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ANALYSIS OF WAVELENGTH SHIFT IN FBGS ON EXTERNAL PERTURBATION

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ABSTRACT

Engineering structures stability depends largely upon the magnitude of parameters like strain, temperature, pressure, chemical and biological effect of environment. Fiber Bragg Grating(FBG) sensor technology has become one of the most rapidly progressing sensing topics of this decade in the field of optical fiber sensors. FBG sensors are currently emerging from the laboratory to find practical applications. Rapid progress has been made in both sensor system developments and applications in recent years. FBG have been applied to sense a number of physical measurements including strain, temperature, pressure, magnetic field, etc. These applications are based on the same principle i.e. the measurement of Bragg wavelength shift caused by the measurands. In this paper we have studied the shift in Bragg wavelength due to change in the grating pitch. The wavelength shift in FBG on simulated external perturbation using a wideband source has been observed. Since the strain or temperature measurement are encoded into wavelength shifts, so by comparing Bragg's wavelength shift with the reference Bragg's wavelength strain or temperature can be calculated.

KEYWORDS: Bandwidth, Fiber Bragg Grating, Sensor, Simulation

INTRODUCTION

FBGs are excellent sensing element due to their high sensitivity, multiplexing ability or temperature, a corresponding shift in reflected light is observed in FBGs. These have been successfully used for longitudinal strain, transverse strain, temperature, pressure, bend, simultaneous strain and temperature measurements and smart structures, etc.[1]. Several distinct types of FBGs have been developed in order to meet certain scientific needs. FBGs have become key passive devices for application in optical fiber communications and in the rapidly developing field of OFSs due to a number of advantages over other optical fiber sensors(OFSs) [2-3], These include

- Immunity against i.e., applicable in
- electromagnetic fields, high voltage, lightning – Explosive
- chemically aggressive & corrosive media – High
- low temperature- nuclear (Ionizing radiation environment)
- Light-weight, miniaturized, flexible, low thermal conductivity
- Non interfering, low loss , long range signal transmission ("Remote sensing").
- Have unique wavelength-division (WDM) and time-division multiplexing (TDM) capabilities,

- Embedding in composite materials (“smart structures”)
- Have the potential to be mass-produced at low cost,
- Have great potential in sensing applications for simultaneous measurements of important physical parameters and in quasi-distributed sensor networks,
- Highly reliable and secure with no risk of fire/sparks
- As a point sensor they can be used to sense normally inaccessible regions without perturbation of the transmitted signals
- Large bandwidth and hence offers possibility of multiplexing a large number of individually addressed point sensors in a fiber network or distributed sensing i.e continuous sensing along the fiber length

Properties of Fibre Bragg Gratings in Sensing

(a) Tuning FBGs

The central wavelength of a FBG is determined by the Bragg condition, in equation

$$\lambda_B = 2n_{eff}\Lambda\,. \tag{1}$$

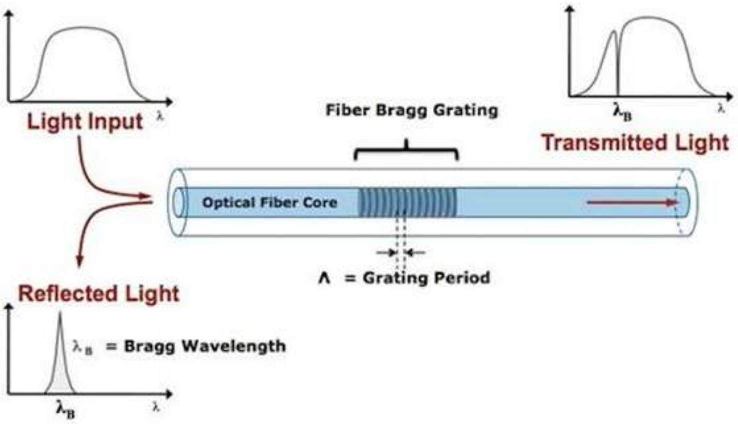

Figure 1: Diagram Illustrating the Properties of FBG

The Bragg wavelength (λ_B) of an FBG is a function of the effective refractive index of the fiber (n_{eff}) and the periodicity of the grating (Λ).

