Analysis of Independent Strain-Temperature Fiber Bragg Grating Sensing Technique Using OptiSystem and OptiGrating

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Abstract—**In this paper, a combination of two simulation tools provided by Optiwave Systems Inc. is used to perform a remote fiber Bragg grating (FBG) based strain-temperature sensor setup. Two Gaussian apodized FBG sensors were designed and characterized by OptiGrating. The customized FBGs were incorporated into OptiSystem tool to perform the analysis. Full ability to utilize the combination to perform remote strain-independent temperature FBG setup was demonstrated. 1.2 pm/µstrain and 14.4 pm/°C sensitivities obtained for strain and temperature respectively.**

Keywords—optical sensor; fiber Bragg grating; OptiGrating; OptiSystem; cross-sensitivity.

I. INTRODUCTION

The capabilities of OptiSystem simulation program in designing, testing and optimizing the optical link have been demonstrated for years [1]. Seamless interfaces to a wide range of tools such as Optiwave have obviously allowed its capabilities to be expanded conveniently. The incorporation of OptiGrating in the OptiSystem allows the customized optical component such as fiber Bragg grating (FBG) to be deployed in a wider range of applications, especially in fiber optic sensing application.

The two tools combination was firstly introduced by Optiwave Systems Inc. to incorporate dispersion compensator into a simple optical system. Several deployments related to providing such dispersion compensation element to wave division multiplexing (WDM) networks have been reported [2]. In addition, the FBG designed by OptiGrating is also incorporated in the OptiSystem-designed passive optical network (PON) to perform a powerful monitoring system [3]. Apart from that, an array of FBGs that is designed in OptiGrating is also incorporated in the OptiSystem and applied for fault detection in PON system designed by OptiSystem [4].

Combining the two tools provides the ability to perform remote FBG sensing systems, where both of the two tools are not able to perform them individually. While the ability to design and characterize FBG sensors in many aspects existing in the OptiGrating, deploying the designed sensors into OptiSystem tool –which is originally designed for optical communications systems- allows more design parameters availability and wider deployment scenarios.

Unlike programming-based numerical simulation, this combination which constructed of two friendly user simulation tools allows the user to perform wide platform of remotely FBG sensing application in less complicated and accessible approaches, without passing through long and complicated programming aspects.

However, to the best of our knowledge, utilizing the combination of the two software for fiber sensor application is not widely common. To certify the two tools ability to perform such systems and provide independent measurements using two identical FBGs in the frequency domain are carried out in this paper.

II. BASIC PRINCIPLE OF FBG

Recently, FBG sensor has found its applications ranging from the civil engineering industry as a structural health monitoring system to the biomedical industry [5], offering many advantages over the conventional electrical sensor such as immunity to electromagnetic interference, light weight, ability to be deployed in an extreme environment and etc.

Based on the Bragg condition, FBG can be expressed as an optical filtering device, reflecting optical signals at a certain wavelength within the core of an optical fiber. The principle of FBG is based on the permanent change made to the fiber core refractive index by exposing it to an intensive ultra-violet (UV) pattern. A very narrow band centered at the resonance Bragg wavelength is then reflected back as a result of modulated core refracted index.

The Bragg wavelength is given by:

$$\lambda_B = 2 * n_{eff} * \Lambda_G \tag{1}$$

where n_{eff} is the effective refractive index of the fiber core, and Λ_G is the period of the index modulation that makes up the grating [5].

Both of the refractive index and the grating period are sensitive to the temperature and strain, which results in the changes of the wavelength shift. This, therefore, leads to the

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cross-sensitivity problem in the FBG measurements when both physical effects take place simultaneously; this topic is chosen to validate the two simulation tools in this paper by using two FBGs with a different resonant wavelength in series [5].

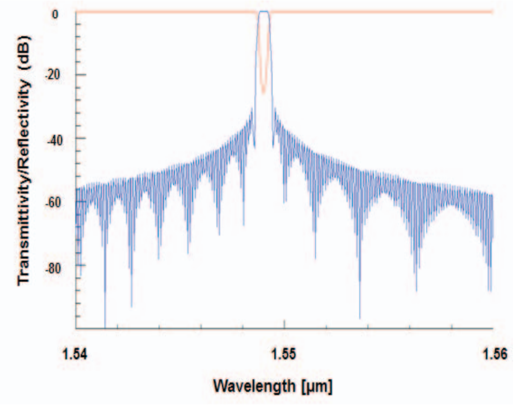

Fig. 1. Reflected and transmitted spectrum of 1549 nm FBG.

