambda = 2 * n_{eff} * \Lambda \qquad (01)$$

With:

- n_{eff} : Effective index
- Λ : Period

Demonstration:

♣

Also for waves whose wavelength is approximately equal to four times the optical thickness of a layer, the reflections combine by constructive interference, and the layers act as a high-quality mirror. We can consequently write:

$$Optical\ thickness = n.L \qquad (02)$$

Or:

- n : Effective index of the two media.
- L : Thickness of each of the layers.

So:

$$\lambda_B = 4.n.L \qquad (03)$$

With:

$$\Lambda = 2.\mathrm{L} \qquad (04)$$

Thus, we get the Bragg wavelength

♦

Demonstration:

♣

This condition can also be found by the following method. Let Λ be the period of the grating, λ the wavelength in vacuum, n the refractive index and M the order of the Bragg diffraction. In the case of an optical fiber, the propagation is collinear and the diffracted light is therefore reflected.

So:

$$\theta_i = \frac{\pi}{2} \qquad (05)$$

And

$$\theta_r = -\frac{\pi}{2} \qquad (06)$$

By replacing these values in the general equation:

$$sin\theta_i - sin\theta_r = \frac{m.\lambda}{n.\Lambda} \qquad (07)$$

We then get:

$$\lambda_B = 2.n_{eff}.\Lambda \quad (08)$$

What also makes it possible to obtain the Bragg condition turn into for $M = 1$

♦

Thus, for the target wavelength of 1550 nm propagating in an optical fiber with an effective index n_{eff} equal to 1.46, a period of 535 nm is necessary and the period targeted on the phase mask is therefore 1070 nm. [2]

For this purpose, we will use Fourier optics to model the effect of the grating on incident light ($\lambda = 248nm$) passing through the mask. We then define the amplitude transmission function for a binary network $t(x)$:

$$t(x) = \begin{cases} e^{(i\Phi)} & 0 \leq x \leq d * \Lambda \\ 1, & d * \Lambda \leq x \leq \Lambda \end{cases} \quad (09)$$

With:

- $\phi = \frac{2\pi\Delta_n d}{\lambda}$ and Δ_n : Difference between the refractive indices of air and Quartz (Δn~0.5)
- h et d : Depth and the ratio of the width of lines over the period.

The application of the Fourier transformation

$$t_n(x) = (\frac{1}{d}) \int_0^n t(x) * \exp\left(-\frac{i2\pi nx}{\Lambda}\right) dx \quad (10)$$

This allows us to obtain:

$$t_0 = d(\exp(i\Phi - 1) + 1 \quad (11)$$

$$t_n = \frac{i}{2\pi n} \{\exp(i\phi) [\exp(-2\pi nd) - 1] + [1 - \exp(i2\pi nd)]\} \quad (12)$$

It is then possible to determine the light intensity of each order by calculating the squared modulus of t_0 et t_n :

$$I_0 = 2d^2 - 2d + 1 + 2(d - d^2)\cos(\Phi) \quad (13)$$

$$I_n = \frac{1}{\pi^2 n^2} [1 - cos(2\pi dn)](1 - cos(\phi)) \quad (14)$$

It is consequently possible to evaluate the light intensity in the different diffraction orders as a function of the depth and the line width to period ratio of the grating inscribed on the mask.

Our goal in this study was to achieve 0-order power of less than 2% while maximizing power in ± 1 orders. This can be seen in the following figure, the light power in the order of 0 for different line / period ratios and as a function of the depth of the network. [3]

Thus, we see in **Fig -1**, that the light power in the order of 0 is minimum for a depth “h” equal to 248nm. This is the minimum coincides with the wavelength of the laser used. Thus, if a different wavelength is used, the minimum power in the order of 0 will correspond to another minimum.

We can also see in this **Fig -1**, the effect of the ratio "d" line width over network period, since the minimum power in the order 0 also corresponds to a ratio $d = 0.5$. This corresponds to a width of lines in the network equal to the space between them. When the conditions h and d deviate from these minima, we see that the light power in order 0 increases significantly.

