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# Characterization of Uniform FBG sensor Operation for Signal Filtering Application

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**ABSTRACT**

*Uniform Fiber Bragg Grating (UFBG) is used almost for sensing technology, while the other possibilities and applications for it was not enriched from researchers. We simulate the solution of Coupled Mode Theory (CMT) by constructing a MATLAB program to study the reflection and transmission light spectra to estimate another application. The laser pulse bandwidth variation due to reflection and transmission of FBG was also studied. The FBG efficiency for a standard device is determined theoretically.*

*Experimental set up were constructed to measure the same above parameters to compare with theoretical analysis. Results show that the UFBG was worked as filter in additional to its basic function. Transmitted spectrum was filtered from shorterincident wavelengths. This meets specific applications such as optical communications.*

**Key words:** Uniform Fiber Bragg Grating (UFBG), Coupled Mode (CM), MATLAB program, power reflectivity, Bragg wavelength

## INTRODUCTION

UFBG sensor has been widely used in sensing applications because of their specifically smart physical characteristics, such as intrinsically large multiplexing capabilities, remote sensing, resistance to electromagnetic fields and safety [2]. UFBG sensor can be used in different experimental fields such as medicine, diagnostic processes and developmental. Also, UFBG sensor are filters of spectral invented inside fibers. [2]. Figure (1) displays UFBG design and it spectra.

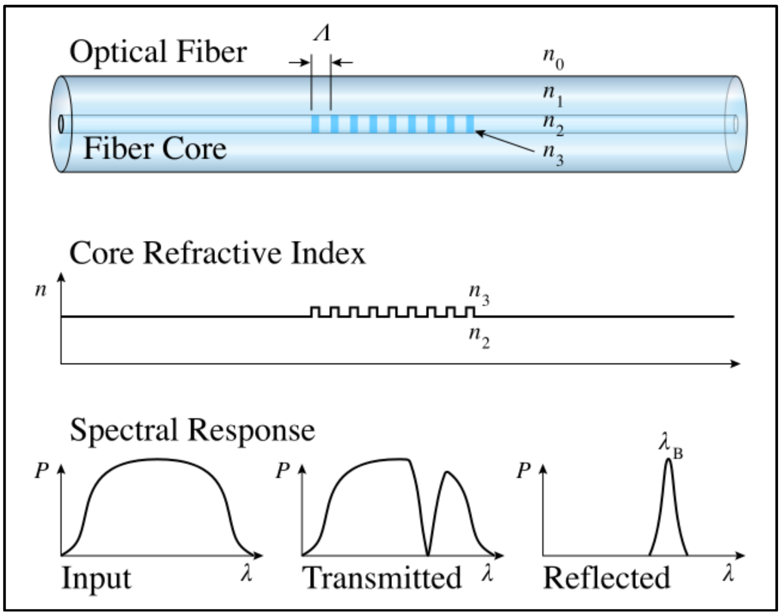


**Fig. 1** UFBG design and its spectra [2]

Optical properties of Single Mode Fiber (SMF) can be changes permanently if exposed to strong radiation from a laser working in the ultraviolet to the infrared spectral region [1]. When lightinserted via a UFBG, its transmission spectrum affected due to the grating variation of refraction index. Insideregions, there exist a stop band for specific wavelengths, makes itback reflected. For pulsesthose areoutof the stop band, spectrum transmitted with specific changes, we will study it in this research. Reflected andtransmitted pulseshave different shape than the incident pulsesdue todispersive properties of UFBG medium and also splitting of the pulses spectrum [1].

**Theory:**

Basic functionof UFBG is that part of incident wavelengths of light back reflected by grating fringes.Accordingly, forward and backward propagating modescan be coupled. This coupling expressed for a maximum reflection of the wavelength which provided by Bragg condition [3]:

$$\lambda_{\mathrm{B}} = 2\, n_{eff}\, \Lambda \qquad (1)$$

where $\lambda_{\mathrm{B}}$ is the Bragg wavelength, $n_{eff}$ is the effected refractive index of core and, Λ is the grating period.

