Assay of Fiber Bragg Grating Sensor and its Simulation for Highest Reflectivity

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ABSTRACT : Through this paper, an attempt has been made to work on simulation of Fiber Bragg Grating (FBG) sensor for least attenuation criteria that is highest reflectivity. The outcome of this research depicts that one can design FBG sensor from basic concepts using a software application. Bragg grating sensor for pressure measurement by first evaluating the grating pitch for maximum reflective power in accordance with given wavelengths and then describe the sensor by differentiating the grating pitch as it would change in presence of strain and noting the decrease in reflected power for a definite wavelength. So simulation tools help us in optimising the design parameters even before inscribing the grating in the fiber. The result received through simulation depicts efficiency in the incorporated method which further can be utilised in real time work in varied field.

Index Term*: Fiber, Bragg Grating, , Instrumentation , Modulation , Optics Wavelenght, Power, Reflection, Simulation, Sensor*

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1. INTRODUCTION

In 1960s, the advent of laser revolutionised the domain of data communications. This imitation further motivated the researchers to study the prospects of fiber optics and its intensity in data communications, sensing, and other aspects. The ongoing advances have significantly transformed the telecom industry. The ability to carry extensive information at considered speed has increased the research potential in optical fibre.

Optical fibre sensors have multiple components. A light source, optical fibre, external transducer and a photo detector . They function by detecting the modulation of certain important properties of light that enters the fibre. Number of fibre optic sensing mechanism has been studied for industrial and biomedical application. However the most common sensors are based on EFPI(external fibre fabry perot interferometer) and FBG (fibre bragg grating).

Fibre Bragg Grating sensors analyse the spectral properties of reflected light to measure different parameters. The fundamental principal of these sensors is that certain factors when applied on the fibre optic pressure sensor affect the bragg wavelength modifying its physical and geometrical properties of the FBG. The FBG do have certain drawbacks the biggest obstacle is to differentiate between strain and temperature changes, when there is significant temperature fluctuations, it becomes difficult to make correct pressure measurement. However this problem can be tackled by either by using sophisticated coating or to implant a temperature compensation system [1]. FBG pressure continue to be available in many industrial application such as monitoring of liquid level in storage tank, down hole pressure measurement, gas turbine engine and other important fields. They have great stability, they are small, portable and not affected by electromagnetic interference [2].

For several decades now , electrical sensors have been used for measuring physical and mechanical phenomena. Despite there wide pressure for significant period ,they are a cause of transmission loss and susceptible to electromagnetic interference that make their utility challenging in many applications [3]. Fibre optic sensing is an excellent solution to these difficulties as they use light instead of electricity and optical fibre in place of copper wire. The significant drop in optical component prices along with improved quality is the result of advances in the field of optoelectronics and fibre optic communication.

Presently, the fibre optic sensors and elements have seen a shift from experimental lab research to wide applicability in various aspects of health and industries.

2. SOFTWARE METHODOLOGY USED TO DESIGN THE FBG SENSOR

GratingMOD is an unified software unit which is able to analyse the grating structure (design) and study the characteristics of grating from measurement or any other spectra. GratingMOD is well suitable with any kind of waveguide transverse profile that are designed in RSoft CAD. In GratingMOD, a periodic longitudinal perturbation is defined to produce a longitudinal grating structure. This leads to a simulation method that is computationally faster than both Bi-Directional BPM and FDTD, and it is equally well suited to both 2D and 3D problemsMoreover, combining sections employing different types of gratings can form complex-grating devices. Grating profile, apodization, and chirp can be chosen from pre-defined functions or specified by user-defined expressions or files. Powerful post-processing includes, but is not limited to, spectrum analysis including determination of bandwidth and side lobe characteristics, delay and dispersion, curve fitting to grating characteristics, and field pattern display.

The procedure and the techniques of designing the Fiber Bragg Grating sensor are briefly described here in this section. GratingMOD is the tool used here and is utilised for synthesizing and analysing of complicated grating profile in optical fibres and integrated wave-guide circuits for a wide variety of photonic applications. Quick innovation in designing ability to handle gratings embedded in irrational waveguide profiles makes this GratingMOD a synergistic addition to the Rsoft tool suit.

Various steps that are included in the process of designing and simulation of FBG sensor using GratingMOD tool are described below.

- Setting up of the fiber
- The grating layout utility
- Modifying the utility output
- Displaying the index profile
- Performing the first simulation *f*
- Performing the second simulation
- Reflection spectra & delay vs. Wavelength

3. DESIGN OF THE FBG SENSOR

Adept light transmission at the operational wavelengths is the important function of fiber optics required for all varied of application.(optical delivery for surgical or biomedical applications, fiber lasers, long haul telecommunications). When the light propagates through a fibre, its reduced intensity is called attenuation. Some existing attenuation in any optical fiber needs that fiber system design address degradation in signal strength accomplishes such approach as interconnect optimization, fiber geometry design, signal amplification and environmental isolation [4]. Thus it is very important to understand the mechanism of attenuation in order to achieve efficient and economic use of fiber optics.

