Use of chirped fibre Bragg gratings for transverse strain sensing purpose

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Thanks to their possibility to measure static and dynamic fields, such as strain and temperature, fibre Bragg gratings are widely used in sensing applications. For the particular case of transversal strain, it has been reported that uniform FBGs written into standard single mode fibre were one alternative to systems using FBGs written into polarization maintaining fibre. In this case, the transversal load monitoring is based on the wavelength dependency measurement of the gratings PDL and DGD. In this paper, we investigate the possibility to use chirped FBG, in place of uniform FBG, to increase the performances of such sensor element.

Introduction

Thanks to their intrinsic advantages, optical fibres are good candidates to monitor temperature or stain inside a material. Hence, several solutions using fibre Bragg gratings (FBG) has been reported. For the particular case of transversal strain, the proposed techniques are based on the analysis of the birefringence effects on the FBG responses. Indeed, by applying a transversal force along an optical fibre, an asymmetry of its section appears which consequently leads to birefringence. If a FBG is placed in this area, its transmission response is affected by the birefringence induced by the strain. In this case, the two FBG responses associated to each eigenmodes (resulting from the presence of the birefringence) differ: they are separated in wavelength by a quantity proportional to the birefringence [1]. It is therefore possible to monitor the transverse strain by analyzing this wavelength separation (in practice, this separation can be observed on the grating amplitude response obtained for an appropriated state of polarization of the input light). However, for weak applied strain, the wavelength separation is weak too so that it very difficult to measure it.
In order to remove this limitation, it has been recently proposed to use the PDL (Polarisation Dependent Loss) and/or the DGD (Differential Group Delay) responses associated a uniform FBG [2]. Indeed, while they induce a difficult to measure wavelength separation, weak birefringence values lead to significant PDL and DGD values [3]. However, while it allows to detect low strain level, this transversal strain sensor based on the measurement of the grating PDL and DGD possesses a weak measurement range. In this paper, we show that it is possible to increase the dynamic of the measurement by using a chirped fibre Bragg grating (CFBG) in place of a uniform one. Simulations results are presented and discussed. In addition, a first experimental result is reported.

PDL and DGD of a CFBG used in reflexion

In presence of birefringence Δn, it can be shown that the amplitude and the phase responses associated to the two grating eigenmodes (called the x et y modes) have a same shape but are spectrally separated by a quantity $\Delta\lambda = 2\,\Delta n\,\Lambda$ (where Λ represents the grating period) [3]. Figure 1 represents the amplitude (R_x et R_y) and the group delay (τ_x et τ_y) responses for a CFBG (linear chirp) used in reflection for a birefringence value $\Delta n = 10^{-4}$. The grating parameters used for simulations are: index variation $\delta n = 10^{-4}$, period $\Lambda_{moyen} = 533.1$ nm, *chirp* C = 0.1 nm/cm and L = 10 cm; in addition, a apodisation is used to reduce the group delay ripple. The wavelength dependency of the grating PDL and DGD are also shown on figure 1. They are defined by [4]:

$$PDL(\lambda) = |10 \log_{10} [R_x(\lambda) / R_y(\lambda)]| \quad (1)$$

$$DGD(\lambda) = |\tau_x(\lambda) - \tau_y(\lambda)| \quad (2)$$

Considering the spectral evolutions of R_x et R_y, the PDL value in the middle of the reflexion band is null for any birefringence value; the measurement of the PDL spectrum is thus not useful in the case of CFBG. However, it is different for the spectral evolution of the DGD : we can observe that the DGD value is constant in the middle of the reflection band (100 ps for the values used in figure 1) and this value differs with Δn.

