Wavelength Characterization of Chromatic Dispersion and Differential Group Delay of Fibre Bragg Gratings: Relationship and Applications

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We present the relationship between the phase parameter (through the Chromatic Dispersion parameter) and the differential group delay (DGD) parameter for birefringent gratings. We show that the evolutions with wavelength of CD and DGD parameters only differ in their amplitude by a constant factor which is proportional to the birefringence. This relationship is advantageously exploited to experimentally determine the amount of grating birefringence. Since this technique is based on the comparison of two experimental results, it offers the advantage to get the birefringence without knowing grating parameters values.

FBG properties in presence of birefringence

Birefringence is defined as the difference in refractive index between a particular pair of orthogonal polarization modes (called eigenmodes or mode x and mode y)

Grating birefringence results from the combination of different potential sources of birefringence:

- photo-induced birefringence
- intrinsic fibre birefringence
- transversal strain induced birefringence

⇒ In this study, we assume **a global linear and uniform birefringence Δn** [1,2].

FBG properties can be derived from the coupled mode theory [3]

⇒ Transmission response in amplitude $T(\lambda)$ and in phase (Group Delay) $\tau(\lambda)$

⇒ Resonant wavelength $\lambda_{max} = 2\,(n_{eff} + \delta n_{eff})\,\Lambda$

(n_{eff}: core refractive index; δn_{eff}: FBG index modulation; Λ: FBG period)

In presence of birefringence,

the two modes experience **different couplings** through the grating (see Table 1)

Due to the small birefringence value, we observe **two nearly identical transmission spectra separated** by $\Delta\lambda = \lambda_{max,x} - \lambda_{max,y} = 2\,\Delta n\,\Lambda$ so that (see Fig. 1)

$T_x(\lambda+\Delta\lambda) = T_y(\lambda) = T(\lambda+\Delta\lambda/2)$ (for the amplitude response)

$\tau_x(\lambda+\Delta\lambda) = \tau_y(\lambda) = \tau(\lambda+\Delta\lambda/2)$ **(for the phase response)**

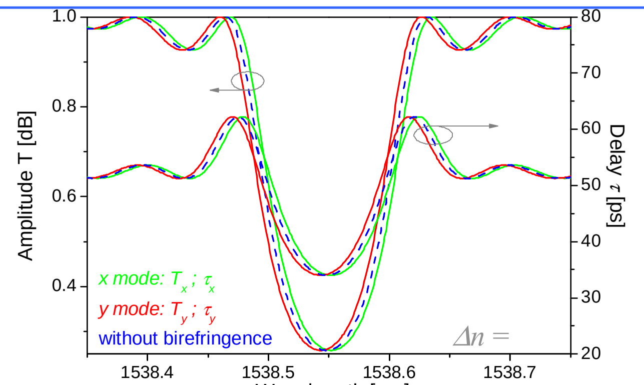


Fig. 1 – FBG spectra for mode x and mode y (with Δn = 7 10^{-5}) and for FBG without birefringence

***x* mode**	***y* mode**
$n_{eff,x} = n_{eff} + \Delta n/2$	$n_{eff,y} = n_{eff} - \Delta n/2$
$\lambda_{max,x} = 2\,(n_{eff,x} + \delta n_{eff})\,\Lambda$	$\lambda_{max,y} = 2\,(n_{eff,y} + \delta n_{eff})\,\Lambda$
$T_x(\lambda)$; $\tau_x(\lambda)$	$T_y(\lambda)$; $\tau_y(\lambda)$

Table 1 – FBG properties in presence of birefringence

Relationship between Chromatic Dispersion and Differential Group Delay

Theory

Let us consider small birefringence values leading to a small wavelength separation between the two polarization modes.