Differentiating equation (1) gives

$$\Delta\lambda_B = 2\left[n_{eff}\Delta\Lambda + \Lambda\Delta n_{eff}\right] \tag{2}$$

$$= 2n_{eff}\Lambda\frac{\Delta\lambda}{\Lambda} + \frac{2\Lambda(\Delta n_{eff})\times n_{eff}}{n_{eff}}$$

$$= \lambda_B\frac{\Delta\lambda}{\Lambda} + \lambda_B\frac{\Delta n_{eff}}{n_{eff}}$$

which gives

$$\frac{\Delta\lambda_B}{\lambda_B} = \frac{\Delta n_{eff}}{n_{eff}} + \frac{\Delta\Lambda}{\Lambda} \tag{3}$$

From equation (3) it is clear that either varying the pitch, $\Delta\Lambda$, or the RI, Δn_{eff} , the central wavelength can be shifted, via one or more of the following effects.

(b) Varying the pitch of the FBG

The periodicity, or pitch, of the grating is simply the distance between the fringes. If the grating has length L with N number of fringes, the pitch will be:

$$\Lambda = \frac{L}{N} \tag{4}$$

Which, when differentiated gives

$$\Delta\Lambda = \frac{\Delta L}{N} \tag{5}$$

Dividing equation (5) by equation (4) gives

$$\frac{\Delta\Lambda}{\Lambda} = \frac{\Delta L}{L} \tag{6}$$

Thus, the relative change of the pitch is identical to the relative change of the grating length.

This change in grating pitch can either be achieved through tensile stress, by simply stretching the fibre or through thermal expansion. The thermal expansion can be determined by the following relation

$$\frac{\Delta L}{L} = \alpha\Delta T \tag{7}$$

where α is the thermal expansion coefficient and can be determined by

$$\alpha = \frac{1}{L}\frac{\partial L}{\partial T} \tag{8}$$

However, the thermal expansion coefficient for silica is only α = 5 × 10-7 K^{-1}, which only gives a negligible contribution to the shift in wavelength compared to temperature and tensile stress [4-5].

(c) Varying the refractive index of the FBG

The RI of the fibre can be varied either through the photo-elastic effect or the thermo-optic effect. The relative change in RI, due to the thermo-optic effect is given by

$$\frac{\Delta n_{eff}}{n_{eff}} = \xi\Delta T \tag{9}$$

where ξ is the thermo-optic coefficient given by

$$\xi = \frac{1}{n_{eff}} \frac{dn_{eff}}{dT}$$

The thermo-optic coefficient (ξ) for Germanium doped silica core is 8.6 × 10^{-6} which is an order of magnitude larger than the thermal expansion coefficient.

Any external agents that is capable of changing grating pitch Λ will displace the reflected spectrum centered at Bragg wavelength. A longitudinal deformation, due to an external force, for instance, may change both Λ and n_{eff} ,and latter by the photo elastic effect and the former by increasing the pitch of the grating. Equally, a variation in temperature can also change both parameters, via thermal dilation and thermooptic effect respectively [6-7].

Therefore FBG is essentially a sensor of temperature and strain but, by designing the proper interface, many other measurements can be made to impose perturbation on the grating resulting in a shift in the Bragg wavelength which can then be used as a parameter transducer. Therefore by using an FBG as a sensor we can obtain measurements of strain, temperature, pressure, vibration, displacement, etc.

