Simulation Design of Fiber Bragg Grating Temperature Sensor Based On Optical Fiber Interferometric Technology

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Abstract.

Photonic sensors have of high interest in recent years due to their amazing features and properties. In this work, a Fiber Bragg Grating temperature sensor had been designed and simulated. Two different structure were chosen; Mach-Zehnder and Fabry –Perot interferometry sensors. This is achieved utilizing OptiSystem simulation software. A shifting in Bragg wavelength was achieved due to the application of temperature degrees in the range of (10-110) ˚C. Both sensors exhibit good sensitivity and linearity. The sensitives were equal to 15 pm/ ˚C and 10 pm/˚C for FBG temperature sensor based on MZI and FPI techniques respectively.

Keywords: Photosensor, Bragg grating, fiber optic.

تصميم محاكاة لمتحسس محزز الياف براك لدرجة الحرارة استنادًا إلى تقنية قياس التداخل بالألياف الضوئية

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الملخص

تحظى المتحسسات الضوئية باهتمام كبير في السنوات الأخيرة بسبب ميزاتها وخصائصها المذهلة. في هذا العمل ، تم تصميم ومحاكاة مستشعر درجة حرارة Fiber Bragg Grating. تم اختيار هيكلين مختلفين؛ مجسات ماك زيندر وفابري–بيروت التداخلية. يتم تحقيق ذلك باستخدام برنامج محاكاة OptiSystem. تم إحداث إزاحة في الطول الموجي لبراك نتيجة لتطبيق درجات الحرارة في حدود (١٠–١١٠) درجة مئوية. يظهر كلا المستحسسين حساسية وخطية جيدة. كانت المواد الحساسة مساوية لـ ١٥ مساءً/ درجة مئوية و ١٠ مساءً / درجة مئوية لمستشعر درجة حرارة FBG بناءً على تقنيات MZI وFPI على التوالي.

الكلمات المفتاحية: المتحسسات الضوئية، محزز براك، اليف بصرية.

1. Introduction

The remarkable interest in optical fibers for their use in sensing applications can be attributed to numerous magical advantages such as: they are flexible, light weighted and small in size (therefore miniaturization can be attained). Because they are solely dielectric, they can be employed in potentially dangerous environments. Electromagnetic interference is not a problem for them. Furthermore, they can be used for distant sensing and distributed sensing. Optical fibers are also very sensitive, resistant to the elements, explosion-proof, and have a big bandwidth and fast response time. Fiber optic sensors offer a wide range of applications in the electrical power business, industrial process control, medical sciences, cars, the defense sector, and research due to these advantages Besides it, fiber optic sensors are significantly advantageous over traditional sensors in many ways such as cost difference and improved quality [1-3].

Because of its ease of fabrication, Fiber Bragg Grating (FBG) technology is one of the most popular options for optical fiber sensors for strain or temperature measurements. They are formed by a periodic modulations of the index of refraction of the fiber core along the longitudinal direction. Fiber is a phrase that refers to a type of The Bragg grating was adapted from the Bragg law and used to inscribe periodic structures inside the core of traditional telecom fiber [4].
When subjected to intense radiation from a laser operating in the blue or ultraviolet (UV) spectral band, silica fibers can modify their optical properties permanently. This photosensitive effect can be utilized to create intra core Bragg gratings by inducing periodic variations in refractive index along the fiber length. Because periodic changes in refractive index only affect a small portion of the spectrum, the FBG serves as a spectrum selector for light waves,therefore different schemes have been using for writing grating of optical fibers. Currently there are four major methods to fabricate FBG, which are; Single_ Beam Internal Technique, Dual_Beam Holographic Technique, Phase Mask Technique, and Point_By_Point Technique [5,6].
At the Bragg wavelength, FBG converts light from a forward propagating mode to a backward or counter propagating guided mode. This is the wavelength for the Bragg reflection, which is the phenomenon in which a single large reflection can be produced by the coherent addition of many small reflections from weakly reflecting mirrors separated by a multiple of the wavelength as it shown in figure 1.

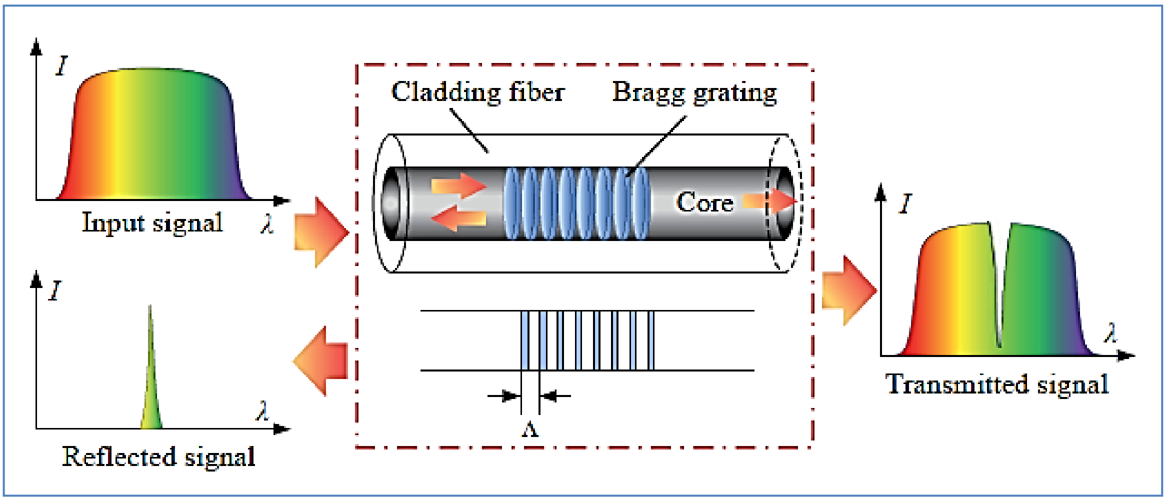


Figure 1. Fiber Bragg grating transmission and reflection spectrum (FBG) [7].