UFBG has a constant grating period, the forward propagated fields and backward propagated fields are expressedby equations known as "Equations of Coupled Mode ECM" [3].

**Solution of Equations of Coupled-Mode (ECM)**

ECM is a manner to analyse the propagation of light waves in a linear periodical media which perturbation until weak waveguide coupled. Idea of this theory or equations are the modesuncoupled structures must bedefined and solved at first [4]. Consideringthe nonlinear effectsisvery weak, wecan be supposing that the fiberis a linear medium [5]. These modes dealing as a trial solution of Maxwell's equations for coupled mode structure. Derivation of ECM and solution then can be done by numerical analysis methods [4].

ECMis widely usedfor feedbackdistribution of semiconductor laser [5], also in FBG problems, i.e. treatment of two mode propagated in different directions inside it [5,6]. Note that the ECM acts when the index variation is so small so that suitableto solveUFBG problems. By solution of ECM, theproperties of refection, transmission anddiffraction efficiency of UFBG can be achieved. The effective refractive index ($n_{eff}$) of propagating modes along the fiber z axis is given by the following equation [7];

$$n_{\,eff}(z) = \delta n_{dc}(z) + n_{ac}(z) cos\left[\frac{2\pi}{\Lambda}\, z + \varphi\,(z)\right] \qquad (2)$$

where; $\delta n_{dc}(z)$ is the "dc" index change on the grating length,$n_{ac}(z)$denotes the index change distribution or "apodization", and parameter (c) is account for additional UV induced change of the average index along the fiber., and φ (z) terms grating chirp. Now, if two modes propagates via the UFBG core, its electric fields expressed as [Yue Qiu];

$$\left.\begin{matrix} R(z) = A(z)exp\,(\,j\delta z\ -\varphi\,/\,2)\ \ fort\,heforwardmode \\ S(z) = B(z)exp\,(-\,j\delta z\ +\varphi\,/\,2)\,forbackwardmode \end{matrix}\right\} \qquad (3)$$

$$\delta = \beta - \frac{\pi}{\Lambda} = \beta - \beta_D = 2\pi n_{eff}\left(\frac{1}{\lambda} - \frac{1}{\lambda_D}\right) \qquad (4)$$

where; $\beta\ = 2\pi\, n_{eff}\,/\lambda$ which is the mode propagation constant, $\lambda_D = 2n_{eff}$ Λis the design wavelength for Bragg scattered for very weak grating ($\delta n_{eff}\ \to 0$ ) at period (Λ) [7].

The solution of ECM is a first-order ordinary differential equation with a constant coupled coefficient for proper boundary conditions $u(L)\ =\ 1$, and $v(L)\ =\ 0$. This solution is UFBG reflectivity forward direction of waves which come from $z\ =\ -\infty$ at length $L$, the reflected coefficient $\rho\ =\ v(0)\,u(0)$, if $\rho = \,|r|^2$ then [7]:

$$\rho = \frac{-\,K\ \sinh(\sqrt{K^2-\hat{\sigma}^2}L)}{\hat{\sigma} sin\,h\left(\sqrt{K^2-\hat{\sigma}^2 L}\right)+i\sqrt{K^2-\hat{\sigma}^2}\cosh(\sqrt{K^2-8}L)} \qquad (5)$$

$$r = \frac{sin\,h^2(\sqrt{K^2-\hat{\sigma}^2}L)}{cos\,h^2\left(\sqrt{K^2-\hat{\sigma}^2}L\right)-\frac{\hat{\sigma}^2}{K^2}} \qquad (6)$$

where;$\sigma$ is a coefficient of period coupling, and K is the coupling coefficient.

**Simulation of UFBG**

Before starting our experiment, experience of UFBG sensorischaracterised theoretically. Reflected spectrumand also reflected pulse bandwidth were analysed by constructing acomputer programin MATLAB language.This calculations was based on the solution of ECM that given in eq. (5), i.e. calculating the $r$ parameter. Remaining parameters in that equation were set as the following;

effective index: 1.444, the length of UFBG:10mm, 4.1µm, core Radius: 4.1µm, Standard Bragg (experimentally measured) wavelength: 1539.185 nm. This is according to parameters given by [9]. Code of the simulation were identical to that given in reference [10]. Flowchart of processes for theoretical analysis by Matlab program explain by figure (2).

