Synthesis of Negative Group Time Delay Bragg Gratings for Continuum Generation

G.A. Iordachescu, X. Wu, J. Jacquet
SUPELEC
LMOPS, Laboratoire Matériaux Optiques Photoniques et Systèmes EA 4423
2 Rue Edouard Belin, 57070 Metz, France

Abstract—**In this paper we present the simulation results of two different methods of grating engineering (Genetic Algorithm and Discrete Layer Peeling) we used for the synthesis of Bragg Gratings with a negative Group Time Delay. This type of gratings could be employed (as it will be demonstrated) for the widening of the resonant modes of a Fabry-Perot cavity.**

I. Introduction

Wide tuning range lasers have been realized thanks to a novel concept of Continuum cavity [1]. This structure is of great importance and can find application in various areas such as resonant optical amplifiers, narrow band filters or WDM agile sources. The principle of this structure relies on the use of an accurately defined optical cavity made of a waveguide inserted between two Bragg mirrors [1]. In this paper we extend this principle by using Bragg gratings engineering to obtain the widening of the resonant modes of the cavity. The structure is that of a simple Fabry-Perot cavity in which one of the mirrors was replaced by a Bragg Grating exposing a negative Group Time Delay (GTD) in the desired bandwidth (Fig. 1). To synthesize such a Bragg Grating we have used two methods already presented in the literature [2], [3], namely the Genetic Algorithm and the Discrete Layer Peeling method. Conversely, the reflection spectra of all structures presented in this paper were realized by the Transfer Matrix Method.

II. Physical Structure

The general schematic of the Continuum cavity is shown in Fig. 1, where the Bragg Grating in the right has the purpose of canceling the Fabry-Perot modes which would normally occur in the bandwidth of resonance. In this figure, the round-trip phase shift has been separated in two terms, one term corresponding to the path through the cavity ($\varphi_{F\text{-}P}$) and the other to the medium path length of radiation in the Bragg grating (φ_{BG}). In a normal cavity the sum of the two is a multiple of 2π for every wavelength λ corresponding to a maximum of transmission. In our case, φ_{BG} should have such a value that the total round trip phase shift ($\varphi_{F\text{-}P} + \varphi_{BG}$) could remain constant on a large bandwidth. In other words (1) the variation of φ_{BG} should cancel the variation of $\varphi_{F\text{-}P}$ with λ.

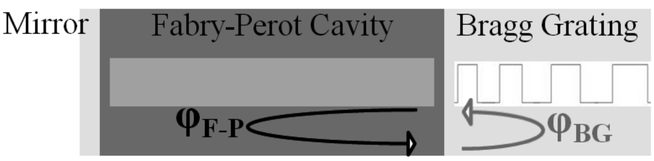

Figure 1. Schematic of a Continuum cavity, in which the round trip phase has been divided between the cavity and the Bragg Grating.

$$d\varphi_{BG} / d\lambda = -d\varphi_{F\text{-}P} / d\lambda \tag{1}$$

If (1) is true for a large enough bandwidth, our structure will show a Continuum behavior. Because the Group Time Delay (GTD) of radiation through a structure is proportional to $d\varphi/d\lambda$, where φ is the phase shift during reflection or transmission, then the GTD of the cavity will always have a positive value. This implies from (1) that the GTD of the Bragg grating should be negative in the desired bandwidth:

$$d\varphi_{BG} / d\lambda < 0 \tag{2}$$

The two methods described next are employed for the design of Bragg gratings for which the condition (2) is true. The necessity for using such synthesis methods comes from the fact that no conventional gratings (uniform Bragg gratings, Linearly Chirped Gratings, etc) exhibit a negative GTD in the reflection bandwidth. For example, in the case of Linearly Chirped Gratings (LCG) we have independently varied three parameters (chirp, grating length and coupling coefficient) without success. Increasing the coupling coefficient (which is a measure of refractive index variation between layers) allows an asymptotical approach to zero, but it does not yield negative values of GTD.

III. Results

A. Genetic Algorithm

The genetic algorithm [2] is a fast way of approaching solutions when the space of variables is so large that an exhaustive search becomes impossible. In our case the variables are represented by the layers of the grating. Each layer has its own thickness value and/or its own value of refractive index, which makes the variable space practically infinite. The genetic algorithm finds optimal solutions in this space according to a fitness function which it uses for evaluation. Its disadvantage is that it does not find a general

978-1-61284-878-5/11/$26.00 ©2011 IEEE

optimal solution, but only local optima according to the random initial population used by the algorithm. As an example, Fig. 2 was obtained by using the fitness function

$$F = \sum R|\, d\varphi/d\lambda \,|, \qquad \text{if } d\varphi/d\lambda < 0, \tag{3}$$

where R is the reflectivity. The summing depends on the number of sampling points used by the algorithm and it takes place only for wavelengths for which we have a negative GTD ($d\varphi/d\lambda < 0$). Despite the fact that F should promote simultaneous encounters of a negative GTD and a maximum reflectivity, we see in Fig. 2 that the regions of negative GTD (encircled regions) coincide only with minima of reflectivity. There can be used numerous other fitness functions, but none of them was better than the simple example above. To force the occurrence of both a negative GTD and a maximum of reflectivity, the Discrete Layer Peeling (DLP) method is employed next.