FBG's are made by using holographic interference or a phase mask to expose a small length of fiber to periodic dispensation of light intensity. As a result of this , the refractive index of fiber is permanently altered in accordance to the light it is exposed to. The resulting cyclic variation in refractive index is called FBG [5]

FBG, reflection from each section of alternating reflecting index intervene constructivity only for a specific wavelength of light which is called the Bragg wavelength. This results in reflection of specific frequency with transmission of all others.

$$\lambda_b = 2n\Lambda \text{ .... } (1)$$

where λb is the Bragg wavelength, n is the effective refractive index of the fiber core, and Λ is the spacing between the gratings, known as the grating period in equation (1).

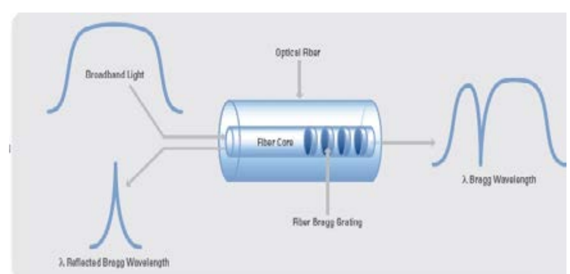

Fig. 1. Operation of an FBG Optical Sensor

Since the Bragg wavelength is a function of spacing between grating, FBG can be constructed by using variations Bragg wavelength which permits different FBG to reflect various wavelength as shown in the figure 1 and figure 2.

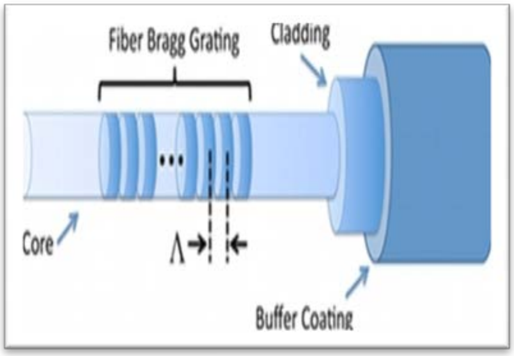

Fig 2. An Expanded View of an FBG

Any variation in strain and temperature affect both refractive index n and grating period Λ of FBG which results in shift in reflected wavelength.This change in different variables can be explained by equation (2) where Δλ is the wavelength shift and λo is the initial wavelength.

$$\frac{\Delta\lambda}{\lambda_0} = (1 - p_e) * \varepsilon + (\alpha_\Lambda + \alpha_n) * \Delta \quad \text{................ (2)}$$

The first expression conveys the affect of strain on wavelenght shift where Pe is strain optic coefficient and ε is the strain experienced by the grating. The second expression describes the effect of temperature on wavelength shift where α thermal expansion coefficient and α_n is the thermo optic coefficient.[7-9].

For accurate strain measurement, we need to multify the temperature effects on the FBG. We can accomplish this by insulating a FBG. Temperature is close thermal contact with FBG strain sensor. The FBG temperature sensor wavelength shift gets subtracted from FBG strain wavelength shift resulting in removal of secong expression of equation (2) providing us with temperature compensated strain value [6].

However, proper understanding of basic phenomena of fiber optics at work and their connection between material composition and structure is required.

The overall optical throughput (transmission) of an optical fiber can be quantified in terms of the output power, P(z) and the input optical power, P(0), observed after light propagates a distance, z, along the fiber length.

$$P(z) = P(0)e^{-\alpha total^{z}} \quad \text{.............(3)}$$

$$\%T = P(z)/P(0) \quad \text{................. (4)}$$

Where αtotal = the total attenuation coefficient (i.e. involving all contributions to attenuation) and %T is the percentage optical power transmission. Equation is referred to as Beer's Law and shows that transmitted power decreases exponentially with propagation distance through the fiber. Refer to equation 3 and 4.

3.1 Setting Up Of The Fiber

Determine facile, consistent FBG and specify the FBG through sinusoidal index perturbation along propagation axis of the fiber. The fiber cladding index is set at 1.45 and here it is assumed to be infinite. The diameter of fiber core is positioned at 5.25µm and its index is set at 1.458. we will verify the modulation depth of the index perturbation in order to study the alteration in the grating operation around the specific set of wavelength. Structure type of fiber is selected as 3D and simulation tool is set as GratingMOD. The profile type is selected as step index / single mode.

