Investigate The Relation B/W Refractive Index and BRAGG Wavelength In Fibre BRAGG Grating

Er. Yashpal Lather1, Er. Megha Goyal2

1Research Consultant, M.Tech (Optical Engg.), PGDIBO, INDIA
2Assistant Professor, ECE Department, Galaxy Global Group of Institutions, Ambala, INDIA

ABSTRACT

Compared with conventional fibre-optic sensors, FBG sensors have a number of distinguishing advantages. FBG sensors prove to be one of the most promising candidates for fibre-optic smart structures. This article presents a comprehensive and systematic overview of FBG sensor technology regarding many aspects including sensing principles, relation between refractive index & Bragg wavelength, grating fabrication techniques. It is anticipated that FBG sensor systems will be commercialized and widely applied in practice in the near future due to the maturity of economical production of FBGs and the availability of cost effective interrogation and multiplexing techniques. In-fibre Bragg grating (FBG) sensors are one of the most exciting developments in the field of optical fibre sensors in recent years.

Keywords— Fiber, Communication Technology, Optical, Sensing system

II. FIBRE BRAGG GRATING

The Fibre Bragg Grating (FBG) was initially demonstrated by Ken Hill., K.O. [2]. FBG is a periodic perturbation of the refractive index along the fibre length in the fibre’s core which is formed by exposure of the core to an intense optical interference pattern. Germanium, a dopant used in many optical fibre cores, is photosensitive to Ultraviolet (UV) light. A grating is a selective wavelength filter in the core of an optical fibre. It is made by exposing a section of the fibre to UV light through a phase mask. An interference pattern of maxima and minima is formed causing a permanent periodic change to the index of the core. A small amount of light is reflected at each index variation. At the "center wavelength" or “Bragg wavelength," all the reflections add coherently. The grating reflects light in a narrow wavelength range, centred at the so-called Bragg wavelength.

A fibre Bragg grating (FBG) is a type of distributed Bragg reflector constructed in a short segment of optical fibre that reflects particular wavelengths of light and transmits all others. This is achieved by creating a periodic variation in the refractive index of the fibre core, which generates a wavelength specific dielectric mirror. A fibre Bragg grating can therefore be used as an inline optical filter to block certain wavelengths, or as a wavelength-specific reflector.
The fundamental principle behind the operation of a FBG is Fresnel reflection, where light travelling between media of different refractive indices may both reflect and refract at the interface. The refractive index will typically alternate over a defined length. The reflected wavelength ($\lambda_B$), called the Bragg wavelength, is defined by the relationship,

$$\lambda_B = 2n_e\Lambda$$

Where, $n_e$ is the effective refractive index of the grating in the fibre core and $\Lambda$ is the grating period. The effective refractive index quantifies the velocity of propagating light as compared to its velocity in vacuum. $n_e$ depends not only on the wavelength but also (for multimode waveguides) on the mode in which the light propagates. For this reason, it is also called modal index. The wavelength spacing between the first minima (nulls, see Fig. 2), or the bandwidth ($\Delta\lambda$), is (in the strong grating limit) given by,

$$\Delta\lambda = \left[\frac{2\delta n_0\eta}{\pi}\right]\lambda_B$$

Where $\delta n_0$ is the variation in the refractive index ($n_3 - n_2$), and $\eta$ is the fraction of power in the core. Note that this approximation does not apply to weak gratings where the grating length, $L_g$, is not large compared to $\lambda_B / \delta n_0$.

$$P_B(\lambda_B) \approx \tanh^2 \left[ \frac{N\eta(V)\delta n_0}{\eta} \right]$$

where $N$ is the number of periodic variations. The full equation for the reflected power ($P_B(\lambda)$), is given by,

$$P_B(\lambda) = \sinh^2 \left[ \eta(V)\delta n_0 \sqrt{1 - \Gamma^2 \frac{N\Lambda}{\lambda}} \right]$$

$$\cosh^2 \left[ \eta(V)\delta n_0 \sqrt{1 - \Gamma^2 \frac{N\Lambda}{\lambda}} \right] - \Gamma^2$$

Where,

$$\Gamma(\lambda) = \frac{1}{\eta(V)\delta n_0} \left[ \frac{\lambda}{\lambda_B} - 1 \right]$$

### III. GRATING FABRICATION TECHNIQUE

Many techniques have been developed for the fabrication of FBG i.e. transverse holographic (G.Meltz,1989), phase mask (K.O.Hill, 1993) and point-by-point techniques [3]. When UV light radiates on an optical fibre, the refractive index is changed permanently; this effect is known as ‘photosensitivity.’ Out of these three, the phase mask is the most common technique due to its simple manufacturing process, great flexibility and high performance.

