Investigative Study of Transmission Spectra of FBG at varying Induced Index & Grating Length

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Abstract:

The wavelength tuning capacities of Fiber Bragg Gratings (FBG) are related with the change in reflectivity of FBG at Bragg’s wavelength. There are two main methods to obtain such effect: by modifying the fiber refractive index or by changing the grating period. In our work, we have simulated a uniform FBG in MATLAB and studied its transmission spectra for different refractive index modulation values at 0.5×10⁻⁴, 1.5×10⁻⁴ and 2×10⁻⁴. The numerical integration of the coupled mode equation was used to solve the properties of FBG. Then a fast and accurate technique that based on T-matrix formalism was used for calculating the input and output fields. Reflectivity shown by FBG of grating length 7mm for different induced index values (Δn) = 0.5×10⁻⁴, 1.5×10⁻⁴ and 2×10⁻⁴ is 27.95%, 88.94% and 96.45% respectively. Reflectivity is also investigated for 10mm & 15mm grating lengths for the same values of Δn.

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Keywords: photosensitivity, FBG, erbium doped fiber amplifier (EDFA)

1. Introduction

Optical fibers have been used for many decades; but the last 20 to 30 years have shown a lot of further development. The introductions of fiber gratings, photonic crystal fibers and new plastic optical fibers have introduced many important new fields with widened range of possible applications [1]. In fiber gratings we have Fiber Bragg Gratings (FBGs) and Long Period Gratings (LPGs). Generally on the basis of grating period both of fiber gratings are differentiated. It is photosensitivity of the optical fiber that leads to the birth of fiber gratings. Photosensitivity means, when the ultraviolet light(UV) illuminates a certain kind of optical fiber, the refractive index of the fiber is changed permanently [1, 2]. This change in refractive index explored many applications of fiber gratings [2].

Today fiber gratings have become a prominent technology that provides convenient, cost-effective and reliable solutions to a large number of design problems in fiber systems; such as filtering, sensing, dispersive elements and stabilization [3], gain-flattening, optical feedback, wavelength control. Fiber Bragg technology has complemented EDFA performance extremely well over the past several years, in the areas of pump laser wavelength stabilization, pump reflectors, and gain wavelength.
flattening fiber gratings [4]. In this paper we have studied the effect on the reflectivity of the FBG by customizing induced refractive index values at different grating lengths.

2. Theory of FBG

In uniform Bragg grating there is periodic modulation of index of refraction in the core of single mode optical fiber, where the phase fronts are perpendicular to the fiber longitudinal axis and the grating planes are of a constant period [5]. Light will be scattered by each grating plane when guided along the core of optical fiber. When Bragg condition is fulfilled for a particular wavelength, then contribution for this wavelength reflected from each grating plane added constructively in the backward direction which results in a back-reflected peak with a center wavelength defined by the grating parameters. The first-order Bragg condition is given by [6],

\[ \lambda_B = 2n_{\text{eff}} \Lambda \] (1)

where, \( \lambda_B \) is the Bragg’s wavelength that will be reflected back from the Bragg grating, \( n_{\text{eff}} \) is the effective refractive index of the fiber core at Bragg’s grating wavelength and \( \Lambda \) is the grating period [7].

3. Simulation Analysis
Consider a uniform Bragg grating formed within the core of an optical fiber with an average refractive index \(n_{eff}\). The index of refractive profile can be expressed as,

\[
n(x) = n_{eff} + \Delta n \cos \left( \frac{2 \pi x}{\lambda} \right)
\]  

(2)

where, \(\Delta n\) is the refractive-index perturbation typically \(10^{-2}\) [8]; \(n_{eff}\) is the effective refractive index and ‘\(x\)’ is the distance along the fiber longitudinal axis. Using the coupled-mode theory analytical description of the reflection properties of Bragg gratings may be obtained [8, 9]. The reflectivity of a grating with constant modulation amplitude and period is given by the following expression [10],

\[
R(l, \lambda) = \frac{\sinh^2(fl)}{\Delta \lambda \sinh^2(fl) + \cosh^2(fl)}
\]  

(3)

where, \(R(l, \lambda)\) is the reflectivity, which is a function of the grating length \(l\) and wavelength \(\lambda\), \(\delta\) is the coupling coefficient, \(\Delta \lambda = k - \frac{\pi}{\lambda}\) is the differential propagation constant; \(k = \frac{2 \pi n_{eff}}{\lambda}\) is the propagation constant and \(f = \sqrt{\delta^2 - \Delta \lambda^2}\). For contra-directional coupling between two LP\(_{01}\) modes having modal field profile \(\psi_1\) and \(\psi_2\) propagating in opposite directions to each other, and if \(\psi_1 = \psi_2\), coupling coefficient can be written as [9],

\[
\delta = \frac{\omega \varepsilon_0}{\varepsilon} \int \Delta n^2(x, y) |\psi|^2 dxdy
\]  

(4)

where, \(\omega\) is the frequency component and \(\varepsilon_0\) is the free space permittivity. At the Bragg grating center wavelength there is no wave vector detuning and differential propagation constant is zero (i.e. \(\Delta \lambda = 0\)) at Bragg grating center wavelength; therefore, the expression for the reflectivity becomes,

\[
R(l, \lambda) = \tan^2(\delta l)
\]  

(5)

The reflectivity increases with increase in the change of induced index of refraction. Similarly, as the length of the grating increases so does the resultant reflectivity [10].

4. Results

A calculated reflection spectrum as a function of the wavelength detuning is shown in figures 2, 3, 4. The side lobes of the resonance are due to multiple reflections to and from opposite ends of the grating region. We have done simulation in MATLAB 7.6. Here center wavelength (Bragg’s wavelength) is 1550.04 nm, core radius = 5 \(\mu\)m, difference in core clad refractive index = 0.0034, grating period = 0.5345 \(\mu\)m and effective refractive index is 1.45. Fig. 2 shows the reflection spectra of 7mm long FBG for different induced refractive index (\(\Delta n\)) values. It has been observed that reflectivity of the grating is 27.95%, 88.94% and 96.45% for \(\Delta n = 0.5 \times 10^{-4}\), 1.5 \times 10^{-4} and 2 \times 10^{-4} respectively.
Fig. 2: Reflectivity versus wavelength at 7mm FBG length.

Fig. 3 shows the reflection spectra of 10mm long FBG for different induced refractive

Fig 3: Reflectivity versus wavelength at 10mm FBG length.
index (Δn) values. It has been observed that reflectivity of the grating is 47.05%, 97.45% and 99.52% for Δn = 0.5×10⁻³, 1.5×10⁻³ and 2×10⁻³ respectively.

![Reflection varying with Effective Refractive Index](image)

**Fig 4:** Reflectivity versus wavelength at 15mm FBG length.

Fig. 4 shows the reflection spectra of 15mm long FBG for different induced refractive index (Δn) values. It has been observed that reflectivity of the grating is 72.42%, 99.79% and 99.98% for Δn = 0.5×10⁻³, 1.5×10⁻³ and 2×10⁻³ respectively.

5. Conclusion

It has been observed that the reflectivity of the FBG increases with the increasing value of induced refractive index perturbation along with the increasing grating length. This behavior of the FBG spectra can be used to enhance EDFA performance. We know that the noise figure of the amplifier is critically dependent on the amount of pump power at the input of the amplifier. So when we use counter-propagating amplifier configuration then for optimum power conversion efficiency, it is good to use a broad, highly reflecting fiber grating in order to double pass the pump light in the amplifier, which in turn increases the overall efficiency of the amplifier.

References


