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Nonlinear chirped grating based tunable dispersion compensation using strain

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ABSTRACT

Chirped fiber Bragg gratings (CFBGs) offer an attractive solution for dispersion management in long haul and high capacity point to point optical links. The deployment of reconfigurable optical networks however demands dynamic dispersion compensation schemes to address channel degrading effects. Dynamic correction of dispersion can be achieved by tuning the optical characteristics of the non-linearly chirped FBG using external controls like temperature, strain, magnetic, acousto-optic and electro-optic techniques. In this work, simulations are carried out to evaluate the performance of nonlinear chirped gratings as tunable dispersion compensators. The induced dispersion of the grating is found to be tunable from −800 ps/nm to −2657 ps/nm using strain as external perturbation. BER of 1.85×10^{-118} and 1.71×10^{-116} is achieved after the transmission of the information through 90 and 140 km section of single mode optical fiber respectively. This is achieved by adjusting or tuning the dispersion offered by the nonlinear chirped FBG dynamically in the required range.

1. Introduction

In the efficient design and deployment of high speed long-haul fiber optic communication system, chromatic dispersion is known to be the major cause limiting transmission bandwidth and/or distance. Small change in the dispersion due to varying operating conditions can degrade the system performance to a great extent, particularly in high speed systems. For instance, changes in the temperature can vary the dispersion and these variations become significant in long haul links [1]. Due to the accumulated effect of dispersion, for example, optical signals that can reach 400 km at 5 Gbps data rate can only reach 20 km at 20 Gbps [2]. To address this issue, the accumulated dispersion is compensated in ‘dispersion managed systems’ by introducing an opposite amount of dispersion using optical component [3–5]. In such systems, the fiber nonlinearities are kept under control by managing some amount of residual dispersion in the optical link [6]. In high speed optical systems, the dispersion accumulated over the fiber length can be compensated by using dispersion compensating fiber (DCF) or chirped fiber Bragg grating (CFBG).

In reconfigurable optical networks, dynamic allocation of routes from one node to another will result in variation of accumulated dispersion as the distance between the source and destination node varies [7]. To address these issues, particularly at high data rates, tunable dispersion compensation schemes need to be developed. Using Tunable Dispersion Compensation (TDC), optimal system performance can be achieved by dynamically adjusting the overall dispersion. Since the DCF’s are manufactured to provide ‘fixed’ amount of dispersion for the given length, they cannot be considered when the amount of dispersion needs to be tuned [8]. Chirped fiber Bragg grating is one of the fundamental components used to develop tunable dispersion compensation mechanism as it offers

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low loss, low cost and simple tuning technique [9]. Tuning of the induced dispersion is mainly achieved by varying the grating period with an external application of temperature [10–14] or strain [15–17]. In a linearly chirped FBG, application of temperature or strain only results in a shift in Bragg wavelength and doesn't change the induced dispersion [18,19]. This is due to the fact that the group delay of a linearly chirped FBG is a linear function of wavelength. Hence, the slope of the group delay, which is nothing but dispersion, remains constant within the bandwidth of the grating.

To achieve dispersion tunability, the grating's period must be chirped nonlinearly along the length. While the chirped FBGs can be developed by either introducing chirp during the writing process or post chirping of uniform gratings, the non-linearity is usually achieved by varying the exposure times. The inscription is based on a near UV-technology that employs a typical wavelength of 300 nm at which absorption of light in the fiber core is sufficiently small, preventing damage at the core cladding interface [20,21]. Applications of nonlinearly chirped FBGs include monitoring of structural-health and transmission lines; measurement of strain and temperature; identification of high pressure events; and dynamic dispersion compensation in high speed fiber optic networks [22]. Contribution of grating chirp coefficient and the refractive index profile to the grating performance is analysed and reported in the noteworthy work [23]. Impact of several taper profiles on the performance of the T-FBGs as dispersion slope compensator is investigated using strain and reported [24]. Spectral characteristics of the nonlinearly chirped grating using strain as external perturbation is also investigated [25].

In this work, a non-linear chirped FBG is considered for tuning the amount of compensation offered by the chirped grating using strain as the external stimulus. Slope of the group delay curve varies with wavelength and thereby facilitates tuning of the dispersion induced by the grating. We have also presented the simulation of 10Gbps optical link using tunable dispersion compensation. Rest of the paper is organized as follows: FBG working and its sensitivity to strain is discussed in Section 2. In Section 3, simulation of linear and nonlinear chirped FBG and their tuning using strain as the external perturbation is described. Design and simulation of 10Gbps optical link incorporated with TDC through nonlinear CFBG is discussed in Section 4. Section 5 presents the results and discussion followed by conclusion in Section 6.

2. FBG theory

The power reflection coefficient of the Fiber Bragg grating is expressed as [26,27]

$$R= \frac{\sinh^2(\sqrt{\kappa^2-\sigma^2}L)}{\cosh^2(\sqrt{\kappa^2-\sigma^2}L)-\frac{\sigma^2}{\kappa^2}} \tag{1}$$

where σ is a general 'dc' self-coupling coefficient and κ is the AC coupling coefficient. Maximum reflection of the grating occurs when $\sigma = 0$ or for the wavelength $\lambda_{max} = \left(1+\frac{\delta n_{eff}}{n_{eff}}\right)\lambda_B$ and from Eq. (1), we have

$$R_{max} = \tanh^2(\kappa L) \tag{2}$$

in which λ_{max} is the wavelength of maximum reflectivity, L is the Grating length and λ_B is the Bragg wavelength given by

$$\lambda_B = 2n_{eff}\Lambda \tag{3}$$

In Eq. (3), n_{eff} is the effective refractive index of propagating optical mode that decides the Bragg wavelength and Λ is the grating period. Group delay and dispersion of the grating can be estimated using the phase of the amplitude reflection coefficient. Group delay for the light reflected inside the grating is [26,27]

$$\tau_p = \frac{d\theta_p}{d\omega} = -\frac{\lambda^2}{2\pi c}\frac{d\theta_p}{d\lambda} \tag{4}$$

Here, θ_p is the phase of the amplitude reflection coefficient and τ_p is the group delay offered by the Bragg grating. Since, dispersion is the slope of group delay, we may write

$$D= \frac{d\tau_p}{d\lambda} = -\frac{2\pi c}{\lambda^2}\frac{d^2\theta_p}{d\omega^2} \tag{5}$$

According to Eq. (3), the reflected wavelength λ_B depends on the pitch and effective refractive index n_{eff}. In a chirped FBG, Bragg wavelength λ_B is a function of position along the grating length and there by result in a relative time delay between different wavelengths of a light pulse. Hence,

$$\lambda_B(z) = 2n_{eff}\Lambda(z) \tag{6}$$

In Eq. (6), the term Λ(z) represents the period along the grating length and is key in determining the position dependent bragg wavelength $\lambda_B(z)$. Shift in the Bragg grating wavelength $\Delta\lambda_B$ obtained by differentiating Eq. (6) is expressed as [18]

$$\Delta\lambda_B = 2\left[\Lambda\frac{\partial n_{eff}}{\partial L} + n_{eff}\frac{\partial\Lambda}{\partial L}\right]\Delta L + 2\left[\Lambda\frac{\partial n_{eff}}{\partial T} + n_{eff}\frac{\partial\Lambda}{\partial T}\right]\Delta T \tag{7}$$

where ΔL is the change in length of the grating and ΔT is the change in Bragg grating temperature. Hence, the center wavelength of the grating can be shifted by applying strain or by changing its temperature.