Using such a device and by injecting a spectrally broadband source of light into the fiber, a narrowband spectral component at the Bragg wavelength will be reflected by the grating. The spectral component will bemissed in the transmitted signal, but the remainder of this light may be used to illuminate other FBGs in the same fiber, each one is tuned to a different Bragg wavelength. The final result of such an arrangement is that we will have all Bragg peak reflections of each FBG back at the brginning of the fiber, each one in its specific wavelength range.[8]

Effects of Strain and Temperature on FBGs:

The core effective index of refraction and the periodicity of the grating determine its centre wavelength so that the change of fiber with strain and temperature will affect its core refractive index. The shift in the Bragg grating centre wavelength due to strain and temperature changes is given by [9] following equation

(a) The temperature increment ΔT affects the refractive index and the grating period, resulting in change in λ_B . For a temperature change ΔT , the corresponding shift in λ_B is given by

$$(\Delta\lambda_B)_{Temp} = \lambda_B(\alpha+\xi)\Delta T = \lambda_B\left(\frac{1}{\Lambda}\frac{d\Lambda}{dT} + \frac{1}{n_{ff}}\frac{dn_{eff}}{dT}\right)\Delta T$$

$$\frac{(\Delta\lambda_B)_{Temp}}{\lambda_B} = \frac{1}{\Lambda}\frac{d\Lambda}{dT}\Delta T + \frac{1}{n_{ff}}\frac{dn_{eff}}{dT}\Delta T \qquad (10)$$

The first term is the thermal expansion of silica(α) and the second term is the thermooptic coefficient(ξ) representing the temperature dependence of the refractive index.

(b) The axial strain affects the FBG response directly through the compression and expansion changes in the spacing of the periodic variation Λ and through the strain optic effect which induces a change in the effective index of the fiber n_{ff} . The wavelength shift, induced by a

longitudinal strain variation $\Delta\in$ is given by

$$(\Delta\lambda_B)_{strain} = \lambda_B\left[\frac{1}{\Lambda}\frac{d\Lambda}{d\in}+\frac{1}{n_{eff}}\frac{dn_{eff}}{d\in}\right]\Delta\in$$

$$\frac{(\Delta\lambda_B)_{strain}}{\lambda_B} = \frac{1}{\Lambda}\frac{d\Lambda}{d\in}\Delta\in+\frac{1}{n_{eff}}\frac{dn_{eff}}{d\in}\Delta\in \tag{11}$$

The first term in equation (11) is the strain of the grating period due to extension of the fiber. The second term in (11) is the photoelastic coefficient, the variation of the index of refraction with strain.

SIMULATION RESULTS

Any physical parameter (like temperature, strain, stress which causes changes in the pitch of the grating and the change in the refractive index can be sensed using a FBG by measuring the shift in the Bragg wavelength or the change in reflection coefficient of a particular wavelength[10].

The FBG sensors were designed with core diameter 5.25 um with refractive index of 1.458 and cladding with refractive index 1.450 um, Grating length is taken 5000 μm, Mod delta =0.0003. The effect of elongating the optical fiber and the grating pitch has been simulated using R-soft optical simulator by taking the output graphs by varying the grating pitch from 0.5320 to 0.5338 um in regular intervals of 0.0002 μm (Table1).

Table1: Simulation Results of Bragg's Wavelength Change Due to Change of Grating Period

Sl No.	Grating Period (um)	Bragg's Wavelength (nm)
1	0.5320	1545.20
2	0.5322	1545.80
3	0.5324	1546.40
4	0.5326	1546.90
5	0.5328	1547.50
6	0.5330	1548.10
7	0.5332	1548.60
8	0.5334	1549.20
9	0.5336	1549.80
10	0.5338	1550.40

Simulated results in the form of graphs of reflected power as a function of wavelength. There is a shift in the wavelength because of changes in the grating period and the index of refraction. Figure 2 provides the simulated results of a FBG centre wavelength shift as a function of Grating period.

