Pressure Sensitivity Improvement of Fiber Bragg Grating Sensor Using Cytop Fiber

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Abstract

Recent demand for using FBG as a pressure sensor in a different industrial application makes several types of research to be conducted to enhance the pressure sensitivity. This paper demonstrates a combination method to enhance pressure sensitivity. Firstly, in this work FBG with polymer fiber named perfluorinated monomer (CYTOP) was used with specific parameters. Secondly, this FBG was covered by a patch of thin polymer material. However, the strain, temperature, and pressure sensitivity were recorded and compared with bare silica FBG. The temperature effect was reduced by using the cascade FBG technique. By applying force on the grating and changing of refractive index; the Bragg wavelength was shifting, making the CYTOP FBG responds more efficiently than silica FBG. This responsivity was leading to an improvement in pressure sensitivity. Experimental results illustrate that the enhanced CYTOP FBG based pressure sensor achieves pressure sensitivity up to 93.5 pm/KPs with a resolution of 0.005 KPa, which was 1500 times higher than bare FBG. The advanced CYTOP FBG based pressure sensor can be functionalized in a technical application for instance, structural health monitoring, pressure of oil wells application, explosion wave, and prevention of erosion.

1. Introduction

Due to numerous advantages of optical fiber sensor OFS over conventional electrical sensors, many FOS researches have been conducting up to date. One of the important FOS technologies is Fiber Bragg Grating FBG sensing. FBG sensor has been employed to sensing different physical measurands, for example, strain, temperature, pressure/acoustics, displacement, torsion, rotation … etc [1–4]. The majority of studies have been done with FBG based silica fiber which gave efficient sensitivity outcomes. However, changing the silica fiber with polymer is still a matter of challenge. Nonetheless, recent relevant polymer researches showed a quantum leap in terms of physical parameter sensitivity, for example, pressure [5–9]. One of the most promising polymer materials is called perfluorinated polymer CYTOP (poly(perfuorotenyl vinyl ether)) which has been implemented in the OFS technologies. Most of the important key features of the CYTOP compared with silica fiber are handling safe, low cost, conformity with biomedical and organic materials [10–15]. The CYTOP has significant characteristics in thermal, surface features, chemical, and electrical aspects. Moreover, the CYTOP has a wide transmission window about (650–1300 nm); at 1300 nm CYTOP reaches less loss about 15 dB/Km. In terms of optical properties, the CYTOP has a low core refractive index of 1.3335 at 1.55 μm with a significant low loss of about 75 dB/Km. Furthermore, the CYTOP is approximately transparent material for wavelengths (0.2-2 μm). It has a minimum dispersion and maximum abbe number values among the optical polymer [16–21]. Moreover, the CYTOP material has excellent stability of mechanical and optical features in humidity circumstances, so this is the reason behind involve it in humidity sensor applications [22]. Additionally, the chemical structure of CYTOP contrary to other polymer materials; the CYTOP has Hydrogen free in the main chain instead there are Fluorine F atoms. This explains the low loss of CYTOP fiber [23–26]. Different methods of fabrication of CYTOP FBG have been reported in recent researches. The most common methods are ‘amplitude splitting technique’, ‘phase mask technique’, ‘femtosecond laser technique', 'point by point and line by line method', and 'Nd: YAG laser pulse method'. Because of the outstanding features of CYTOP fiber, it has been used in different applications such as fiber laser, fiber communication, a mechanical sensor, strain monitoring, composite material monitoring, robotic application, health equipment, and an ultrasound sensor. However, this paper presents a method of enhancement pressure sensitivity of FBG based on CYTOP fiber, so the principle of working of the FBG sensor needs to be illustrated first [23–29].

2. Basic Principle Of Fbg Sensitivity:

FBG is a periodic inscription of the refractive index of the fiber core; this is leading to the reflection of a certain wavelength and transmission of all others. These segments can be formed by exposing the core to intense light. The principle of operation of FBG depends on the shifting of Bragg wavelength caused by any external change in physical parameters; the following equation explains the concepts of FBG working [30–33]:

$$\lambda_B = 2n_{eff}\Lambda$$

1

λ_B is the central Bragg wavelength, n_{eff} is the effective refractive index of core and Λ is the period of the grating. The reflectivity equation can be given by:

$$R(l, \lambda) = tanh^2(\Omega l)$$

2

l is the FBG length and Ω is a coupling coefficient. However, changes in core refractive index or grating period will induce a wavelength shift which can be employed in sensing technologies for different physical measurands as mentioned before. FBG sensing technology attracts conducting many researches to improve the sensitivity of pressure. This paper is intended to produce a pressure sensitivity improvement using CYTOP fiber and a thin patch on FBG [32–36].