3.2 The Grating Layout Utility

Now we use grating layout utility in order to speed up this type of grating mechanism. This option is available at utility icon in the CAD menu. Layout option is set to fiber , and the grating type to volume index. Modulation depth was set 0.0012 in order to designate that we want to create an index modulated fiber structure. Waveguide length and height is set to 5.25µm and delta to 0.0008 to set the index and geometry related parameters. Lastly enter a layout file meta prefix such as fbg and press OK button. In the CAD window automatically fbg.ind file will be formed as shown in the figure 3 [10].

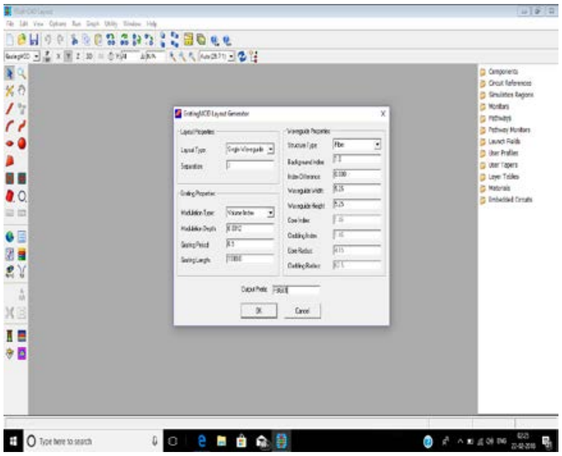

Fig. 3. The GratingMOD grating layout utility window used to create a simple uniform FBG structure.

The file consists of single fiber segment with aimed index perturbation. Segment properties dialog box can be accessed and it controls all the parameters for the fiber, including the index modulation and perturbation. In our case we have set index perturbation to user-defined grating taper function [11].

3.3 Modifying The Utility Output

Now that the basic structure is been defined, we are required to do additional changes in order to get desired structure. In the global setting dialog box, the value of background index has to be changed to 1.45. Length of the grating needs to be changed after this.

The length of the grating is set to N=10000 periods. Value of predefined symbol length=N*Period and the symbol length is length of the segment. The parameter is also predefined but later on we will see that its value will be chosen by GratingMOD based on Bragg condition in order to work for chosen central wavelength [12].

3.4 Displaying The Index Profile

After the index information and fiber geometry are all set it is advised to check the index profile before starting the simulation. This is done to check the structure achieved is adequate. In order to perform this, press compute index profile button in the CAD window. In order to decide the grating structure well we need to sum up only profile for the first 10 periods. Z - domain is set to maxium of 10*Period [13]. Z- compute step and Z- slice step is set to 0.1 . Finally display button is pressed and change the index max from its default value to background_index + delta*(1 + ModDepth) as in figure 4.

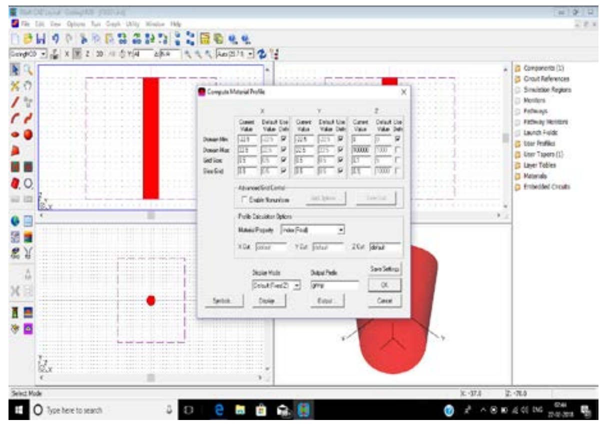

Fig. 4. The simulation parameters for the index profile calculations.

With this we will establish a maximum value for displayed index equal to maximum value of index of grating. Index profile will be calculated on pressing twice the OK button and to do this press compute index profile key present in the CAD window.

To visualise better structure we are calculating a profile for the first 10 periods. As soon the computation completes index perturbation appears distinctly and index profile gets displayed [14] as shown in the figure 5.

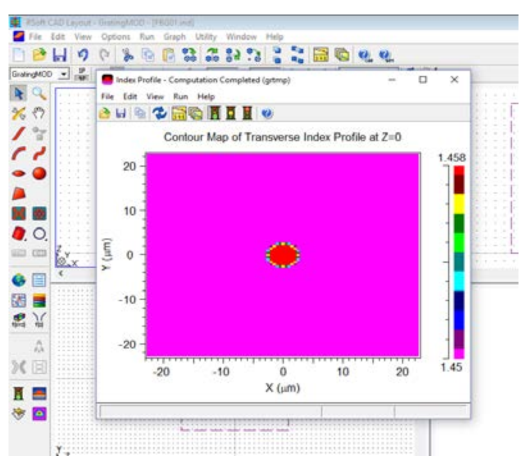

Fig 5. The computed index profile for a uniform FBG

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Furthermore we have to calculate the reflection spectra and group delay in the design. Various index modulation depth will be analysed. Here we will study the results for a modulation depth of both 0.0012 and 0.0003 and then display these results later.