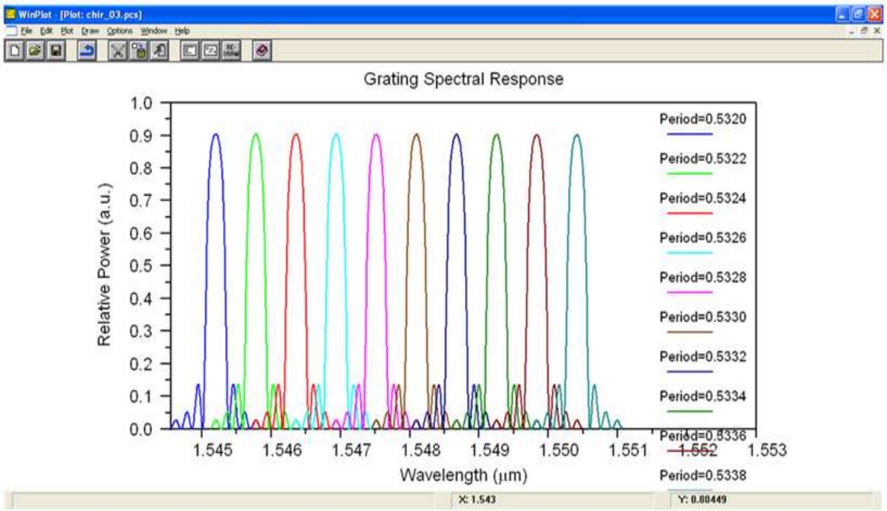

Figure 2: Bragg's Wavelength Shift as a Function of Grating Period

From the graphical simulations using advanced simulation tools, it can be concluded that increase in the grating pitch will cause a shift in Bragg's wavelength.

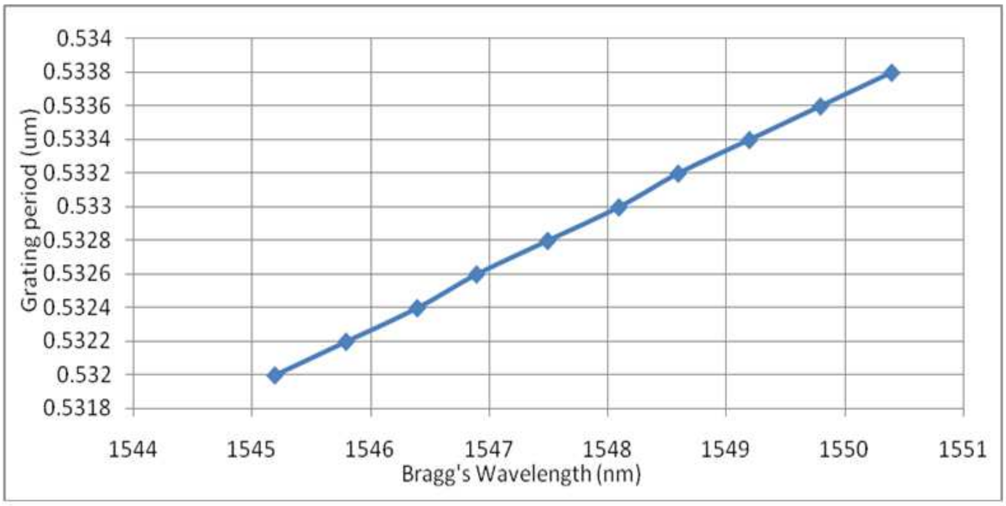

Figure 3: Bragg's Wavelength vs. Grating Period

It is observed from the simulated results that when there is a change in optical properties of a material (FBG) the Bragg wavelength shifted.There is a linear relationship between the Bragg wavelength shift and the grating period (Figure 3).

CONCLUSIONS

From the graphical simulations, it can be concluded that a slight change in the strain, temperature, pressure, etc changes the grating period of the FBG and induces a measurable change in the spectral location of these extremum. Using the advanced simulation tools it is possible to design the fiber Bragg grating sensor for strain, temperature, etc measurement.So by comparing the shifted Bragg wavelength due to the thermo-optic and elasto optic with reference Bragg wavelength at room temperature and without any stresses, it is possible to sense the temperature and strain with neglible error.

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