3. Experimental And Simulation Work:

The previous information of POF FBG was employed in the working steps. The fiber used in this work was Graded index CYTOP fiber with FBG inscription. The CYTOP used was a commercial one with 1.3348 refractive index of core and 1.33 refractive index of cladding. The diameter of the core was 8 μm and 120 μm for the cladding. The fiber length was 20 cm with four FBGs written along with the fiber with 4 cm spacing. Each FBG length was 5 mm. The design of grating periods was properly different for each grating. This is done to obtain free interference in the reflected spectrum. The multiplexing FBG method was done to eliminate any surrounding effect factors, especially, temperature fluctuations. Figure (1) shows the setup used in this work. The applied strain was affected on all FBGs. The first FBG was

nts and the third one was covered by a softer polymer patch to enhance the pressure sensitivity. The second and fourth FBGs were functionalized as references. Firstly, when applying strain, the temperature was fixed. This was done for strain values range from (200 με – 2500 με). Again the same steps were repeated with fixed strain value and temperature ranged from (25°C – 90°C). The values of wavelengths shifting were recorded using a smart scan integrator. Using the OptiGrating tool, the simulation was done for all the data obtained above. With the same technique, a range of forces was applied on the third FBG. The forces act like applied pressures which have an impact on the Bragg wavelength shifting. Nevertheless, a non-uniform grating structure was formed due to the distributed of strain was not uniformly on the FBG sensor. Correspondingly, T-matrix method was achieved in the simulation in order to form a multiple sub-gratings FBG sensor; hence, an asymmetrical spectrum was obtained using MATLAB. All the data recorded using a spectrum analyzer and plotted with MATLAB. The final step was covering the third FBG with a polymer patch and again the same forces, temperatures, and strains were applied. The obtained data were compared with the pressure measurements of bare silica FBG.

4. Results And Discussion:

Based on the results, the wavelength response of CYTOP FBG was more sensitive to the physical measurand than bare silica FBG, Fig. (2) demonstrates the CYTOP FBG reflection spectrum at the Bragg wavelength 1.3 μm. In other words, applying a strain of 2000 με on CYTOP FBG caused a wavelength shift of 3.4 pm as Fig. (3) shows, while it caused 2.9 pm a wavelength shift of bare silica FBG. Similarly, the applied pressure caused a more accurate wavelength shift in the CYTOP FBG sensor case. Table (1) summarizes these values under the same conditions in both silica and CYTOP FBG sensors.

Table (1): strain and pressure sensitivity for silica and CYTOP FBG (with removing temperature effect)

Applied strain (με)	Δλ silica (pm)	Δλ CYTOP (pm)	Applied pressure (Pa)	Δλ silica (pm)	Δλ CYTOP (pm)
1000	2.74	2.80	7500	3.28	3.43
1500	2.82	3.15	10000	3.37	3.52
2000	2.91	3.32	12500	3.51	3.71
2500	2.95 3.57	15000	3.54	3.95	

Obviously, the FBG sensor is affected by the surrounding temperature. Figure (4) shows the effect of the 35°C on the wavelength shift of the Bragg wavelength. Interestingly, it is found from the values of wavelength shift that the CYTOP FBG has the ability to sense temperature change to a higher extend. However, the cascade FBGs method used in this work yields a more efficient reading of pressure sensitivity, which is estimated 10 times accurate than using a single FBG sensor. Additionally, this method was used to track the fluctuations of several surrounding factors simultaneously. The reference FBGs work very efficiently in eliminating the temperature impact on the experimental pressure reading.

Likewise, the thin polymer patch placed above the FBG sensor contributed to minimizing the temperature influences on the FBG pressure sensor caused a higher sensitivity roughly 4 times higher than without using this patch. Table (2) illustrates the benefits of using this thin patch. However, the performance of pressure sensitivity was linear at a certain range of temperature as Fig. (5) shows.