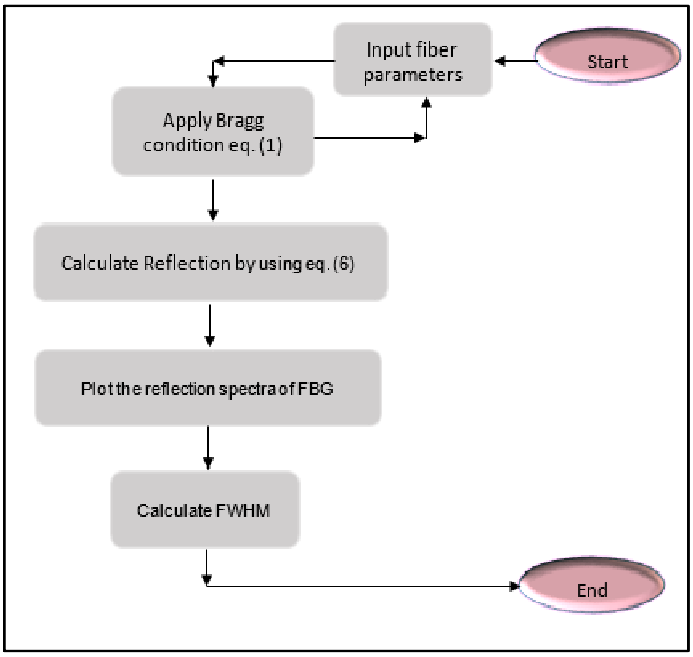


**Fig. 2** Flowchart of the program

## EXPERIMENTAL SETUP

In this experiment, the used FBG consists of is a single mode optical fibergrating, acrylate coated, with FC/FC connectors. The fiber radius is 2.0mm, and fiber length is 3m, with standard operating wavelength 1539.185nm. Bragg transmission bandwidth is 0.176nm and peak reflectivity is 94.25%. All these parameters were employed to measure the spectrum of reflectivity and transmitted.

Wavelength of the used laser source was 1550nm. Avante Optical Spectrometer (AOS) was used to analysis spectrum. Origin Data Analysis and Graphing 2018 was employed to data analysing. Figure 3 shows experimental set up for measuring the transmitted spectrum, figure 4, its experimental diagram, figure 5, shows the experimental setup for measuring the reflected spectrum.