B. Discrete Layer Peeling (DLP)

The DLP algorithm [3] is a method first adapted by Feced [4] from Digital Signal Processing (DSP). It uses an Inverse Fourier Transform to translate into time domain an ideal frequency response. Once in time domain, the response is passed through different functions (truncate, windowing and shifting) in order to become realizable. It is then translated back into frequency domain by a Fourier Transform. Thus by starting with a desired frequency response we arrive, after a series of mathematical manipulations, to a realizable frequency response. Not every response is possible, and the reason for this is that certain time responses are anti-causal and thus could not be obtained by the use of gratings. In Fig. 3 we have applied an anti-alias treatment (zero-padding method of DSP) to a desired frequency response. It is shown that only positive GTDs ($d\varphi_0 / d\lambda > 0$) are possible simultaneously with maxima

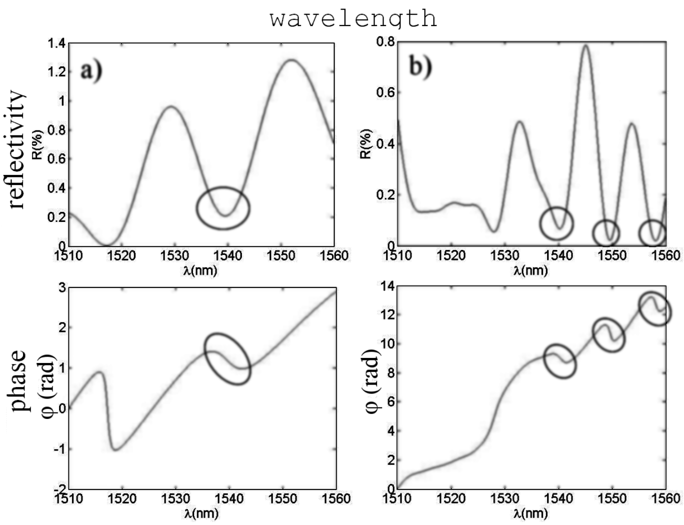

Figure 2. Spectra of gratings obtained by the Genetic Algorithm using the fitness function of (3). Reflectivity (top) and phase (buttom) are plotted as a function of λ. The number of layers for each Bragg grating is: a)100; b)300.

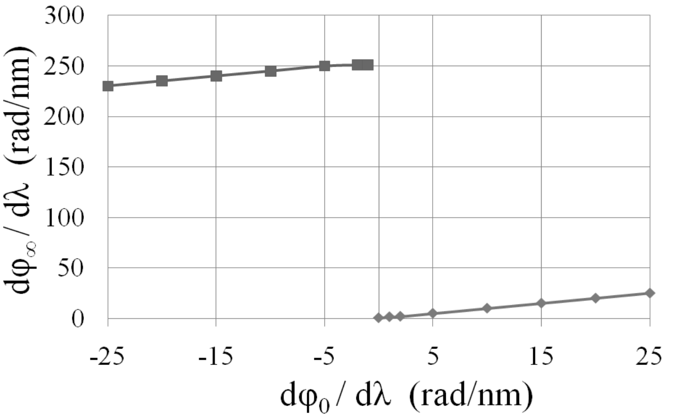

Figure 3. Real (anti-aliased) phase derivative ($d\varphi_\infty / d\lambda$) as a function of ideal phase derivative ($d\varphi_0 / d\lambda$) for a grating synthetised by the DLP method. Reflectivity is considered to be maximum for every simulation point.

of reflectivity. Meanwhile, each time we try to design a Bragg grating with a negative GTD ($d\varphi_0 / d\lambda < 0$) in the reflection bandwidth, we are in fact designing a grating with a positive GTD ($d\varphi_\infty / d\lambda > 0$) but which, at certain sampling frequencies, appears to have a negative GTD because of aliasing.

IV. Conclusion

From our knowledge, we tried for the first time to extend the bandwidth of resonant modes in a Fabry-Perot cavity by Bragg grating engineering (Fig. 1). We demonstrated that for this to happen, the designed grating must have a negative GTD. Sadly, this also implies (Fig. 3) the impossibility to simultaneously have a maximum of reflectivity. We have nevertheless obtained a few practical examples of negative GTD gratings by way of Genetic Algorithm, of which one example is shown in Fig. 2.

Acknowledgment

The authors would like to thank the “Conseil Regional de Lorraine” (France) for financial support of this project. This work is also financially supported by the French National Research Agency (ANR) grants through the CONTINUUM project ANR-09-NANO-035 01. All partners of this project are kindly acknowledged.

References

[1] A. Bergonzo, E. Gohin, J. Landreau, O. Durand, R. Brenot, G-H. Duan and J. Jacquet, "Tuning Range Extension by Active Mode-Locking of External Cavity Laser Including a Linearly Chirped Fiber Bragg Grating", IEEE Journal of Selected Topic in Quantum Electronics, Vol. 9, n°5, P 1118, September/October (2003).

[2] J. Skaar and K. M. Risvik, “A Genetic Algorithm for the Inverse Problem in Synthesis of Fiber Gratings,” Journal of Lightwave Technology, vol. 16, no. 10, October 1998.

[3] J. Skaar, L. Wang and T. Erdogan, “On the Synthesis of Fiber Bragg Gratings by Layer Peeling,” IEEE Journal of Quantum Electronics, February 2001.

[4] R. Feced, M. N. Zervas and M.A. Muriel, “An efficient inverse scattering algorithm for the design of nonuniform fibre Bragg gratings” J. Quantum El., vol. 35, 1999, pp. 1105–1115.