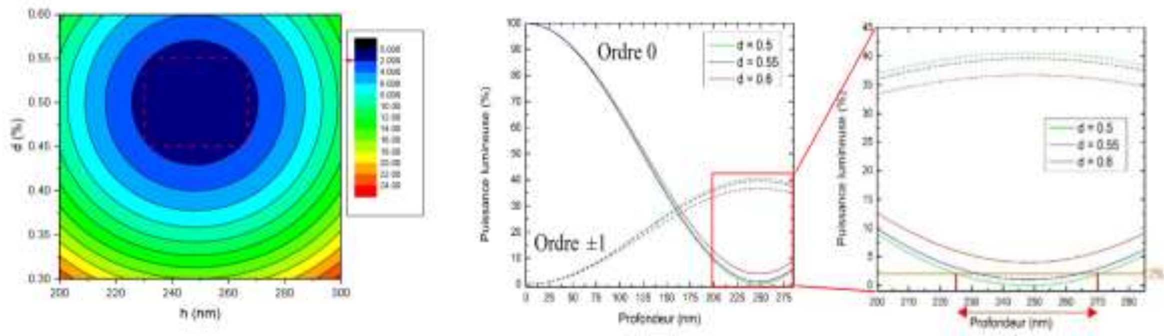

Fig -1: Distribution of light power in 0 orders as a function of pattern depth (h) and line width / period ratio (d)

To achieve the goal of this study of less than 2% power in 0 order, it is possible to set some latitude on these two critical parameters when manufacturing masks. Thus, we will attempt to obtain at the end of the manufacturing process, a depth of 248 ± 20 nm and a line width over period ratio of 0.5 ± 0.05 (an error of ± 50 nm on the line widths), combined with straight engraving profiles. [4]

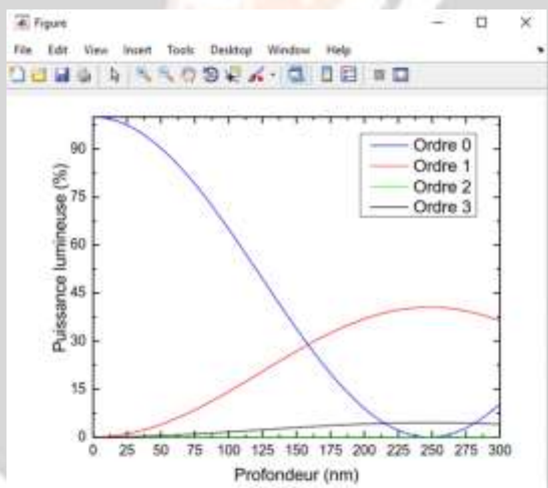

Fig -2: Variation of the light power in the different orders depending on the depth of the grating on the mask

As shown in Figure 2, when the optimal conditions are met, nearly 80% of the initial light intensity is transferred in the two orders ± 1. The remaining power is then distributed in the higher orders. We therefore observe that it is not possible to remove the 0 order and these higher orders simultaneously.

2. RELATIONSHIP BETWEEN PHASE MASKS AND BRAGG GRATINGS ON OPTICAL FIBER

After estimating the performance of phase masks, the performance of Bragg gratings on optical fibers was also simulated in order to understand all the different parameters influencing the optical response of Bragg gratings. [5]

2.1 Mathematical approaches

There are several approaches to describe the operation of Bragg gratings. We will use that of the coupled modes, because it is intuitive and faithfully describes the experiences. [6]
A Bragg grating can be reduced to a periodic disturbance ($\delta_{neff}(z)$) of the refractive index such that:

$$n_{eff} = n_{core} * sin(\theta) \quad (15)$$

Either the perturbation ($\delta_{neff}(z)$) of the fiber can be described as follows:

$$\delta_{neff}(z) = \overline{\delta_{neff}(z)} \left\{1 + v * cos\left(\frac{2 * \pi}{\Lambda} z + \Phi(z)\right)\right\} \quad (16)$$

With:

- $\delta_{neff}(z)$: Average value of the magnitude of the trouble over a period of the network.
- v : Magnitude of the trouble.
- Λ : Network periods.
- $\Phi(z)$: Network phases.

In the case of a uniform grating, we can consider a Bragg grating as a simple optical diffraction grating (**Fig -3**).