III. SIMULATION SETUP

The simulation setup consists of two parts. First, two FBG sensors were designed and tested under several values of strain and temperature for characterization purposes by using OptiGrating. Then the designed FBGs were exported as spectrum files that are readable by OptiSystem, thus, it can be deployed later in the sensing setup designed by the OptiSystem tool. The system is then validated in terms of its ability to provide strain and temperature measurements discrimination based on the wavelengths shifts induced by both effects.

A. *OptiGrating Section*

OptiGrating is used to design two Gaussian apodized FBG sensors with a bandwidth of 0.48 nm, 7 mm length and 0.0005 modulation index. The spectrum of one of the FBGs designed is depicted in Fig.1, showing that the spectrum is identical to those provided by OptiGrating samples library. Both of the designed FBG sensors were characterized in terms of their linearity response and sensitivity to the applied physical measurand. The first FBG centered at 1549 nm is dedicated to both strain and temperature measurements and will be mentioned as FBG_1 while the second one is centered at 1551 nm and exposed only to temperature changes and will be mentioned as FBG_2.

Fig. 2 and Fig. 3, respectively illustrate the characterization results of the two sensors under different changes in the strain and temperature in OptiGrating. Adequate linearity is obtained for each sensor with respect to the physical effect applied. The characterization results also show 0.12 nm wavelength shift with respect to every 100 µstrain applied on FBG_1, while in FBG_2 characterization, 0.36 nm wavelength shift is noted according to every 25°C change. The sensitivities obtained are similar to the those obtained with Matlab simulation tool and another OptiGrating deployment [6, 7].

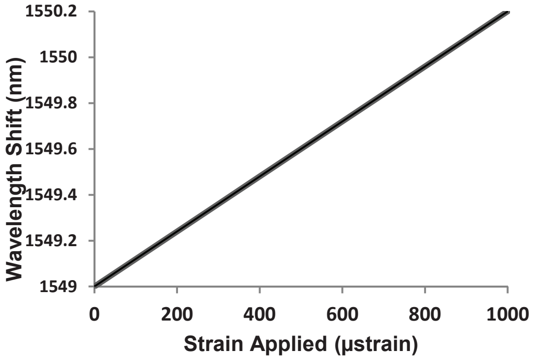

Fig. 2. Wavelength shift with respect to the strain applied to FBG1.

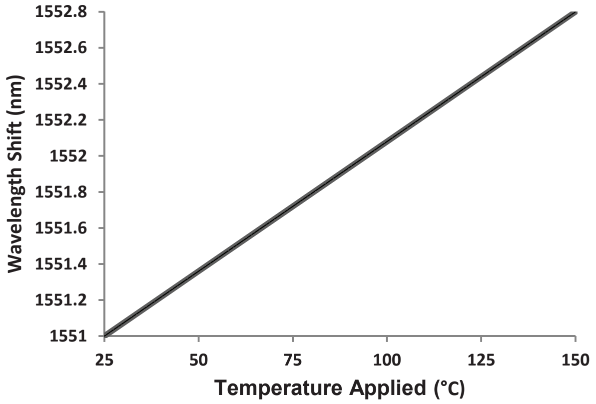

Fig. 3. Wavelength shift with respect to temperature applied to FBG_2.

B. *OptiSystem Section*

As a first step with the OptiSystem simulation tool, the two FBGs were characterized in terms of their responses to the strain/temperature; a good linearity is obtained for both sensors and the results show ± 0.001 nm difference when compared to that of OptiGrating.

The simulated remote sensing setup as illustrated in Fig. 4 includes white light source, an ideal optical circulator, a single mode optical fiber of 1 km length, two OptiGrating-designed FBG sensors and an optical spectrum analyzer (OSA).

An optical source with the power of 20 dBm average is launched into the optical fiber via the circulator, in which the reflected signal of the two FBG sensors are directed to the OSA for analyzing and decoding the response signals. The two FBG_1 and FBG_2 which have been designed by the OptiGrating as stated in the previous subsection are uploaded into OptiSystem. It is assumed that the two sensors are located at same sensing point for monitoring the strain-independent temperature. There is a separation in their center wavelength of 2 nm to prevent signal overlapping.

To distinguish the cross-sensitivity of the two measurands (strain/temperature), the FBG_1 is assumed to strain isolated, while the FBG_2 in another hand would be exposed to the physical effect. When both strain/temperature being applied simultaneously, the reflected wavelength of the FBG_2 shifts as a result of only temperature variation. Whereas the wavelength shift of the FBG_1 encodes both strain and temperature information signals.

