UNIFORM FIBER BRAGG GRATINGS PROPERTIES

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ABSTRACT

This work discusses the properties of the Bragg grating used for semiconductor laser stabilization at wavelength about λ = 760 nm. The main point is reflection and band width analyze in dependence of grating dimensions and material properties. The same principal is used in optical band pass for telecommunication systems witch works at wavelength about λ = 1550 nm and λ = 1300 nm.

1 INTRODUCTION

Fiber Bragg grating are widely used in many optical systems as band filters, dispersion compensators, in-fiber sensors or fiber grating lasers and amplifiers. The principle of the fiber grating is in core refractive index modulation. The modulation is along the fiber axis creating periodic structure of refractive index change, δn. The refractive index change is accomplished e.g. by UV laser irradiation of photosensitive fiber core. In the most case, photosensitivity of fiber is due to presence of Ge in Ge-doped fiber core. Refractive index change is approximately 1×10^{-4} for high germanium doped fibers (10-30 mol%) [1]. A lot of techniques to increase fiber photosensitivity in Ge-doped and Ge-free fibers were found. More about these techniques can be found in [1, 2].

2 FIBER BRAGG GRATINGS THEORY

It is important to know the term “uniform fiber Bragg grating”. A grating is a device that periodically modifies the phase or the intensity of a wave reflected on, or transmitted through, it [2]. The propagating wave is reflected, if its wavelength equals Bragg resonance wavelength, λ_{Bragg}, in the other case is transmitted. The uniform means that the grating period, Λ, and the refractive index change, δn, are constant over whole length of the grating. The equation relating the grating spatial periodicity and the Bragg resonance wavelength is given by [1, 2]:

$$\lambda_{Bragg} = 2 n_{eff} \Lambda \qquad (1)$$

where n_{eff} is effective mode index.

A typical layout of uniform fiber Bragg gratings with input and output signal indicated is shown on fig. 1.

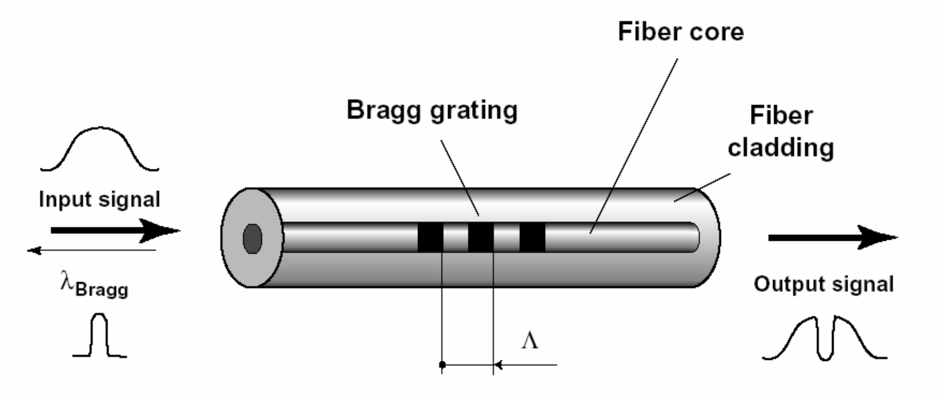

Fig. 1: *Uniform fiber Bragg grating [2]*

3 FUNDAMENTAL BRAGG GRATINGS PROPERTIES

The simulation of spectral properties is necessary to find optimal grating dimension. In all calculations was considered SG682 fiber with the core diameter 1.8 μm, core refractive index 1.47 and cladding refractive index 1.457. Reason for simulation grating with SG682 is that we already have this fiber for real grating fabrication. The refractive index change depends also on UV exposition time. Consequently simulations were made for four possible values. All calculations were made in Matlab software using the equations mentioned bellow.