In this condition, the **Chromatic Dispersion** (**CD**) parameter is, in first approximation, not polarization dependent. It can be consequently expressed by

$$\mathbf{CD}(\lambda) \equiv d\tau / d\lambda$$

Due to the presence of birefringence, grating exhibits polarization dependent properties and more particularly **Differential Group Delay** (**DGD**). The relationship defining the wavelength dependency of the grating DGD is

$$\mathbf{DGD}(\lambda) \equiv |\tau_x(\lambda) - \tau_y(\lambda)|$$

Taking into account the previous relationships that geive the FBG properties in presence of birefringence, the DGD parameter can be expressed by

$$\mathbf{DGD}(\lambda) \cong |\tau_x(\lambda) - \tau_x(\lambda+\Delta\lambda)| \cong |\tau(\lambda-\Delta\lambda/2) - \tau(\lambda+\Delta\lambda/2)|$$

Let us now consider a "new" parameter corresponding to the ratio between DGD(λ) and $\Delta\lambda = 2\Delta n\Lambda$

$$\mathbf{DGD}(\lambda)/\Delta\lambda \cong |\tau(\lambda-\Delta\lambda/2) - \tau(\lambda+\Delta\lambda/2)| / \Delta\lambda \approx |CD(\lambda)|$$

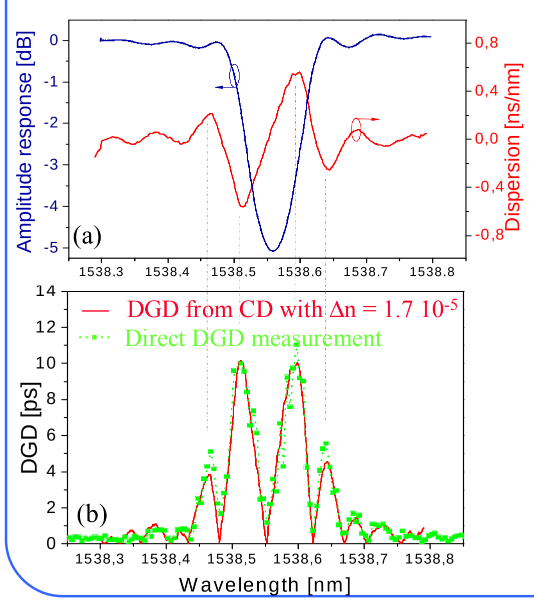
Considering the definition of the grating chromatic dispersion, this last equation is the mathematical approximation of the absolute value of the grating chromatic dispersion. Consequently, since the Δλ parameter is not wavelength dependent, the **wavelength dependency of DGD** is directly **related to** the **wavelength dependency of the absolute value of the CD**. They **only differ in their amplitude by a quantity equal to 2 $\Delta n\,\Lambda$**. (Note that this study remains valid for any kind of FBGs (uniform, apodised, and chirped FBGs)).

Experimental results

Uniform Bragg grating: written using a 1070.40 nm period phase mask given a period Λ of ± 535 nm. The set-up was adjusted to obtain a 1 cm long FBG with $\delta_{neff} \approx$ 1 10^{-4}.

Evolution with wavelength of CD was measured by using the phase-shift technique. The result is depicted **in Fig (a) in red** as well as the amplitude response in blue).

DGD evolution with wavelength was obtained by measuring the Jones matrix of the grating in transmission versus wavelength (Jones matrix eigenanalyzis method [5]) using a tunable laser source and a polarimeter. The result is depicted in **Fig (b) - dotted line**



This experimental DGD evolution agrees with the theoretical study presented in [4].

In Fig (b) - red line, we present the **DGD curve derived from the CD measurement** by using our equation with Λ = 535 nm.

The grating birefringence Δn was adjusted in order to obtain the best fit between the two experimental results.

We report a very good agreement for a birefringence value equal to 1.7 10^{-5}.

This obtained birefringence value exactly corresponds to the value get from the technique described in [4].

Application and Conclusion

The derived relationship can be exploited to experimentally obtain the amount of grating birefringence (i.e. during or after the writing process). For that purpose, **DGD and CD spectral evolutions of the grating are separately measured**. The DGD evolution is then calculated from the CD measurement using the derived relationship in which the grating period is directly known (with a precision less than ±1%) from the configuration of the writing setup. The **amount of grating birefringence** finally corresponds to **the value giving the best fit between the derived DGD evolution and the direct DGD measurement**.

Since it is **based on the comparison of two experimental results**, the **advantage** of this technique (compared to other technique presented in [4]) is to offer the possibility to **get the birefringence value without knowing the grating parameters**.

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n_{eff}	fibre mean effective index
Δn	birefringence
δ_{neff}	FBG effective index modulation
Λ	FBG period
$T(\lambda)$	FBG amplitude response
$\tau(\lambda)$	FBG phase response