Table (2): pressure sensitivity with and without patch

Applied pressure on CYTOP FBG	Δλ without patch	Δλ with patch
10 KPa	3.52 pm	13.88 pm
12.5 KPa	3.71 pm	14.03 pm
15 KPa	3.95 pm	15.45 pm

5. Conclusion

This paper presents a work aimed to enhance the FBG pressure sensitivity using CYTOP fiber. It is concluded that using this type of material with certain parameters can participate in a way to improve the pressure sensitivity in 1500 times higher than silica fiber. Similarly, using a thin polymer patch on the FBG contributes significantly in enhancement of the CYTOP FBG pressure sensitivity. Thus the CYTOP fiber is considered a promising candidate in photonics and optoelectronics application. Nonetheless, more consideration related to the fiber dimensions should be taken into account in future researches. Further, a different polymer material type could choose to investigate pressure sensitivity improvement.

Declarations

Acknowledgment

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Figures

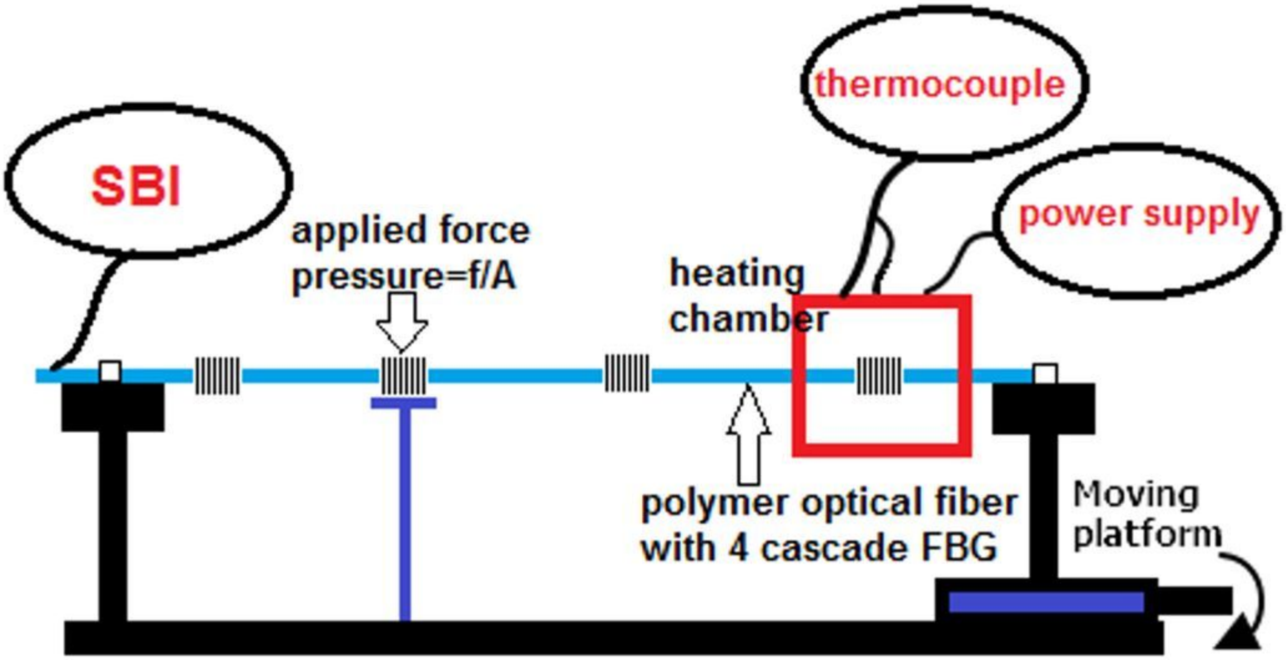

Figure 1

Setup used in this work

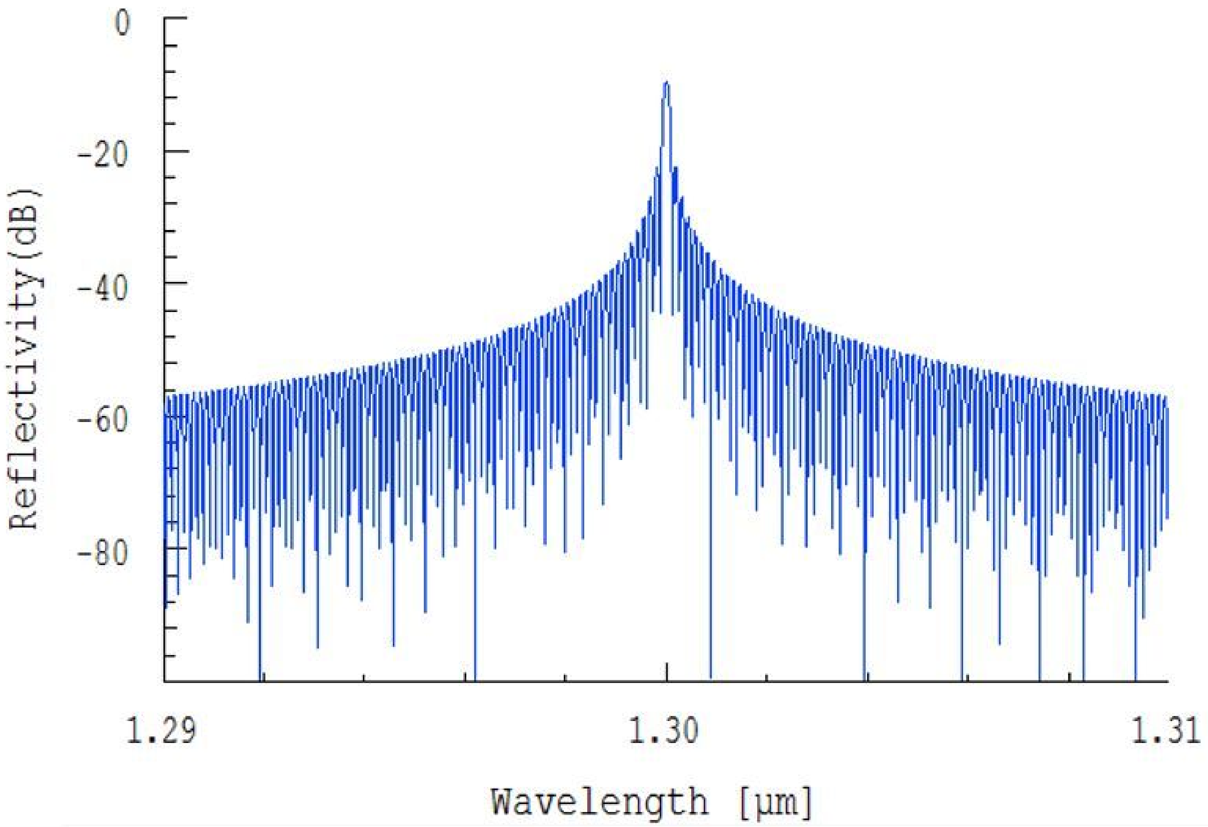

Figure 2

CYTOP FBG Spectrum at Bragg Wavelength 1.30 μm

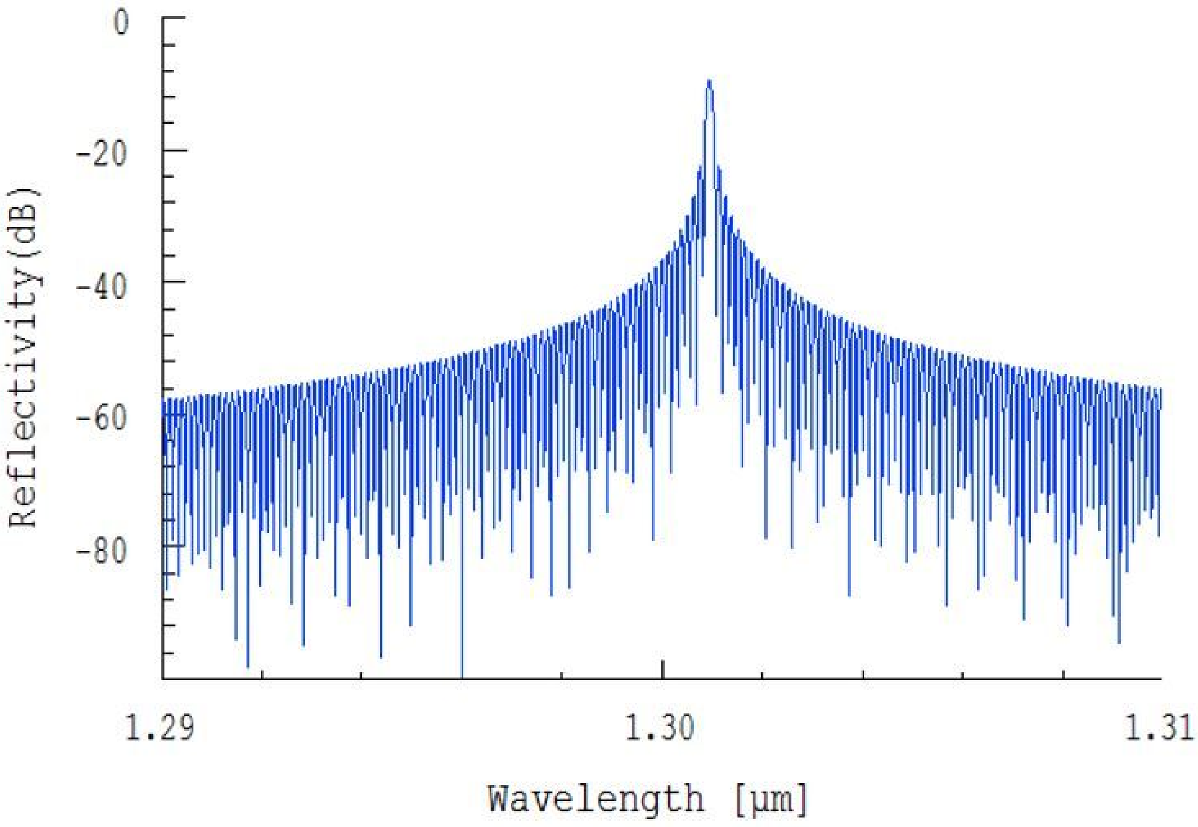

