Optik 125 (2014) 1860–1863

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Study and investigation of long period grating as refractive index sensor

Amit Singh[a,*], Shashi B. Rana[a], Maninder Singh[b], Anish Sharma[c]

[a] Department of Electronics Technology, Guru Nanak Dev University Regional campus, Gurdaspur, Punjab, India
[b] Department of Electronics Technology, Guru Nanak Dev University, Amritsar, Punjab, India
[c] Department of Electronics and Communication Technology, Punjab University, Chandigarh, India

ARTICLE INFO

Article history:
Received 6 March 2013
Accepted 5 October 2013

Keywords:
Fiber optics
Long period grating
Refractive index
Transmission spectrum
Coupling coefficient

ABSTRACT

In this paper, we have investigated the response of long period grating (LPG) as refractive index sensor. The response has been studied for refractive index variation ranging from 1 to 1.45. In this work, we found that the sensing mechanism is based on two different aspects. First is the change of coupling power from the guided core mode to other co-propagating cladding modes and second is the wavelength shift of the peak resonant wavelengths from their original positions due the change of refractive index of the environmental (external) medium surrounding the cladding of the grating.

1. Introduction

In recent years, long period grating (LPG) has been one of the most important fiber-optic devices. LPG has found enormous applications in optical communication and sensing system. LPG helps to promote the coupling between the propagating core mode and co-propagating cladding modes. The high attenuation of the cladding modes results in the transmission spectrum of the fiber containing a series of attenuation bands centered at discrete wavelengths, each attenuation band corresponding to the coupling to a different cladding mode. In optical communications, LPG devices have been demonstrated for numerous applications such as in band-rejection filters [1], temperature and strain sensors [2] and refractive index sensors [3]. These sensors possess a number of unique advantages over conventional sensors. For example, they possess low insertion loss, low back reflection, good sensitivity and good long-term stability. They are also free from corrosion attack [4], and electromagnetic interferences [5] that seriously affect many conventional sensors. Physical quantity changes are reflected as wavelength shift of the peak resonant wavelength in the transmission spectrum of LPG.

The use of long period grating as refractive index sensor has been used in variety of applications such as detection of paraffin oil adulteration in coconut oil [6], chemical sensing applications [7], hydrocarbon detection [8] and solution concentration sensors [9]. Long period grating is much better than fiber Bragg grating (FBG) as refractive index sensor because FBGs are intrinsically insensitive to the external refractive index (RI), since the light coupling takes place only between well-bound core modes that are well screened from the influence of the surrounding medium by the cladding layer.

The basic principle involved is to couple light from the fundamental guided mode (i.e. the LP_{01} mode present in the core) to other forward co-propagating cladding modes (LP_{0m} mode with m = 1, 2, 3, 4...) in the fiber with periodical variation of the RI is shown in Fig. 1.

The phase matching condition between the fundamental core mode and the forward co-propagating cladding mode for the long-period grating (LPG) is given by [10].

$$\lambda_{res} = (n_{eff,co}(\lambda) - n^{m}_{eff,cl}(\lambda))\Lambda \quad (1)$$

where λ_{res} is the resonant wavelength, $n_{eff,co}$ is the effective refractive index of the core mode and $n^{m}_{eff,cl}$ is the effective refractive index of the m^{th} cladding mode. Λ is the grating period.

2. Theory

Our first step involved in this work is the calculation of core and cladding mode propagation constant and observe the variation of these parameters due to change in ambient refractive index.

Propagation constant for a core mode is calculated from a LP mode dispersion relation using the Eigen value equation. In this

* Corresponding author.
E-mail address: er.amitsingh07@gmail.com (A. Singh).

0030-4026/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.ijleo.2013.10.002

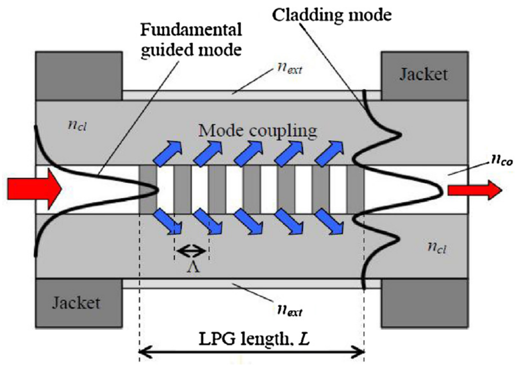

Fig. 1. Coupling of a fundamental guided core mode to a cladding mode in a long-period grating [10].