The wavelength shift by strain therefore independently can be obtained by subtracting the two wavelength shifts as follow [5].

$$\Delta\lambda = \lambda\ (FBG_1) - \lambda(FBG_2) \tag{2}$$

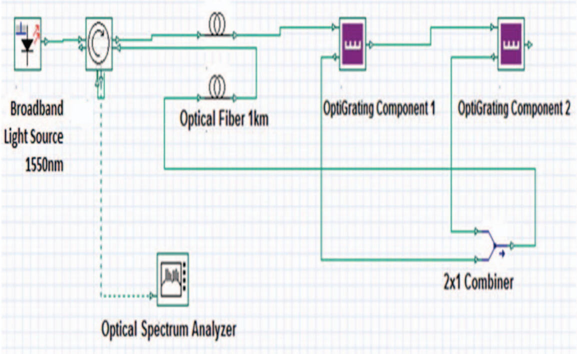

Fig. 4. FBG Interrogation scheme in Optisystem

IV. RESULTS & DISCUSSION

The tracing tools included to the OptiSystem optical spectrum analyzer monitoring tool allows to track the spectrum of each FBG center points accurately with negligible error percentage. As a representative, the spectrum of FBG_1 and FBG_2 is illustrated in Fig. 5, showing that the wavelength of FBG_2 is centered at 1551.36 nm, which indicates that 50 °C of temperature was applied while the spectrum of the FBG_1 is centered at 1550.08 nm which is resulted from applying both strain and temperature at a time. By subtracting FBG_1 wavelength shift from FBG_2 according to Eq. (2), the value of 1549.72 nm obtained, which indicates that 600 µstrain was applied to the sensor.

By applying the same method of measurement, the relationship between temperature and strain applied to FBG_1 and the wavelength shift is illustrated in Fig. 6. The results show full ability to obtain both of the temperature and strain measurements independently. A good linearity between the wavelength shift and strain is obtained at different values of temperature with the same slope for all values, which indicates constant sensitivity during the entire measurements. The strain and temperature sensitivities of the two FBGs were found to be 1.2 pm/µstrain and 14.4 pm/°C respectively, confirming that the values obtained are the same in both of OptiGrating and OptiSystem characterization.

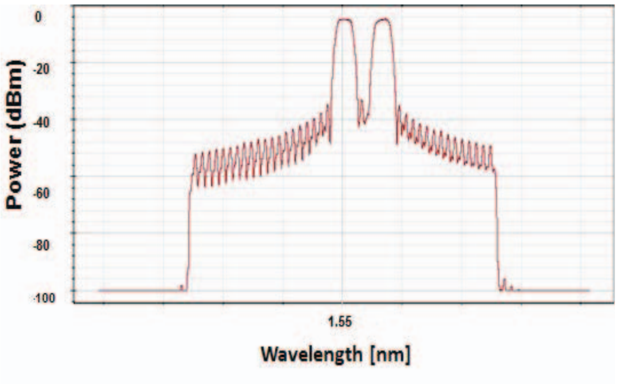

Fig. 5. Spectrum obtained by OptiSystem OSA for FBG_1 and FBG_2.

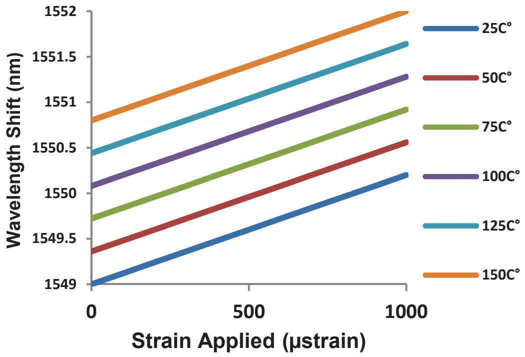

Fig. 6. Wavelength shift with respect to both of strain and temperature applied to FBG_1.

V. CONCLUSION

A combination of two simulation tools which are provided by Optiwave Ltd. to perform an FBG interrogation system is reported. The compatibility between the two tools has been introduced. Two FBG sensors being designed by OptiGrating was uploaded to OptiSystem in order to perform discrimination strain/temperature remotely sensing point. Wavelength shift of both sensors has been analyzed to decode and separate the signals. Discriminating strain and temperature by using two FBGs with different center wavelength has been chosen to validate the ability of the two simulation tools to integrate and deliver such sensing deployments. Fine linearity was obtained for both sensors with respect to strain and temperature applied. Having the ability of combining both software tools to deploy FBG sensors in the frequency domain, we now focus on time domain interrogation system for FBG sensors array and other applications using optical pulse technique.

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