Figure 3

CYTOP FBG Spectrum at Bragg Wavelength 1.30 μm with 2000 μ and fixed temperature

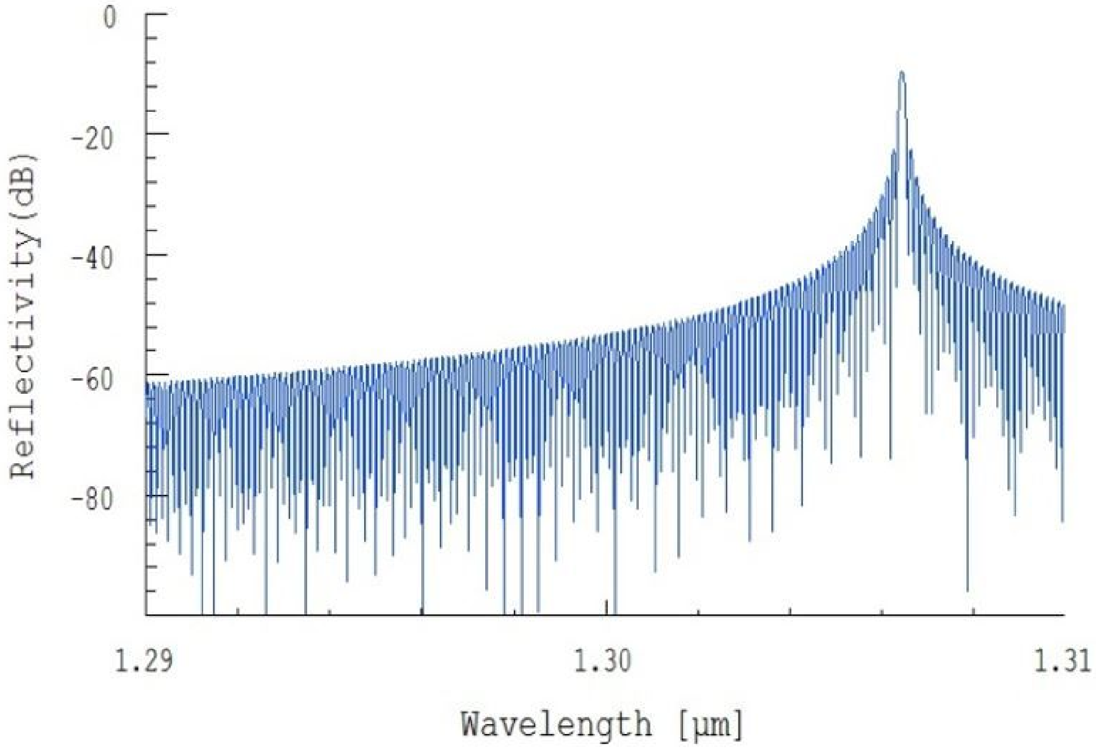

Figure 4

CYTOP FBG Spectrum at Bragg Wavelength 1.30 μm with 2000 μ and 35 Co

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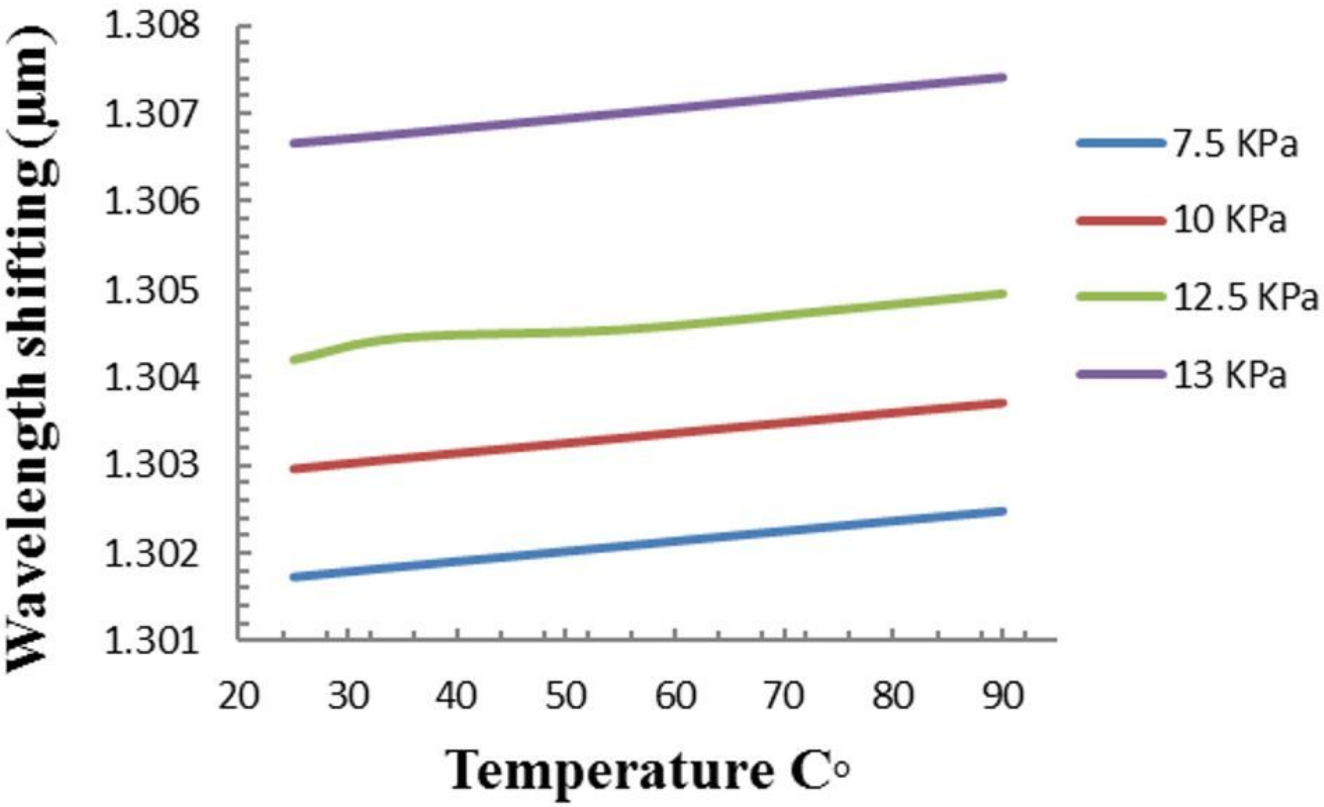

Figure 5

CYTOP FBG Temperature sensitivity as a function of wavelength with different applied pressure