**Transverse holographic technique:** The light from an UV source is split into two beams that are brought together so that they intersect; the intersecting light beams form an interference pattern that is focused using cylindrical lenses on to the core of optical fibre [3]. The fibre cladding is transparent to UV light, whereas the core absorbs the light strongly. Due to this light beam the core is irradiated from the side, thus giving rise to its name transverse holographic techniques. The holographic
technique for grating fabrication has two principal advantages.

- Bragg gratings could be photo imprinted in the core without removing the glass cladding.
- The period of the induced grating depends on the angle between the two interfering coherent UV light beams.

**Phase Mask Technique:** In this technique the phase mask is placed between the UV light source and the optical fibre. The shadow of the phase mask then determines the grating structure based on the transmitted intensity of light striking the fibre [4] & [5].

**Point-by-Point technique:** In this technique each index perturbation is written point by point. Here, the laser has a narrow beam that is equal to the grating period. This method of FBG inscription deep gratings have been written in a range of optical fibres at arbitrary wavelengths. It can be used to write gratings with periods of approximately 1 μm and above in a range of optical fibres [5]. In point by point technique, a step change of refractive index is induced along the core of the fibre at a time. A single pulse of the UV light passes through a mask to the core of the fibre containing a slit and thus the refractive index of the corresponding core section increases locally. The fibre is then translated along a distance corresponding to the grating pitch in parallel direction to the fibre axis, this process is repeated to form the grating structure in the fibre core.

**Grating structures**

The structure of the FBG can vary via the refractive index, or the grating period. The grating period can be either uniform or graded or localized and distributed in a superstructure. The refractive index profile in FBG can be uniform or aphorized, and the refractive index offset is positive or zero. There are six common structures for FBGs:

- Uniform positive-only index change
- Gaussian aphorized
- Raised-cosine aphorized
- Chirped
- Discrete phase shift

IV. APPLICATIONS

**Communications**

The primary application of fibre Bragg gratings is in optical communications systems. They are specifically used as notch filters. They are also used in optical multiplexers and demultiplexers with an optical circulator, or optical add-drop multiplexer (OADM). The FBG is set to reflect one of the channels, here channel 4. The signal is reflected back to the circulator where it is directed down and dropped out of the system. Since the channel has been dropped, another signal on that channel can be added at the same point in the network. Demultiplexer can be achieved by cascading multiple drop sections of the OADM, where each drop element uses an FBG set to the wavelength to be demultiplexed. Conversely, a multiplexer can be achieved by cascading multiple add sections of the OADM. FBG demultiplexers and OADMs can be also tunable. In a tuneable demultiplexers or OADM, the Bragg wavelength of the FBG can be tuned by strain applied by a piezoelectric transducer. The sensitivity of a FBG to strain is discussed below in fibre Bragg grating sensors.

![Fig 3: Optical add-drop multiplexer](image)

V. FIBRE BRAGG GRATING SENSORS

As well as being sensitive to strain, the Bragg wavelength is also sensitive to temperature. This means that fibre Bragg gratings can be used as sensing elements in optical fibre sensors. In a FBG sensor, the measurand causes a shift in the Bragg wavelength, $\Delta \lambda_B$. The relative shift in the Bragg wavelength, $\Delta \lambda_B / \lambda_B$, due to an applied strain ($\varepsilon$) and a change in temperature ($\Delta T$) is approximately given by,

$$\frac{\Delta \lambda_B}{\lambda_B} = C_S \varepsilon + C_T \Delta T$$

Or,

$$\frac{\Delta \lambda_B}{\lambda_B} = (1 - p_e) \varepsilon + (\alpha_A + \alpha_n) \Delta T$$

Here, $C_S$ is the coefficient of strain, which is related to the strain optic coefficient $p_e$. Also, $C_T$ is the coefficient of temperature, which is made up of the thermal expansion coefficient of the optical fiber, $\alpha_A$, and the thermo-optic coefficient, $\alpha_n$.