As was said, Bragg resonance wavelength depends on grating period, Λ, and effective mode index, n_{eff}. The fiber effective mode index depends on the propagation constant, β, and on the vacuum wave number, k; $k = 2\pi/\lambda$, where λ is wavelength:

$$n_{eff} = \frac{\beta}{k} \qquad (2)$$

Because the propagation constant calculation needs solution of Bessel functions and is relatively complicated there was used approximated expression valid for a weakly guiding singlemode step index fiber, given by [2]:

$$n_{eff}^2 \cong n_{cl}^2 + \frac{\lambda^2}{4\pi^2 r^2}(1.1428V - 0.996)^2 \quad \textit{for } 1.5 \le V \le 2.4 \qquad (3)$$

where V is fiber normalized frequency, $V = \frac{2\pi r}{\lambda}\sqrt{n_c^2 - n_{cl}^2}$, r is core radius, n_c and n_{cl} are core and cladding refractive indexes.

In the most cases, uniform grating can be represented as a sinusoidal modulation of refractive index, $n(z)$, through the fiber core given by:

$$n(z) = n_c + \delta n\left[1 + \cos\left(\frac{2z\pi}{\Lambda}\right)\right] \qquad (4)$$

where n_c is core refractive index, δn is amplitude of core index change, z is fiber axial direction and Λ is grating period.

Using the coupled-mode theory analytical description, the reflection properties of Bragg grating may be obtained. The reflection of uniform grating is given by [3]:

$$R(L,\lambda) = \frac{\Omega^2 \sinh^2(sL)}{\Delta k^2 \sinh^2(sL) + s^2 \cosh^2(sL)} \qquad (5)$$

where $R(L, \lambda)$ is reflectivity as function of grating length, L, and wavelength, λ, Ω is coupling coefficient, $\Delta k = \beta - \pi/\Lambda$ is detuning wave vector, β is propagation constant and $s = \sqrt{\Omega^2 - \Delta k^2}$. The coupling coefficient, Ω, for the sinusoidal refractive index modulation is given by:

$$\Omega = \frac{\pi \delta n\, \eta(V)}{\lambda} \qquad (6)$$

where $\eta(V)$ is function of fiber V parameter and is, approximately, $\eta(V) = 1 - 1/V^2$.

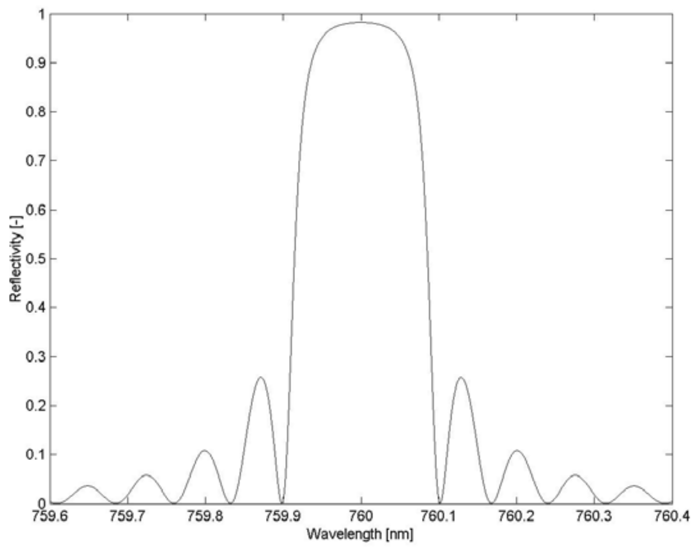

Fig. 2: *Reflectivity against wavelength, calculated for grating length 2.5mm and $\delta n = 5x10^{-4}$ in SG682 fiber*

The spectral characteristic on Fig. 2 was simulated in Matlab using equation (5). It is clear, that the spectral properties of the uniform grating are similar to sinc function. The bandwidth of the grating is considered between the zeroes of the main peak. The bandwidth and the peak reflectivity are dependent on the grating length and the refractive index change as is shown bellow.