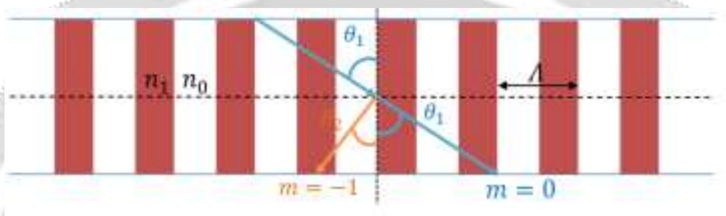

Fig -3: Reflection of light as it propagates through the RDB

We can therefore consider the effect of the grating on a light wave propagating with an angle θ_1 with the following equation:

$$nsin(\theta_2) = nsin(\theta_1) + m * \frac{\lambda}{\Lambda} \quad (17)$$

With:

- θ_2: the diffraction angle of the diffracted wave
- m: the coefficient specifying the order of diffraction.

This equation helps to determine in which direction θ_2, the interference pattern appears, but does not predict at what wavelength the grating allows maximum coupling between two modes. In the case of a Bragg grating in reflection, only the coupling between the reflected light and the incident light, we have the following relation:

$$(\theta_2 = -\theta_1) \quad (18)$$

We then introduce the propagation constant:

$$\beta = (2\pi\lambda) * n_{eff} \quad (19)$$

And we can rewrite as follows:

$$\beta_2 = \beta_1 + m\frac{2\pi}{\Lambda} \quad (20)$$

Demonstration:

♣

Thus:

$$nsin(\theta_2) = nsin(\theta_1) + m * \frac{\lambda}{\Lambda} \tag{21}$$

Also:

$$\beta = (2\pi\lambda) * n_{eff} \tag{22}$$

By taking the equation of β in the previous equation, we obtain:

$$\beta_2 = \beta_1 + m\frac{2\pi}{\Lambda} \tag{23}$$

♦

In the Bragg grating used in reflection, the first order diffraction dominates and m, we obtain:

$$n_{eff} = n * \sin(\theta_2) < 0 \tag{24}$$

Demonstration:

♣

For the case of reflection in the negative modes, diffraction therefore dominates:

$$m = -1 \tag{25}$$

By relating the value of m in the following equation:

$$\beta_2 = \beta_1 + m\frac{2\pi}{\Lambda} \tag{26}$$

We deduce the following relation:

$$n_{eff} = n * \sin(\theta_2) < 0 \tag{27}$$

♦

The following relation is true because for a diffraction, $m = 1$

We consequently obtain the following relation:

$$\beta_2 = \beta_1 + m\frac{2\pi}{\Lambda} \tag{28}$$

We consequently deduce the resonant wavelength for the reflection of an index mode $n_{eff,1}$ with an index mode $n_{eff,2}$:

$$\lambda = (n_{eff,1} - n_{eff,2}) * \Lambda \tag{29}$$

For $\theta_2 = -\theta_1$, we then find the Bragg relation:

$$\lambda = 2 * n_{eff} * \Lambda \tag{30}$$

In this study, the transfer matrix method was chosen to model the spectral response of Bragg gratings. This allows a fast and close to reality simulation of the optical reflection response of a Bragg grating. [7]

Another advantage is its flexibility, which also makes it possible to simulate non-uniform Bragg gratings. The electric fields of light waves propagating in the positive and negative directions in a section of length "l" of the RDB are written as follows:

$$E_a(z,t) = A(z)e^{i(wt-\beta z)} \tag{31}$$

$$E_b(z,t) = B(z)e^{i(wt+\beta z)} \tag{32}$$

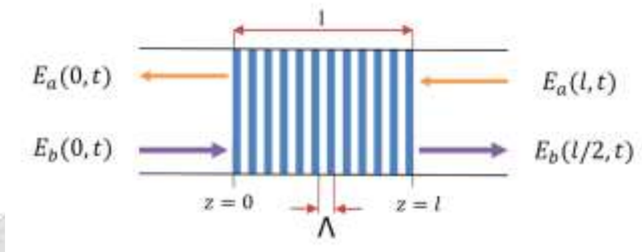

Fig -4: *Representation of reflected and transmitted waves*

The complex amplitudes A (z) and B (z) are described by the theory of coupled modes as follows:

$$\begin{cases} \dfrac{dA(z)}{dz} = ikB(z)e^{-2i(\Delta\beta)z}, & 0 \le z \le l \\ \dfrac{dB(z)}{dz} = -ik^*A(z)e^{+2i(\Delta\beta)z}, & 0 \le z \le l \end{cases}$$

With:

- The coupling constant$k = \frac{\pi \Delta n}{\lambda}$
- $\Delta\beta = \beta - \frac{\pi}{\Lambda}$