3.5 Performing The First Simulation

For the first simulation we have set the modulation depth of grating at 0.0012 and this is done by symbol ModDelta which was defined by grating layout utility.
Perform simulation icon in the CAD window will open the GratingMOD analysis dialog box and check that grating simulation module is set to Grating analysis. This will lead to grating analysis[15].
In the earlier section we decided that we are going to fix the central wavelength and permit the GratingMod to calculate the Period in order to gratify the Bragg condition.
To accomplish this, we select a Fix Centre Wavelength and then set the wavelength to 1.55 For this example, the default values for the rest of the simulation parameters are appropriate [16] as shown in Figure 6.
Next, press output button to set the output options for this simulation. Mark the delay / dispersion to yes, select the output spectrum to reflected and this will save the desired data from the simulation to disk. Lastly output prefix is assigned as such as FBG_01 and click OK to perform the simulation [17].

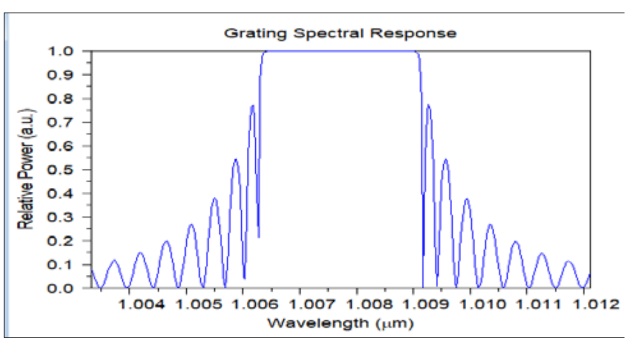

Fig 6. Simulation results from 1st grating analysis

After the automatic mode calculation, the reflected spectrum will appear and the data from this simulation has been saved in the files with the prefix FBG_01 with its plot files. The first simulation results are shown in the Figure 7 respectively [18].

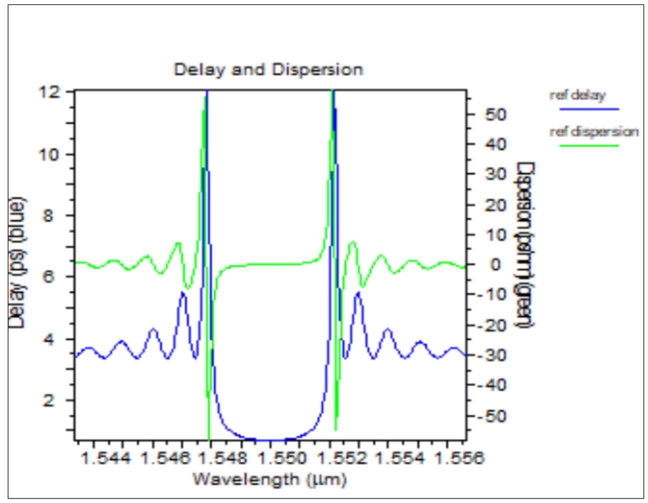

Fig 7. Simulation results from 1st grating analysis.

3.6 Performing Second Simulation

After the first simulation is executed, a second simulation with a modulation depth of 0.0003 is to be performed. Change the value of Modulation depth to 0.0003, set the output prefix a name, such as FBG_02 and start the second simulation. The second simulation results are shown in the Figs. 7(a) & (b) respectively. Note that grating period is calculated accordingly in order to satisfy the Bragg condition, which is presented on top of the graph.

4. SIMULATION RESULTS & DISCUSSIONS

Here we are going to discuss the results and outcome of simulation done. We are also going to conclude into statement of results from simulation.
The process of modelling was done with a help of dynamic and intelligent tool. During the creation of FBG there were parameters which were selected as per our requirement for desired sensor development. We chose single mode fiber with its core diameter measuring 5.25 µm. Refractive index

of core was 1.458 and the index difference was 0.01. under undisturbed situation the grating length will be 1mm. Roughly the count of grating pitch in this length is 2000 [19-20]

It is very essential to keep in mind that spurious strain considered is well within the limit of breaking strain, that is roughly 4%.