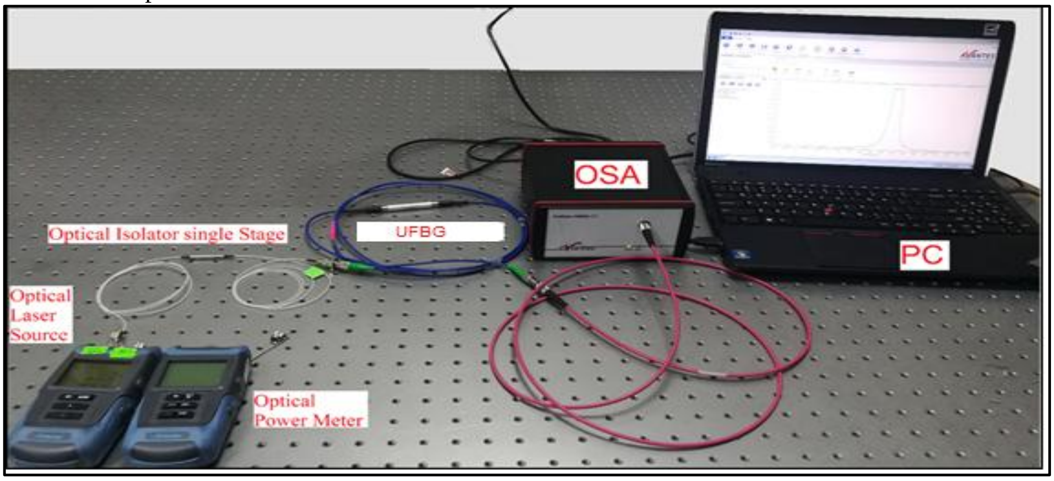


**Fig. 3** Experimental setup for measuring the transmitted spectrum

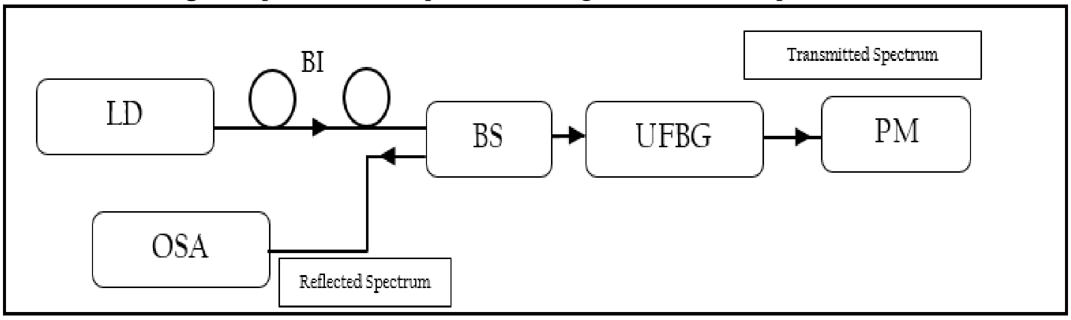


**Fig. 4** Experimental system setup diagram

LD: Laser Diode, BI: Beam Isolator, BS: 2 × 1 Beam Splitter, PM: Power Meter

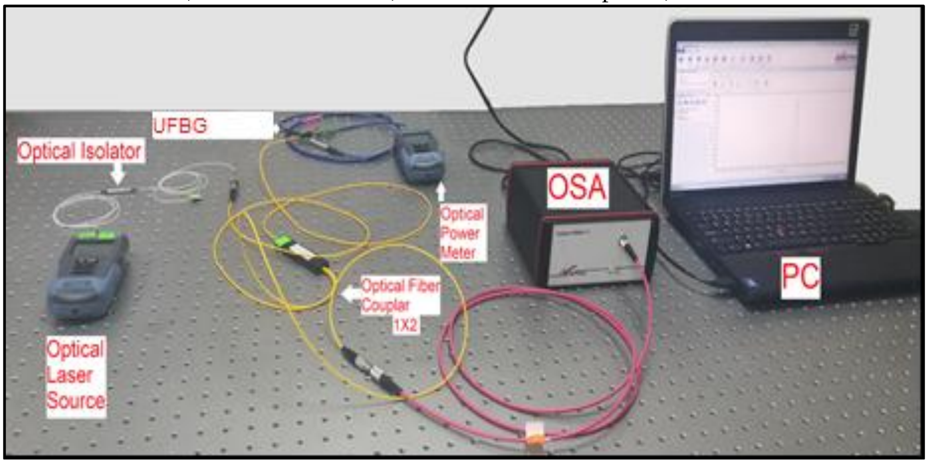


**Fig. 5** Experimental setup for measuring the reflected spectrum

## RESULTS AND DISCUSSION

The important and main optical characteristics of a UFBG is the reflected pectrum. The output of the program for reflected powerwith wavelength (nm) is given in figure 6, while the bandwidth for this simulationwas equal to (0.198 nm).

The reflectivity is plotted with respect to the wavelength for one grating region by assuming $n_{\text{eff}}$ = 1.444 and L = 1 cm. at Bragg wavelength, sharp beaks appeared representinggrating regions. These peaks satisfy Bragg condition according to eq. (1). Narrowing of reflected spectrum bandwidth was observed, which is due to the effect of grating region.