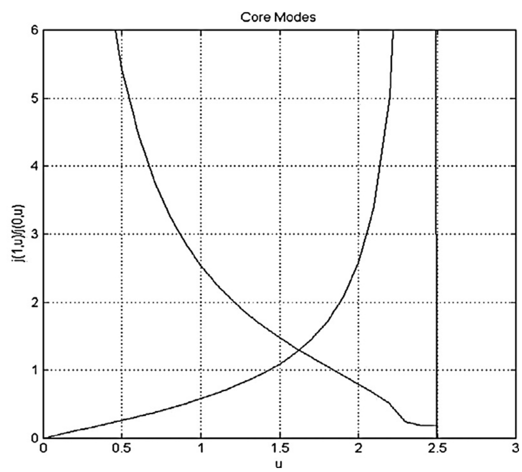

Fig. 2. Calculation of core mode.

approach the inner cylinder is made up of core and outer cylinder is made up of infinite and uniform cladding. [11].

$$u_{co}\left(\frac{J_1(u_{co})}{J_0(u_{co})}\right) = w_{co}\left(\frac{K_1(w_{co})}{K_0(w_{co})}\right) \quad (2)$$

where $J_0(u_{co})$ and $J_1(u_{co})$ are Bessel functions of first kind, of order zero and one respectively and k represents the modified Bessel function of second kind. Where u_{co} and w_{co} are normalized transverse wave numbers that can also be written in terms of the fiber's V-number. The relation between u_{co} and w_{co} is as follows:

$$w_{co}^2 = V^2 - u_{co}^2$$

$$V = \frac{2\pi a_{co}}{\lambda}\sqrt{n_{co}^2 - n_{cl}^2}$$

Thus using graphical approach we can find the intersection point and corresponding value of u_{co}.

$$\beta_{co} = \sqrt{(pn_{co})^2 - \left(\frac{u_{co}}{a_{co}}\right)^2} \quad (3)$$

$$n_{\mathrm{eff,co}} = \frac{\beta_{co}}{p}$$

p is free space propagation constant.

Core mode is well confined to the fiber's core and is not influenced by the changes in ambient refractive index. Thus, there is no variation of core mode propagation constant due to change in ambient refractive index (Fig. 2.).

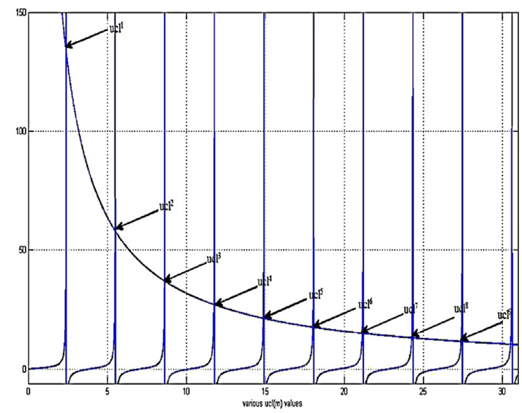

Fig. 3. Calculation of various cladding modes.

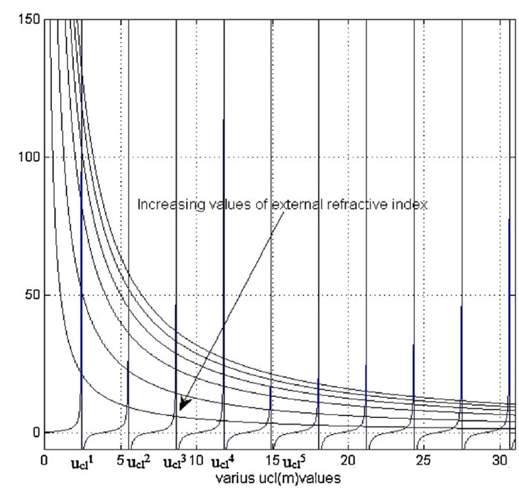

Fig. 4. Variation in various cladding modes due to variation of surrounding (ambient) refractive indices.

Each cladding mode propagation constant is found from a LP mode dispersion relation in the form of an Eigen value equation. In this approach, the presence of the core is ignored so that the fiber geometry once again consists of two concentric cylinders with a step-index profile. Now the inner cylinder comprises of homogeneous solid consisting entirely of the cladding material, whereas the outer cylinder is made up of the infinite but uniform medium surrounding the fiber [12]. Remaining technique of calculating cladding modes is same as that of finding core mode as given in Eq. (2), the only difference is that in this approach cladding become core and external (ambient) material is considered as cladding. By following this procedure, we are getting a plot of various cladding modes as illustrated and shown in Fig. 3. This figure is used to retrieve several sets of normalized transverse wave numbers (ucl^m) at points of intersection corresponding to the number of cladding modes. Whereas the variation in various cladding modes due to change in ambient refractive index is represented in Fig. 4. In our analysis part, we have studied and investigated only the variation of LP_{03} cladding mode resulted due to change in ambient refractive index. Enlarged view of n_{cl}^3 from Fig. 4 is clearly shown in Fig. 5. Fig. 5 clearly gives us the various intersection points related to different values of ambient refractive index values, which further helps us to calculate various ucl^3 values. Various values of ucl^3 give us different values of n_{cl}^3 as shown in Table 1.

The variation of cladding mode propagation constant due to change in ambient refractive index will results in shifting of both amplitude and resonant dip in the LPG transmission spectrum.