For the second simulation some of the parameters are altered keeping rest same as the first simulation. The parameters are mentioned below:

- Simulation tool : Grating MOD
- Profile type : Step index, single mode
- Grating type : Volume index
- Structure type : Fiber
- Modulation depth : 0.0003
- n = 10,000
- Period = 0.5
- Waveguide width : 5.25 µm
- Waveguide height : 5.25 µm
- Length = n * period = 5000
- Fix wavelength = 1.0275 µm

The interrogating wavelength of light signal was selected to 1550nm, this falls under criteria of low attenuation during transmission between FBG sensor electronic instrumentation.[21]

The procedure applied for designing and analysing of grating sensor are depicted in following figures. Refer to figure 9 to 14.

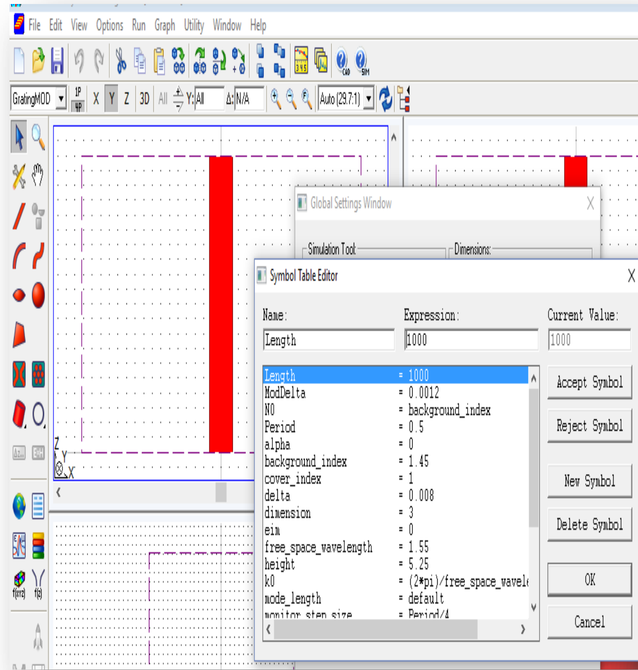

Fig 9. Parameters specification 1

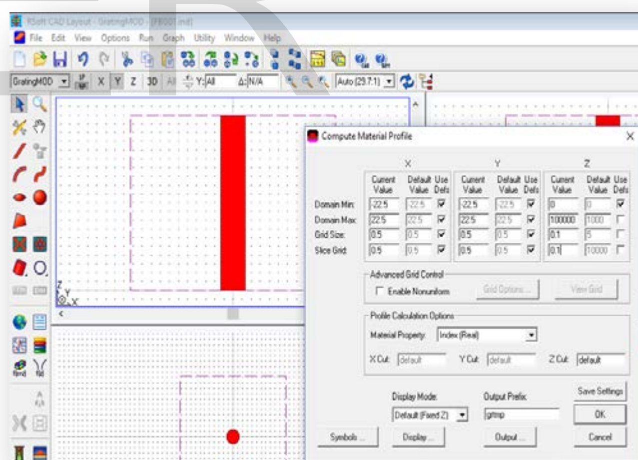

Fig. 10 Parameters specification 2

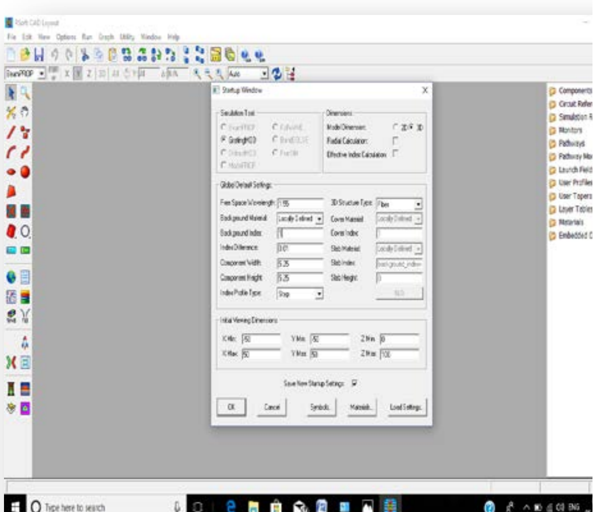

Fig 8. Startup window

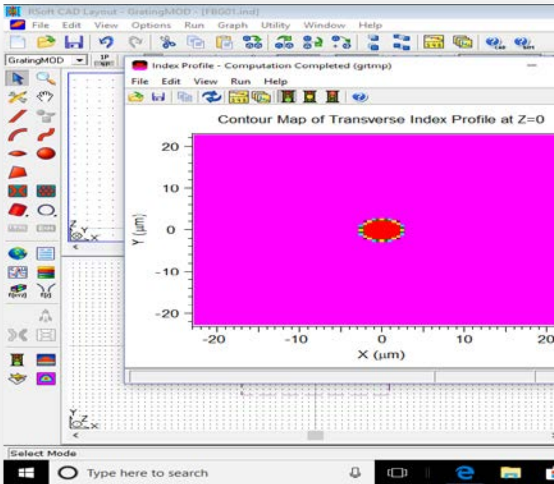

Fig. 11. Parameter specification 3

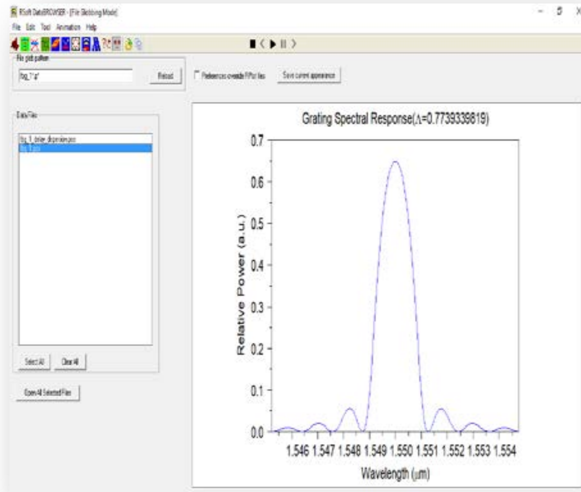

Fig.13. Grating spectral response, i.e., relative power vs. wavelength

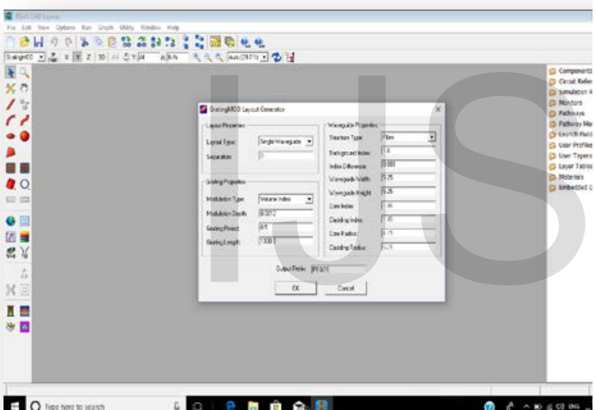

Fig. 12. Parameter specification 4

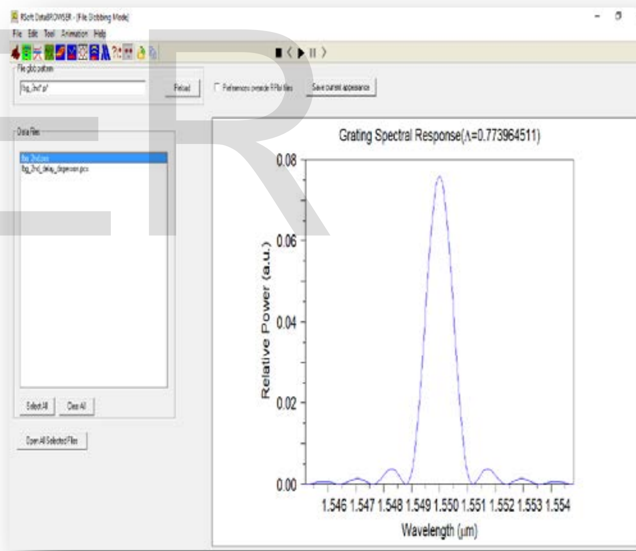

Fig.13. Grating spectral response, i.e., relative power vs. wavelength

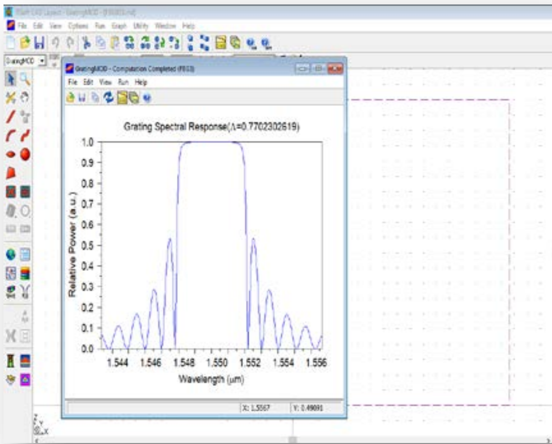

Fig. 14. Grating spectral response, i.e., relative power vs. wavelengthfor second simulation