These equations are the basis for the modeling of Bragg gratings on optical fiber. By applying the boundary conditions:

$$B(0) = B0 \tag{33}$$

$$A(l) = Al \tag{34}$$

In the equation, we get the solution of this system and therefore the z dependence of these two waves:

$$a(z) = A(z)e^{-\beta z} \tag{35}$$

$$b(z) = B(z)e^{i\beta z} \tag{36}$$

The reflected wave a (0) and the transmitted wave b (l) can be expressed by a diffusion matrix:

$$\begin{bmatrix} a(0) \\ b(l) \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a(l) \\ b(0) \end{bmatrix} \tag{37}$$

With the expressions of a (0) and b (l) from the previous equation, we get the following relations:

$$S_{11} = S_{22} = \frac{iSe^{-\beta_0 l}}{-\Delta\beta \sinh(Sl) + iScosh(Sl)} \tag{38}$$

$$S_{12} = \frac{K}{K^*} S_{21} e^{2i\beta_0 l} = \frac{Ksinh(Sl)}{-\Delta\beta \sinh(Sl) + iScosh(Sl)} \tag{39}$$

With:

$$S = \sqrt{K^2 - \Delta\beta^2} \tag{40}$$

Based on the diffusion matrix and the equations of $S_{11}$and S_{12}, we obtain the following transfer matrix:

$$\begin{bmatrix} a(0) \\ b(l) \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} a(l) \\ b(0) \end{bmatrix} \quad (41)$$

With:

$$T_{11} = T^{*}{}_{22} = \frac{\Delta\beta \sinh(Sl) + iScosh(Sl)}{iS} e^{-i\beta_0 l} \quad (42)$$

$$T_{12} = T^{*}{}_{21} = \frac{Ksinh(Sl)}{iS} e^{-\beta_0 l} \quad (43)$$

The determination of the transfer matrix allowed us to efficiently model Bragg gratings differently. This is divided into N sections consisting of a uniform Bragg grating. Each section can be a varying length from 1 to multiple periods. However, in the case of modeling a network with a step changing incrementally, special attention must be paid to the maximum size of the block used.

Indeed, the use of a too large section induces oscillations in the reflection also the delay time and that it is therefore necessary to limit the length of the sections in order to ensure that the Bragg grating approaches the case of a network with a linear step.

The ideal case is to have a section consisting of only one period. In order to avoid excessively long simulation times, a long section of 10 periods ($l = 5.35\ \mu m$) proved to be an acceptable compromise and was therefore used in the rest of this journal.

The optical responses of each "l" size section will add to each other to ultimately obtain the "L" length Bragg grating response. It is thus possible to assign a different period to each section to simulate non-uniform RDBs. Mathematically, we get:

$$[T_L] = [T_1][T_2] \dots [T_N] \quad (44)$$

Which give:

$$\begin{bmatrix} a(0) \\ b(0) \end{bmatrix} = [T_N][T_{N-1}] \dots [T_1] \begin{bmatrix} a(L) \\ b(L) \end{bmatrix} \quad (45)$$

The purpose of calculating wavelengths is to calculate the transfer matrices for each section and multiply them to ultimately obtain the Bragg grating response.

We then obtain a transfer matrix T of the form:

$$[T] = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \quad (46)$$

Il est ainsi possible d'obtenir la réflexion « r » et « θ » la phase de la lumière grâce au coefficient r :

$$r = \left| \frac{T_{21}}{T_{11}} \right| \quad (47)$$

$$\theta = \arg\left(\frac{T_{21}}{T_{11}} \right) \quad (48)$$

For a uniform lattice with uniform effective refractive index and period, we obtain:

$$r(L,\lambda) = \frac{K^2 sinh^2(SL)}{\Delta\beta^2 sinh^2(SL) + K^2 cosh^2(SL)} \quad (49)$$

Thus, for the Bragg wavelength λ_B,

With:

$$\Delta_\beta = 0 \quad (50)$$

We obtain:

$$r(L, \lambda_B) = tanh^2(KL) \quad (51)$$

The advantage of this modeling is that it is possible to assign a different period to each section. Therefore, to model non-uniform networks becomes possible. It is also possible to go back to the delay time or "group delay" (τ_ρ) which corresponds to the time taken by each wavelength to be reflected using the following formula:

$$\tau_\rho = -\frac{\lambda^2}{2\pi c}\frac{d\theta}{d\lambda} \qquad (52)$$

With:

- θ : phase
- c : Speed of light

Similarly, the effect of apodization, a technique of applying a variable refractive index difference along the grating can be simulated.