For the Bragg resonance wavelength the propagation constant $\beta = 2\pi n_{eff}/\lambda_{Bragg}$ is equal to $\pi/\Lambda = \pi/(\lambda_{Bragg}/2n_{eff}) = 2\pi n_{eff}/\lambda_{Bragg}$ and detuning wave vector $\Delta k = 0$. For this wavelength the reflectivity reaches its maximum, R_{peak}, and equation (5) became to:

$$R_{peak} = \tanh^2(\Omega L) \qquad (7)$$

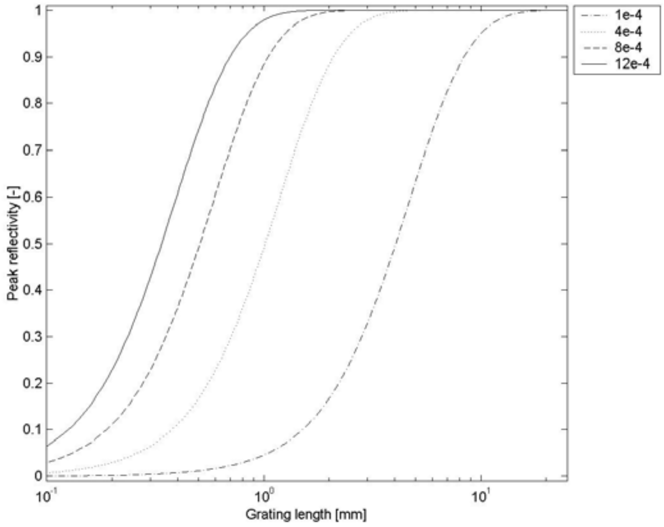

Fig. 3: *Peak reflectivity as function of grating length, calculated for SG682 fiber, parameter δn*

Fig. 3 shows the dependence between peak reflectivity, R_{peak}, as a function of the grating length and refractive index change. It is clear, that it is possible to reach the same peak reflectivity with shorter gratings using fiber with high δn values. That is very useful to find effective length of grating.

Dependence between the grating length, refractive index change and the bandwidth is approximately given by [2]:

$$\Delta\lambda_{FB} \cong \frac{\lambda_{Bragg}^2}{n_{eff}\pi L}\left[(\Omega L)^2 + \pi^2\right]^{\frac{1}{2}} \qquad (8)$$

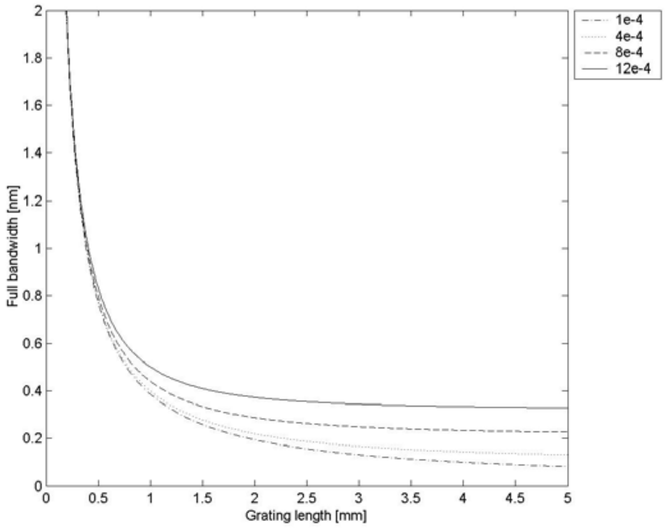

Fig. 4: *Full bandwidth as function of grating length, calculated for SG682 fiber, parameter δn*

As is shown on fig. 4, for grating shorter than approximately 1mm a small variation in the length induces a big variation in the bandwidth. On the other side, grating longer than approximately 5 mm is almost not affected by length variations. The magnitude of the refractive index change has a very low influence on the bandwidth for short gratings. For long grating the bandwidth is approximately linearly dependent on refractive index change.

4 CONCLUSION

The results of fiber Bragg grating simulation shows that spectral properties of grating depends the most on grating length, *L*, and refractive index change, δn. Dependence between grating length, refractive index change and bandwidth to reach same peak reflectivity are:

- longer grating with low δn value cause more narrow bandwidth
- shorter grating with high δn value cause more wide bandwidth

This simulation method shows fundamental dependences between the grating dimensions and its properties. This is the basic method for making a grating proposal and next many other methods are used for real grating modeling.

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