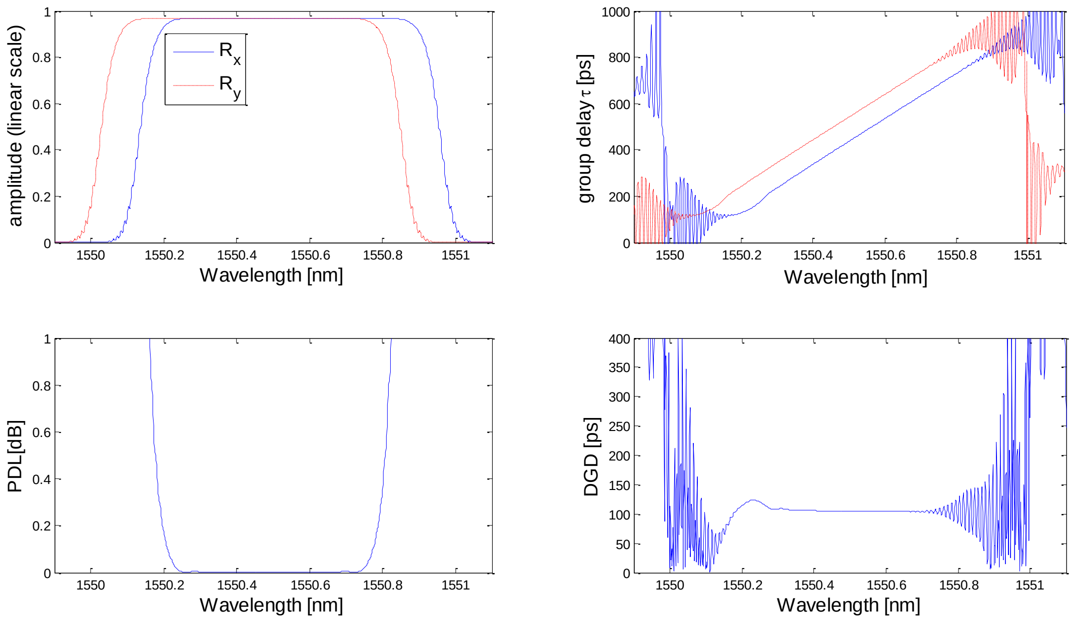

Fig. 1 : (up) Amplitude and phase response (group delay) for the two CFBG eigenmodes; (down) the corresponding PDL and DGD wavelength dependencies

The figure 2 represents the evolution of the DGD values measured in the middle of the reflection band versus the birefringence. This evolution is linear since (cf. figure 1) the DGD value linearly increases with the wavelength separation $\Delta\lambda$ induced by the birefringence. On this figure, we have also represent the result obtained for a 1 cm long uniform FBG with a index variation $\delta n = 10^{-4}$ (let us mention that, for a uniform FBG, the DGD spectrum presents a maximum value; the DGD values given in figure 2 corresponds to this value as it is done in [2]). We clearly observe the limited useful measurement range associated to the uniform FBG (this corresponds to the birefringence range for which the DGD curve monotonously increases [2]). Figure 2 clearly shows that this range is upgraded by using a chirped FBG. The maximum birefringence value ($5\ 10^{-4}$ in the case of our simulation parameters) then depends on the grating bandwidth: indeed, considering the group delay and the DGD curves presented in figure 1, we observe that the maximum possible wavelength separation corresponds to the half of the grating bandwidth. For a chirped FBG presenting a wavelength band equals to 1 nm, the measurable maximum birefringence value is then about $5\ 10^{-4}$.