2.2 Results of the modeling

We have therefore studied several parameters influencing the optical performance of Bragg gratings, namely:

- The length L of the network;
- The difference in refractive index Δ_n between the exposed and non-exposed part of the RDB on optical fiber;
- Delay time and bandwidth of chirped networks;
- Apodization functions.

2.3 Uniform Bragg Grating Modeling Results

From equations 51, we find that when seeking to optimize a uniform Bragg grating, the only two critical parameters are the lattice length and the effective index change.

2.4 Influence of network length

In order to check the consistency of the results on the modeling of uniform Bragg gratings of different lengths were performed with a difference in refractive index:

$$\Delta_n = 2e^{-4} \qquad (53)$$

The **Fig -5** shows the power reflected by the Bragg grating as a function of the wavelength of light for different grating lengths.

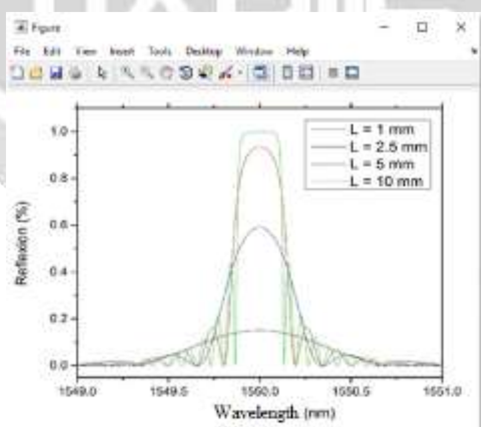

Fig -5: Uniform Bragg array with different wavelengths and a period of 535 nm and $\Delta_n = 2e^{-4}$

We thus observe an increase in the reflected light power when the length of the grating is increased until a total reflection is obtained for a length greater than 10mm.

Through the definition, the delay time of a uniform network is constant throughout the bandwidth, which differentiates it from a non-uniform network. This means that all wavelengths included in the passband are reflected at the same time.

2.5 Influence of Δ_n

In order to continue the validation of our modeling, the influence of Δ_n on the optical response of a network with a constant length must also be verified. Δ_n Represents the difference in refractive indices between the exposed part and the non-exposed part of the Bragg grating on optical fiber.

This value is correlated with the degree of UV exposure of Bragg on optical fiber and is therefore an important parameter in exposure on optical fiber. Uniform networks of 5 cm long were modeled with different values of Δ_n. In **Fig -6** we can observe the reflected power as a function of the wavelength by Bragg grating having different refractive indices.

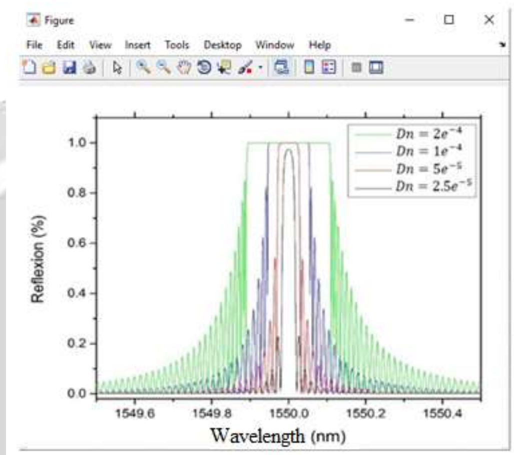

Fig -6: A 5cm long Bragg lattice with a period of 535nm and different Δ_n

For:

$$\Delta_n = 2e^{-4} \tag{54}$$

We find that the network is saturated with maximum reflection. When Δ_n decreases, we see a decrease in the reflected light power until the saturation is lost for $\Delta_n \leq 2.5e^{-5}$. Concretely, the variation of Δ_n is a consequence of the energy deposited in the different fiber.

This behavior as a function of the refractive index has already been observed in the experiments and allows to validate the mathematical modeling for the simulation of non-uniform lattice. Thus, to avoid saturation, it seems that $\Delta_n \sim 2.5e^{-5}$ is the ideal value and will therefore be used for all the modelizations of the networks which follow in this chapter.