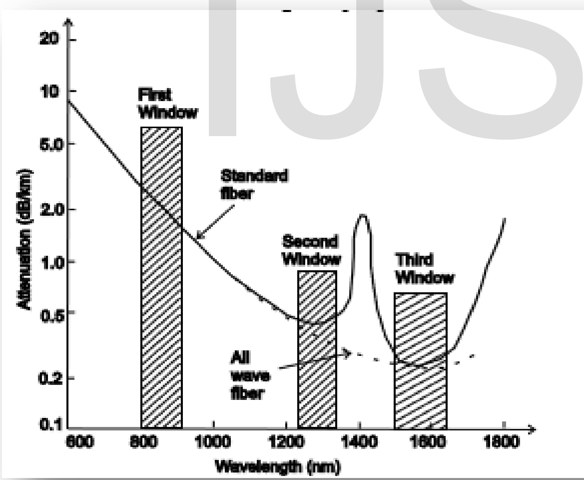

Fig.15 Optic fiber attenuation as a function of wavelength

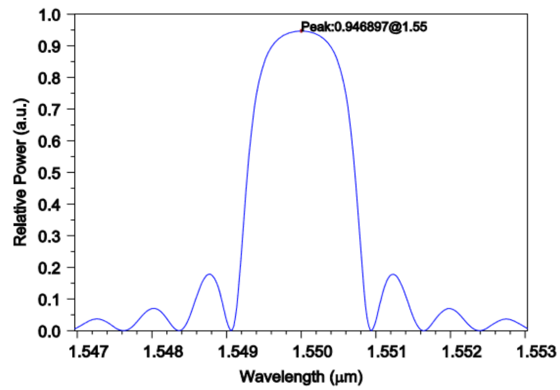

Fig.16. Reflected power as a function of wavelength at 1550 nm

To analyse result of strain(pressure or any kind of compression) in optical fiber, the grating pitch has been varied from 0.5325 to 0.5327 with regular interval of 0.0001μm.[22]This observation help us to determine the strain in the fiber and further analogous measurement can be done as shown in the figure 15.

Above figure 16. shows that for grating pitch 0.5325 μm the reflectivity at selected wavelength 1550nm has minimised to 81.5% [22].

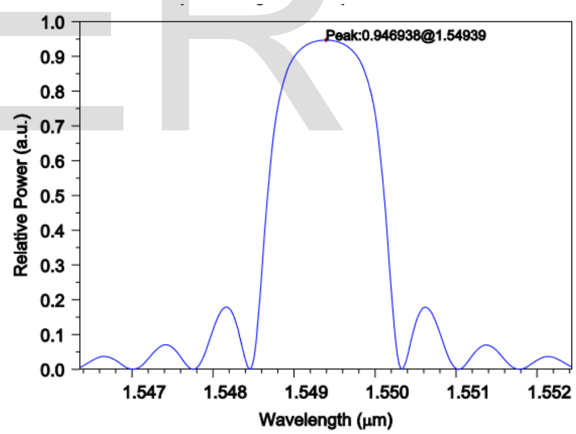

Fig.17. Reflected power as a function of wavelength with fiber having pitch 0.5323 μm. Reflected power at 1550 nm is approximately 81.5 %

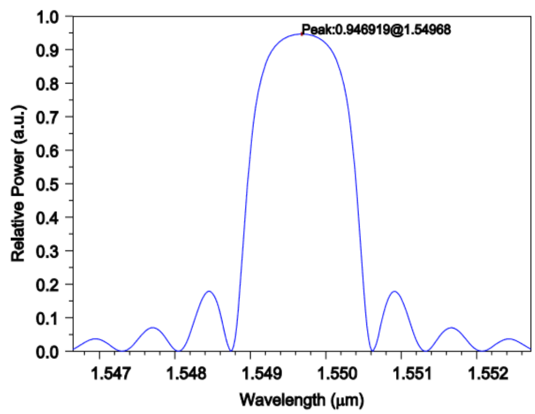

Fig. 18. Reflected power as a function of wavelength with fiber having pitch 0.5324 µm.

Reflected power at 1550 nm is approximately 93%
Figure 17 and figure 18. shows that for grating pitch 0.5326 µm the reflectivity at selected wavelength 1550nm has almost decreased to 81.5% and the reflected power as a function of wavelength with fiber having pitch 0.5324 µm respectively . Reflected power at 1550 nm is approximately 93% .