Fiber Bragg gratings can then be used as direct sensing elements for strain and temperature. They can also be used as transduction elements, converting the output of another sensor, which generates a strain or temperature change from the measured, for example fibre Bragg grating gas sensors use an absorbent coating, which in the presence of a gas expands generating a strain, which is measurable by the grating. Technically, the absorbent material is the sensing element, converting the amount of gas to a strain. Specifically, fibre Bragg gratings are finding uses in instrumentation applications such as seismology, pressure sensors for extremely harsh environments, and as downhole sensors in oil and gas wells for measurement of the effects of external pressure, temperature, seismic vibrations and inline flow measurement. As such they offer a significant advantage over traditional electronic gauges used for these applications in that they are less sensitive to vibration or heat and consequently are far more reliable. In the 1990s, investigations were conducted for measuring strain and temperature in composite materials for aircraft and helicopter structures.
VI. LITERATURE SURVEY

[1] M.S. Brahman, et al., investigated the effect of the refractive index of cladding (n_cl) to the Bragg wavelength and reflectivity of the grating. They found that the effect of the cladding refractive index was not linear. The Bragg wavelength shifted periodically with the change of cladding refractive index. The power also varied in a quadratic manner with a change of n_cl.

[2] D.W. Huang, et al., worked on reflectivity-tunable FBG reflector with acoustically excited transverse vibration of the fibre. They observed that when the transverse vibration induced the coupling between the core and cladding, the Bragg reflectivity varied from its original value to zero. With this technique, they varied the Bragg reflectivity after a fibre grating was fabricated.

[3] Caucheteur, et al., investigated the polarization properties of Bragg grating. They concluded that FBGs prepared by high-intensity laser pulse were characterized by high value polarization-dependent loss (PDL) and differential group delay (DGD).

[4] F.Z. Zhang, et al., examined the effect of the zeroth-order diffraction of the phase masks on FBG in polymer optical fibre by observing and analyzing the micrographs of the grating. When the strain was larger than 2%, the viscoelasticity of the polymer fibre was noticed. The 60nm Bragg wavelength shift was observed when they investigated the strain response by stretching the polymer optical fibre up to 6.5% of the polymer optical fibre.

[5] B.A. Tahir, et al., described the FBG sensing system for strain measurement. They calculated the reflectivity by keeping the grating length constant and varying the index modulation amplitude of the Grating. In their model, the average reflectivity was 96% and negligible change in reflectivity was observed by variation in index modulation. Also, if applied strain was uniform then Bragg wavelength shift occurred without modification of initial spectrum shape. Good linear response was observed between applied strain and Bragg wavelength shift.

[6] F. Zeng, et al., proposed an approach to implement optical microwave filters using an FBGS with identical reflectivity. The spectrum profile of the broadband light source can be controlled using an optical filter, which could be used to control the filter coefficients to suppress the filters side-lobes.

[7] M. ANDO, et al., 2004, investigated the dependence of FBG characteristics on grating length. They concluded that under the standard FBG fabrication condition, the exposure time of the FBG to excimer laser irradiation for a given transmission time was inversely proportional to the length of the grating. During their investigation, they fixed the value of amplitude of refractive index modulation of the grating even when the length was varied.

[8] S. Ugale, et al., found that the reflectivity increases with increase in grating length as well as index difference.

VII. CONCLUSION AND FUTURE SCOPE

The effect of number of grids and grating length of FBG on reflectivity and Bragg wavelength by keeping other parameters constant is analysed. The pitch of grating is directly proportional to grating length and inversely proportional to number of grids. On increasing the number of grids, keeping the grating length as fixed, the Bragg wavelength decreases and at the same time, the reflectivity increases. Also, when the grating length is varied, keeping the number of grid constant, the Bragg wavelength shifts and reflectivity decreases. A device that modulates the Bragg reflectivity of a fibre grating by exciting the transverse vibration of the fibre through an acoustic wave. The excitation of the transverse vibration, leading to fibre microbending, induces the coupling of the fibre core mode into cladding modes. This leads to the reduction of core-mode power and hence that of Bragg reflection. This mechanism provides us a means to control the reflectivity after a fibre Bragg grating is fabricated.

REFERENCES