2.6 Variable pitch Bragg gratings

In order to model variable pitch gratings, the mathematical equation is adapted to reproduce as closely as possible the optical properties of such gratings. In the case of a Bragg grating having a period increasing linearly, it is a question of assigning a period slightly greater than each section (always 5.35 µm long). The pitch of a Bragg grating can then be defined by the following equation:

$$p = \frac{\Lambda_2 - \Lambda_1}{L} \tag{55}$$

With

- Λ_1 et Λ_2 : periods at the ends of the network
- L: Length.

Thus, it is possible to model a network with diversified step values without increasing the simulation time. In this study, the steps mentioned are those implemented on the network on the phase mask. We thus obtain a pitch twice as small on the optical fiber.

Modeling Bragg gratings with a linear step makes it possible to demonstrate the effects of a linear increase in period along the grating on reflection and delay time. In the cases presented in FIG. 7, we have taken the conditions of the reference which constitute to our knowledge the best performances in terms of dispersion with a Bragg grating having a step of 0.055 nm / cm.

We observe in **Fig -7 (a)** the evolution of the delay time as a function of the wavelength and in **Fig -7 (b)** the power reflected by the Bragg grating as a function of the wavelength.

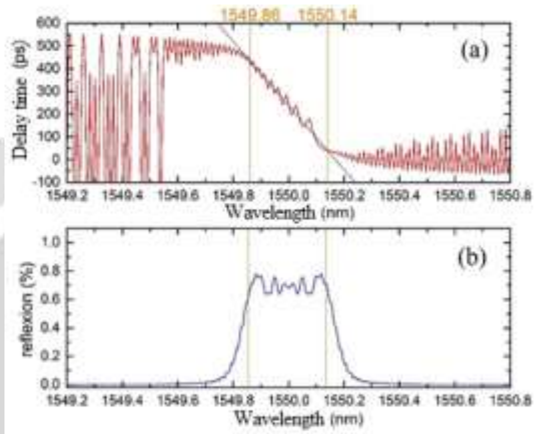

Fig -7: Modeling of a Bragg grating length 5 cm with a difference in refractive index $\Delta_n = 5e^{-5}$ and a step of 0.05 nm / cm

The linear variation of the delay time as a function of the wavelength makes it possible to estimate the dispersion of the grating. We thus obtain a dispersion of 1404 $ps\ /\ nm$ which joins that measured experimentally of 1311 $ps\ /\ nm$, and thus validating our model.

We can also estimate the bandwidth in a simpler way with the Bragg relation by calculating the wavelengths reflected by the periods at the ends of the Bragg grating, Λ_1 and Λ_2:

$$\lambda_1 = 2 * n_{eff} * \Lambda_1 \quad (56)$$

$$\lambda_2 = 2 * n_{eff} * \Lambda_2 \quad (57)$$

Or

$$\Delta\lambda = 2 * n_{eff} * \Delta\Lambda \quad (58)$$

With:

- $\Delta\lambda$: La différence entre $\lambda_2\ et\ \lambda_1$
- $\Delta\Lambda$: La différence entre Λ_1 et Λ_2

Demonstration:

♣

So:

$$\lambda_1 = 2 * n_{eff} * \Lambda_1 \quad (59)$$

$$\lambda_2 = 2 * n_{eff} * \Lambda_2 \quad (60)$$

$$\lambda_2 - \lambda_1 = 2 * n_{eff} * (\Lambda_2 - \Lambda_{1)} \quad (61)$$

We obtain the value of $\Delta\lambda$:

$$\Delta\lambda = 2 * n_{eff} * \Delta\Lambda \quad (62)$$

Thus, in the case of a 5 cm long grating on a phase mask with a step of 0.05 nm / cm with n_{eff}~ 1.46, we obtain $\Delta\lambda$ = 0.365 nm, which matches the value obtained by modeling the grating.

3. APODIZATION

As we can see in **Fig -8**, uniform Bragg gratings have so-called "satellite" reflection lobes on the sides of the main peak. These satellite lobes also become more intense as the reflected light power increases, or even saturates. This experimentally observed phenomenon is critical for telecommunication applications due to the risk of overlapping of the different communication channels.

The quality of the apodization depends on the extremity exposure profile. Several usual functions can be used, but we will use the hyperbolic tangent function:

$$f(z) = \tan h\left(\frac{2az}{L}\right) \quad (63)$$

Or :

$$0 \leq z \leq \frac{L}{2} \quad (64)$$

$$f(z) = \tan h\left(\frac{2a(L-z)}{L}\right) \quad (65)$$

Or :

$$\frac{L}{2} \leq z \leq L \quad (65)$$

With :

- z : Position of the network
- L : Length

Optimization of the profile is possible with the parameter ‘a’ in order to minimize the variations observed in the course of delay time.

