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Spectral properties of nonlinearly chirped fiber Bragg gratings for optical communications

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ABSTRACT

Numerical investigation of spectral properties of nonlinearly chirped grating under strain is made. Calculation is performed using Matlab code based on solving the coupled mode equations using transfer matrix method. Our findings show that, by optimizing the linear and higher-order nonlinear chirp coefficients, the reflection bandwidth, side lobes, and group delay could be tunable with the increment of the applied tension. Indeed, the fiber grating chirp is tunable by the applied tension represented by the increase of the reflection spectrum bandwidth and the decrease of the group delay ripples. Besides, the time delay curve typically exhibits two behaviors within the rejection bandwidth: a linear variation for large wavelengths and a quadratic variation for short wavelengths. Therefore, with such kind of grating, it is possible to compensate both linear and nonlinear dispersion in high speed optical networks.

1. Introduction

Currently, the different applications of fiber optics in telecommunications and sensing industries represent a real technological evolution of paramount importance for the well being of humanity. Indeed, several passive and active components based on optical fibers are developed in recent years. Among these components, which represents one of distinguished invention of the century, we find fiber Bragg gratings (FBGs) whose applications are very diverse. Fundamentally, silica fibers can change their optical properties permanently when they are exposed to intense UV laser radiation. This photosensitive effect can be used to induce periodic changes in the refractive index along the fiber length, resulting in the formation of an intracore Bragg grating [1–5]. In fact, the periodic refractive index modulation forms a highly resonant micro-cavities leading to the formation of resonant devices for some specific wavelengths satisfying Bragg resonance condition, which is given by

$$\lambda_D = 2n_{eff}\Lambda \quad (1)$$

where λ_D is the wavelength design, n_{eff} is the effective index of propagating optical mode and Λ is the grating pitch.

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Nowadays FBGs technology is used to create various types of devices such as pump stabilizers [6], feedback mirrors in fiber lasers [7], narrow and broad band pass filters [8–10], pulse spectrum shaping [11], optical add-drop multiplexers [12,13], gain-flattening filters [14,15] and chromatic dispersion compensators [16,17].

In actual fact, the strong dispersion of chirped fiber Bragg grating has been used to compensate for dispersion in optical fiber links and for optical pulse shaping. There are chiefly two ways to make chirped gratings either by post chirping a uniform grating or introducing a chirp during the writing process using special instrumentation. According to Eq. (1), the fiber grating can be chirped by varying either the effective modal index or the grating pitch along its length [18–20]. Sinusoidal and hyperbolic function chirps of grating periods have been introduced to improve their performance as dispersion compensators and multi-channel filters [21–23].

In recent years, considerable attention has been paid to the investigation of spectral properties of fiber grating under strain. However, much of it is confined to fiber grating structures with linear chirping. To the best of our knowledge, spectral properties of nonlinearly chirped fiber grating in presence of an applied tension haven't been uncovered yet. Compared with that for the linear chirp, the case for nonlinear chirping will be more important due to the richness of nonlinear phenomena.

In this paper, a nonlinearly chirped fiber Bragg grating with sinusoidal cladding profil is proposed and numerically analyzed. The application of a tension along the grating axis involves a modulation of its physical parameters, and hence a tunability of its spectral responses. Our work is organized as follows. A concisely theoretical analysis is introduced in Section 2. Numerical simulation parameters details, results, and their discussion are presented in Section 3. Finally, a conclusion is summarized in Section 4.

2. Theoretical analysis

The proposed nonlinear chirped fiber grating is made by modifying its period Λ by applying an axial tension F. For FBGs fabricated using UV laser beam interference pattern, the index profile along of its axis z can be described by [9]

$$n(z) = n_0 + \delta n_{eff} \cos\left[\frac{2\pi}{\Lambda_0} z + \varphi(z)\right] \quad (2)$$

where n_0 is the background refractive index of the unmodified core, δn_{eff} is the refractive-index modulation change spatially averaged over a grating period, Λ_0 is the initial grating period, and $\varphi(z)$ represents an accumulated phase shift, which leads, according to coupled mode theory, to a reduction in coupling between the two counter propagating beams.

When the grating is held under the tension F, its period in any point z becomes [24]

$$\Lambda(z) = \Lambda_0(1 + \epsilon(z)) \quad (3)$$

where $\varepsilon(z)$ is the axial strain at position z formed by the applied tension.

For a linear chirped fiber grating, the grating period can be assumed as:

$$\Lambda(z) = \Lambda_0(1 + c_0 z) \quad (4)$$

According to (4), when the fiber grating is subjected to an axial strain, its period may be expressed as [25]

$$\Lambda(z) = \Lambda_0(1 + c_0 z + \varepsilon(z)) \quad (5)$$

However, higher order dispersion compensation can also be taken into account by using a nonlinearly chirped fiber grating (NLCFG) having a period given by the expression $\Lambda(z) = \Lambda_0(1 + c_0 z + c_1 z^2 + c_2 z^3 + \cdots)$ [26,27]. When the grating is held under tension, its period in any point becomes

$$\Lambda(z) = \Lambda_0(1 + \varepsilon(z) + c_0 z + c_1 z^2) \quad (6)$$

where c_0 and c_1 are the linear and first-order nonlinear chirp coefficients, $\varepsilon(z)$ is the axial strain at position z formed by the applied tension, which is given by the following expression

$$\varepsilon(z) = \frac{F}{EA(z)} \quad (7)$$

where F is the tension applied to grating, E is Young's modulus, $A(z) = \pi r^2(z)$ is the cross-section area of the grating at position z.

The cladding radius along the grating length (z) is described by [28]:

$$r(z) = \frac{r_0}{\sqrt{(1 + g[1 + f(z)])}} \quad (8)$$

where r_0 is the maximum cladding radius, g is the etching factor and $f(z) = \sin(2\pi z/L)$ is the sinusoidal function, L is the grating length $(-L/2) \leqslant z \leqslant (L/2)$.

By combining the above equations, the grating period can be expressed as follows

$$\Lambda(z) = \Lambda_0 \left\{ 1 + c_0 z + c_1 z^2 + \frac{F}{\pi E r_0^2}[1 + g(1 + f(z))] \right\} \quad (9)$$