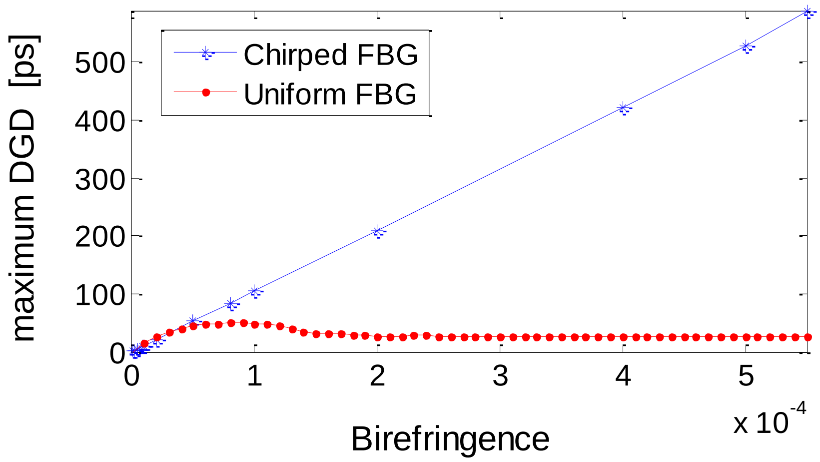

Fig. 2 : Evolution of the maximum DGD values versus the birefringence

Experimental results

A first experimental result has been obtained by using a 1.3 cm long chirped (chirp of 2 nm/cm) and apodised fibre Bragg grating. Different pressures have been applied to the fibre by using a mechanical setup able to induce a transversal strain (a priori, a uniform transversal strain). The DGD has been measured by using a vectorial optical signal analyzer. The DGD curves as well as the transmission response of the unstrained FBG are reported in figure 3. We observe an increase of the mean DGD level with the strain, in accordance with the theory. However, despite the use of an apodisation function, the presence of the group delay ripple leads to a variation of the DGD value in the grating bandwidth. Hence, this results shows that, in order to get the strain level from the DGD measurement, we must consider the mean value of the DGD over the grating bandwidth rather that the maximum DGD value. Moreover, we can observe on figure 3 that the mean DGD level is less important in the higher part of the grating bandwidth; we think that this reduction is due to the non-uniformity of the applied strain. So, in addition to the possibility to get the strain level, the measurement of the DGD of a chirped FBG, thanks to the wavelength encoding of the position, can be used to detect the profile of the applied strain or to verify its uniformity, which is not possible with a uniform FBG.

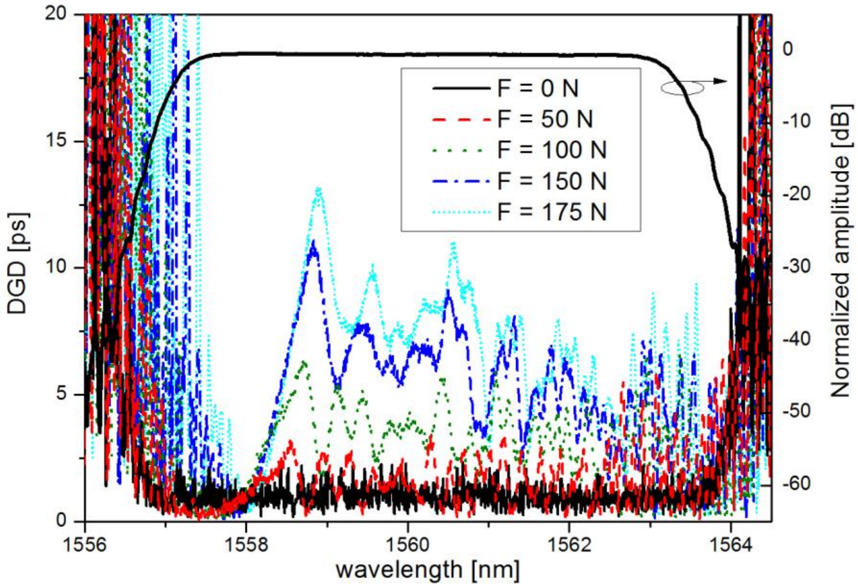

Fig. 3 : Experimental results: DGD evolution of a CFBG for different transversal loads

Conclusion

In this paper, we presented the possibility to use the DGD measurement of a chirped fibre Bragg grating for transversal strain sensing purpose. The theoretical study has shown that that this solution allows, compared to uniform FBG, to increase the measurement range of the sensor. Experimental results have been finally presented in accordance with the theory.

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