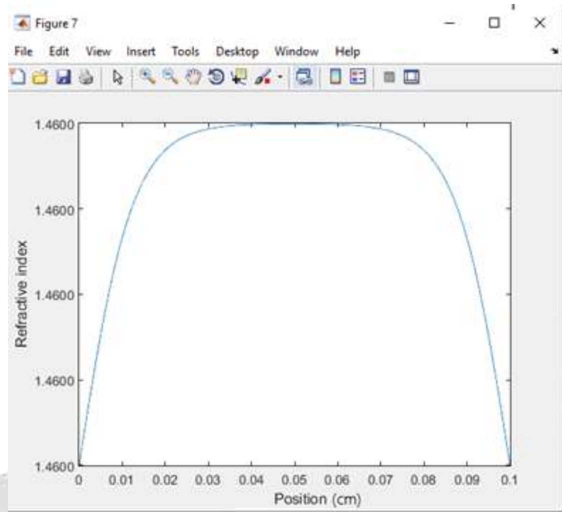

Fig -8: Example of a possible variation of the refractive index along the grating in the case of an apodization with the function tanh and $a = 4$ of a Bragg grating of length 15 cm

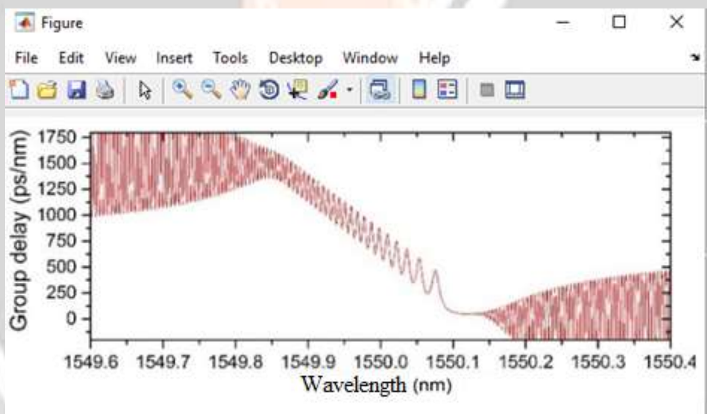

Fig -9: Group delay as a function of the wavelength of a Bragg grating with a step of 0.0125 nm / cm, length 15 cm with $\Delta_n = \mathbf{5}\ \boldsymbol{e}^{-5}$ not apodized

We observe in **Fig -8**, the evolution of the average refractive index along the grating during an apodization with an optimal value of $a = 4$. It was possible to integrate this apodization into the simulation in order to verify the effectiveness of this technique.

We have chosen to model here a network with a variable pitch of 0.0125 nm / cm, which corresponds to the smallest variation of period obtained during this mastery work, to reach the desired dispersion of 5000 $ps\ /\ nm$.

We observe in **Fig -9**, the delay time and the reflected signal of such a network without apodization then with the applied apodization. It can be seen that apodization makes it possible to effectively decrease the oscillations in the delay time and to smooth the reflected signal. The experimental setup of apodization during Bragg grating exposure will therefore be carried out in order to obtain strictly linear delay times.

Without apodization the oscillations in the delay time confirm its importance. The **Fig -10** shows the influence of the delay time as a function of the wavelength.