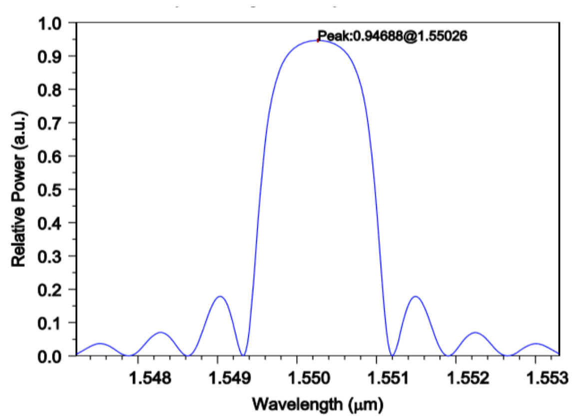

Fig. 19. Reflected power as a function of wavelength with fiber having pitch 0.5326 µm. Reflected power at 1550 nm is approximately 91.5%

A figure 19 and figure 20. shows that a graph of reflected power as a function of wavelength with fiber having pitch 0.5326 µm. Reflected power at 1550 nm is approximately 91.5% for grating pitch 0.5327 µm and the reflectivity at selected wavelength 1550nm has almost decreased to 81.5% [23].

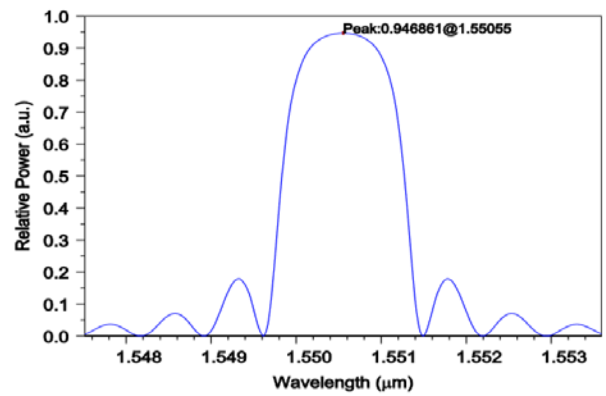

Fig. 20. Reflected power as a function of wavelength with fiber having pitch 0.5327 µm . Reflected power at a reflectivity of 1550 nm is approx 81 %

Thus, we can conclude that change in the pitch, changed the reflectivity of the interrogating wavelength. The above depicted plot help us to evaluate the efficiency of developed FBG sensor . Sensor characteristics were also studied and analysed.
In conclusion the product of different pitch studied and percentage of reflected power is elaborated as table below.

Table 1. Reflected power as a function of wavelength

No.	Pitch	Wave-length	Relative power
1.	0.5323 µm	1550 nm	81.5 %
2.	0.5324 µm	1550 nm	93 %
3.	0.5325 µm	1550 nm	94.6 %
4.	0.5326 µm	1550 nm	91.5 %
5.	0.5327 µm	1550 nm	81 %

Thus we conclude that on increasing the pitch, the reflectivity of interrogating wavelength changes. The above demonstrated plot and table and simulation results clearly shows that reflection coefficient at interrogating wavelength 155nm can be same for two different pitches, one lesser and one greater than grating pitch of 0.5325µm (which gives bragg wavelength of 1550nm) as shown in the the table 1. This is why, we have to find out the direction in which pitch would change prior to measurement of any kind of physical parameters [24].

5. CONCLUSION

Through this paper, an attempt has been made to work on simulation of FBG sensor for least attenuation criteria that is highest reflectivity. The outcome of this research depicts that one can design FBG sensor from basic concepts using a software application. Bragg grating sensor for pressure measurement by first evaluating the grating pitch for maximum reflective power in accordance with given wavelengths and then describe the sensor by differentiating the grating pitch as it would change in presence of strain and noting the decrease in reflected power for a definite wavelength.

So simulation tools help us in optimising the design parameters even before inscribing the grating in the fiber. FBG sensor works on the principle that Bragg wavelength varies with the pitch of grating and refractive index. Thus any physical factors such as temperature, strain shifts which alters the above parameters can be accurately sensed using FBG by simply estimating the shift in Bragg wavelength in the change in reflection coefficient of a given wavelength.

When fiber Bragg grating is interrogated with light of a particular wavelength, the reflection coefficient changes with variation in the grating pitch between the refractive index caused by physical parameter to be measured.

FBG may be defined as longitudinal periodic variation of refractive index in the core of optical fiber. The interval in between variation depends upon the wavelength of light to be reflected.

This research work presented in this paper usually dealt with physical parameters such as strain to be sensed using fiber Bragg Grating sensor. In addition, we can also use other factors such rotation, acceleration electric field & magnetic field measurement, temperature, pressure, displacement, acoustics, vibration and linear and angular position, stress, strain, humidity viscosity and chemical measurements including the refractive index.

Few software are available which provide with facility to plot graph between wavelength versus reflective power to the efficiency of the FBG sensor, which may be in work of future.

Also the simulated FBG sensor could be constructed are tested for consistency and reliability. A real time experiment which could be done in future can authenticate the experimental result and the simulated result.

6. ABBREVIATIONS

OFBG Optical Fiber Bragg Grating
FBG Fiber Bragg Grating
CAD Computer Aided Design

7. REFERENCE

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