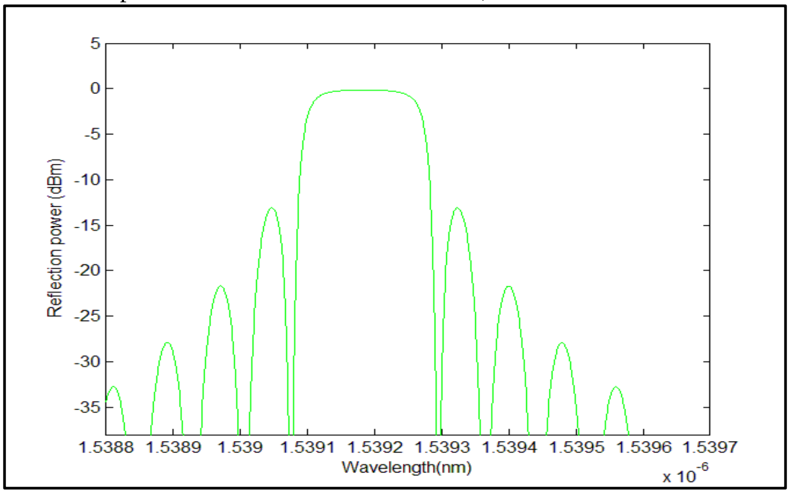


**Fig. 6** Simulated reflection spectrum of UFBG $\lambda_B$ =1539.185 nm

Optical Laser Source Power Meter from (Shaanxi Aitelong Technology) with output power ranges between (-6.4) to (-6.94) -dBm and wavelength (1550) nm have been used to measure spectrum of UFBG. The experimental work consists observing the UFBG both transmitted and reflected spectrum. The observation is based on light intensity calibrated withcounts. Another observationis; bandwidth, peak wavelengthand efficiency of these spectra. Experimental results in are given in table (1); were the reflection spectrum intensity is less than transmission spectrum intensity. The same behaver appeared for bandwidth and efficiency. That is due to the laser pulses reflects only a small part from incident power, and these pulses have high bandwidth depends on laser source properties.

**Table -1 The spectrum parameters according to number of grating regions**

| | **Experimentally Measured Parameters** | | | | |
|---|---|---|---|---|---|
| **Part of Spectrum** | **Peak Wavelength $\lambda_p$(nm)** | **Intensity (Counts)** | **FWHM (nm)** | **Output Power (-dBm)** | **Efficiency of Power (%)** |
| Incident | 1496.847 | 66350.0 | 100.141 | -6.4 | 95.50 |
| Transmitted | 1557.680 | 68542.38 | 57.177 | -6.87 | 89.74 |
| Reflected | 1539.44 | 65812.9 | 21.16 | -6.94 | 89.12 |

Relation between measured wavelength and intensity of reflection and transmission spectrum is shown in figure 7.
The FBG sensor is attractive in several applications especially in a filters [11]. Scanning the spectrum of laser source which is used, we note that there are several short wavelengths at the beginning of the spectrum at wavelengths range (1000-1200) nm at maximum intensity (10000) counts, and these wavelengths began to disappear when using FBG sensor until reaching the reflected spectrum, figures: (7) and (8), these two figures representing the experimental spectrum by direct measuring (figure (7)), and the drawn figure in two and three dimensions. These results ensure that this FBG sensor was work as filter [12].