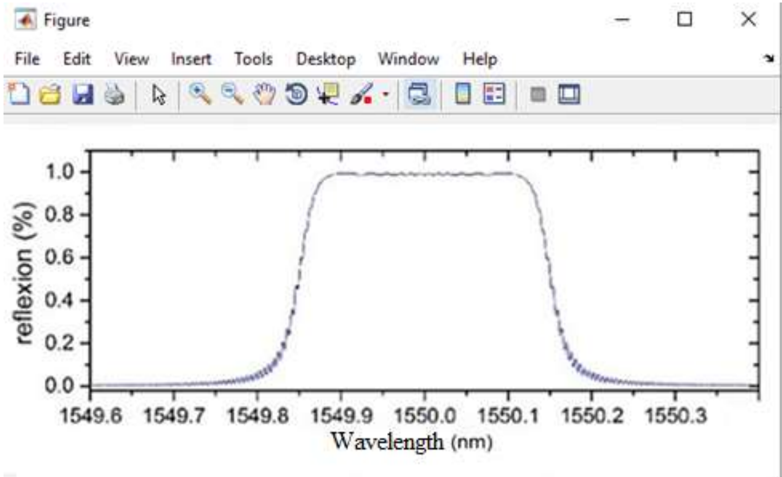

Fig -10: Reflection as a function of the wavelength of a Bragg grating with a step of 0.0125 nm / cm of length 15 cm with Δ_n = $\mathbf{5}\ \boldsymbol{e}^{-\mathbf{5}}$ not apodized

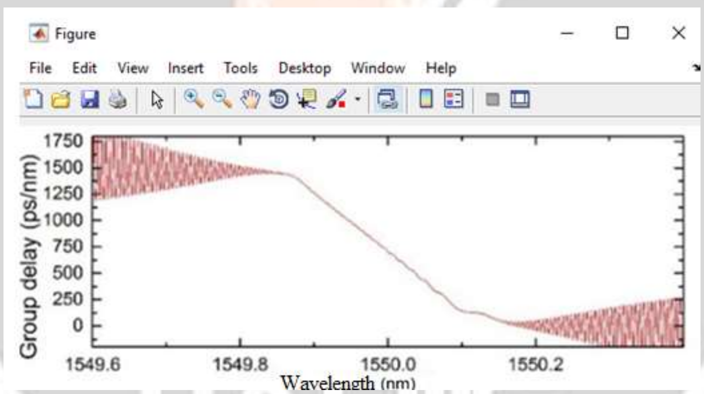

Fig -11: Group delay as a function of the wavelength of a Bragg grating with a step of 0.0125 nm / cm of length 15 cm with Δ_n = **5** apodized with the hyperbolic tangent function and a = 4

The insertion of the analytical apodization function which is the hyperbolic tangent function effectively eliminates the oscillations in the delay time and will therefore be mainly used for Bragg gratings on optical fibers.

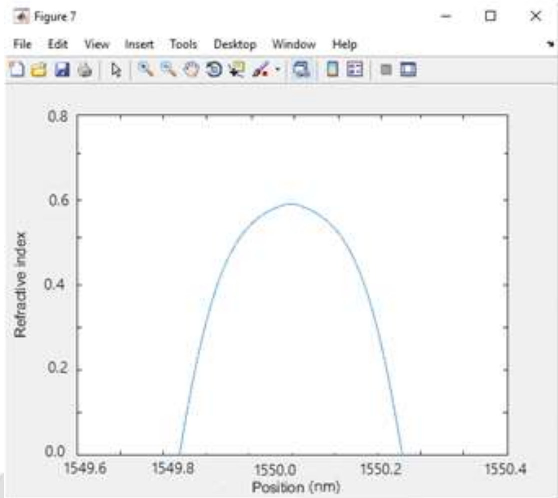

Fig -12: Reflection as a function of the wavelength of a Bragg grating with a step of 0.0125 nm / cm length 15 cm with Δ_n = **5** apodized with the hyperbolic tangent function and a = 4

Through these models, we were able to observe the effects of each parameter on the optical characteristics of uniform and non-uniform Bragg gratings. Modeling the Bragg gratings has shown the influence of grating length as well as the difference in refractive index on the optical properties of uniform and non-uniform Bragg grating.

4. CONCLUSION

The modeling of a Bragg grating by the plane formula $\lambda = 2 * n_{eff} * \Lambda$ is approximate, the main objective of this study is the innovation of this plane formula in matrix form for a more precise and complete representation of an optical fiber composed of a Bragg grating. After this matrix representation, which resulted in a matrix of order 2, the discovery of the 4 parameters influencing the Bragg grating have been identified is the next step. The improvement of these 4 parameters allows the improvement of the phase mask which is one of the key elements of the Bragg grating. We were able to verify in this study that a "line width over period" ratio of $1/2$ and an etching depth of 250 nm will be necessary in order to minimize the light power transmitted in the 0 order and to maximize the ± 1 orders. So, when we are producing the phase masks, a dimensional tolerance of ± 50.0 nm on the line width to period "d" ratio from the optimum value will be allowed, as well as a deviation of ± 20.0 nm when performing the phase mask.

5. REFERENCES

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