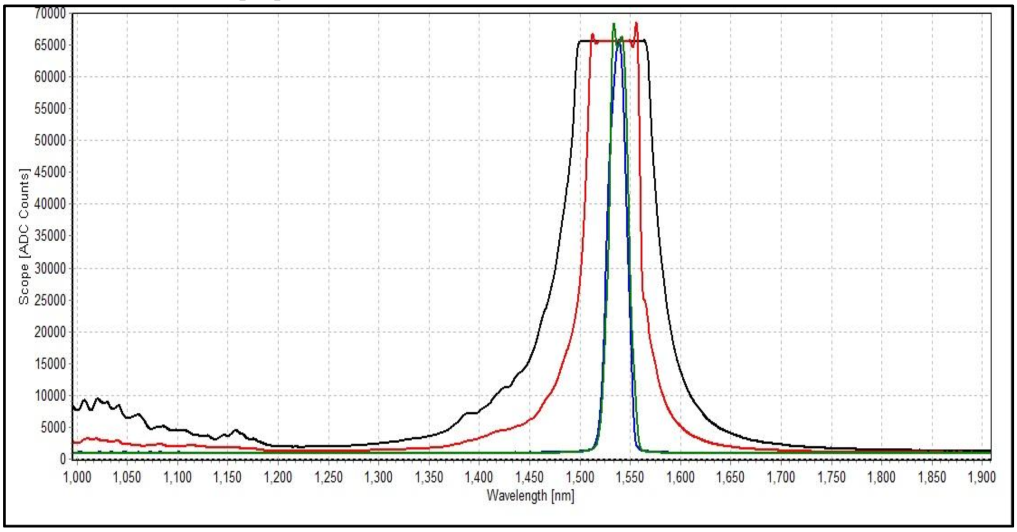


**Fig. 7** The spectrum of standard FBG (one grating regions)

Black: input spectrum, Red: transmitted spectrum, Green: mixed transmitted and Reflected spectra, Blue: reflected spectrum.

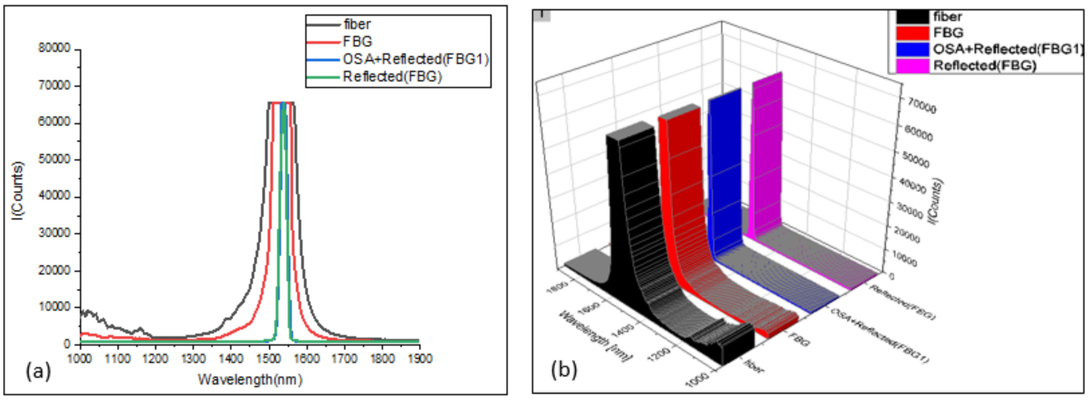


**Fig. 8** UFBG Spectrum: (a) 2D (b) 3D

For these figures,the black line has many small intensities (less than 10000 counts) in wavelength range (1000 to 1180nm). These wavelengths vanished when we used FBG.
In our work study [13] can be compared this work with different type of FBG isSuperstructure Fiber Bragg Grating abbreviated as (SFBG) with two grating region and that found the following: Efficiency of Power for UFBG higher than SFBG because increases grating region and in UFBG appeared one high peak while in SFBG appeared two peaks due two number of grating region.

## CONCLUSION

The solution of CME in UFBG was employed to spectral analysis for laser light. We discussed both the theoretical and experimental results based on that solution.
The measured bandwidth of reflection spectrum is 21.16 nm, which is larger than that achieved bytheoretical calculations, 0.198 nm. That is due to the presenceof large number of wavelengths in reality close to the centre laser wavelength. While in theoretical calculations there exists only one wavelength, which is 1539.185 nm.
The achieved efficiency of reflection and transmission peaks was 89.74% for transmission spectrum and 89.12% for reflection spectrum. Also it found experimentally that FBG filters the incident pulses until reflectsthe remaining part. A modification was observed when we make acomparisonforthese spectra and pure spectrum (spectrum without using FBG) showinga widedifference in bandwidths.These resultsveryattractive and can be employed in many applications to get specific wavelengths for the desired application such as communications and heat and pressure sensing technology.

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