The equation relating the grating periodicity and the Bragg wavelength (B) depends on the effective refractive index of the transmitting medium neff, and the spacing between two adjusting gratings (Λ), is given by [6]:
$B=2neff$……………………………..… (1)

The FBG sensor is one of the most important and direct application directions of fiber_grating_sensing technology because the wavelength shift of the FBG reflection spectrum is directly proportional to temperature or strain/stress variations [6].
To calculate the sensitivity of the Bragg wavelength to temperature and strain, we begin with Eq. (1) and note that the sensitivity to temperature is the partial derivative with respect to temperature [6]:
$BT=2neff\,\partial T+2neff\partial T$……..…..……… (2)

By substituting twice (1) in (2) we get:
$BT=1\partial TB+1neffneff\partial TB$…………….. (3)

$BB= 1\partial TT+1neffneff\partial TT$…………….. (4)

The first term is the thermal expansion of silica (α) and the second term is the thermo_optic coefficient (ηT) representing the temperature dependence of the refractive index (dn/dT).
Substituting we have [6]:
$BB=\alpha+\eta T$………………………………(5)

The sensitivity with strain is the partial derivative of (1) with respect to displacement:
$BL=2neff\ \partial L+2neff\partial L$……………..…. (6)

By substituting we gate:
$BB=1\partial LL+1neffneff\partial LL$…………….. (7)

The first term in Eq. (7) is the strain of the grating period due to the extension of the fiber. The second term in Eq. (7) is the photo_elastic coefficient (e), the variation of the index of refraction with strain. In some solids, depending on the Poisson ratio of the material, this effect is negative, that is, when one expands a transparent medium, as an optical fiber for instance, the index of refraction decreases due to the decrease of density of the material.
Then, when an extension is applied to the fiber, the two terms in Eq. (7) produce opposite effects, one by increasing the distance between gratings and thus augmenting the Bragg wavelength and the other by decreasing the effective RI and thus decreasing the Bragg wavelength. The combined effect of both phenomena is the classical form of the Bragg wavelength displacement with strain [8]:
$BB=1-eZ$……………………………(8)

where Z is the longitudinal strain of the grating. Combining (5) and (8) together we finally end up with the sensitivity of the Bragg wavelength with temperature and strain [8]:
$BB=1-eZ+\alpha+\eta T$……………………(9)

For a silica fiber with a germanium doped the values of above parameters are [8]:
$e=0.22$, $=0.55\times10^{-6}/^{\circ}C$, $= 8.6\times10^{-6}/^{\circ}C$.

Fiber Bragg Grating have many applications in field of industry, medical, environments so many researchers have a very good interests in this field. Ali et al. 2020 [9] submit a simulation design of FBG temperature and blood pressure sensor which is used in medical field. The designed sensor was very sensitive to human temperature and blood pressure ranges which were 13·632 pm/°C and 15·75 pm/mmHg, respectively. In addition, Al-Attar et al. 2020 [10] introduce a simulation and experimental study of optical heterodyne temperature sensor based on Fiber Bragg Grating also in range of human temperature. The sensitivity of the modified heterodyne FBG temperature sensor is about 67·63 pm/°C. In 2019 Majeed et al [11] design an accurate blood pressure sensor based on FBG technology. The obtained sensor sensitivity is equal to 0.1pm/ µstrain.
In this paper a simulation design using Opti-System simulation to design temperature sensor in range of (10-110)˚C. Two strictures will be presented Mach-Zehender (MZI) and Fabry-Perot (FPI) interferometers.

2. Simulation Design

The performance of FBG as a temperature sensor achieved utilizing OptiSystem simulation software (V.16), a high temperature range chosen to simulate the radiation effect on fiber (10-110) ˚C. OptiSystem from Optiwave Inc. is an optical communication system simulation package for the design, testing, and optimization of virtually any type of optical link in the physical layer of a broad spectrum of optical networks, from analog video broadcasting systems to intercontinental backbones. In this work this OptiSystem version16 is used to design and simulation FBG temperature sensor. Two different structures had been utilized to design FBG temperature sensor based on MZI and FPI techniques.

Figure 2 shows the schematic diagram of the FBG temperature sensor based on the MZI technique. A CW laser with center wavelength (1552) nm and line width 10 MHz had been connected to the input port of the Optical Coupler (OC). In this design 2x2, OC was used, this coupler has two inputs port and two outputs ports. One of the input ports is connected to the laser source the other neglected using optical null. The output ports were connected to the FBG reference (FBGR) and the other to the FBG sensor (FBGS). The two FBG’s have Bragg wavelength (1550) nm and grating length (2) mm. The transmission spectra of both fibers were coupled by another 2x2, OC then the output port connected the Optical Spectrum Analyzer (OSA). The FBGR represents the reference arm of the structure, while the FBGS represents the sensor arm on which the temperature will applied with range from (10-110) ˚C.

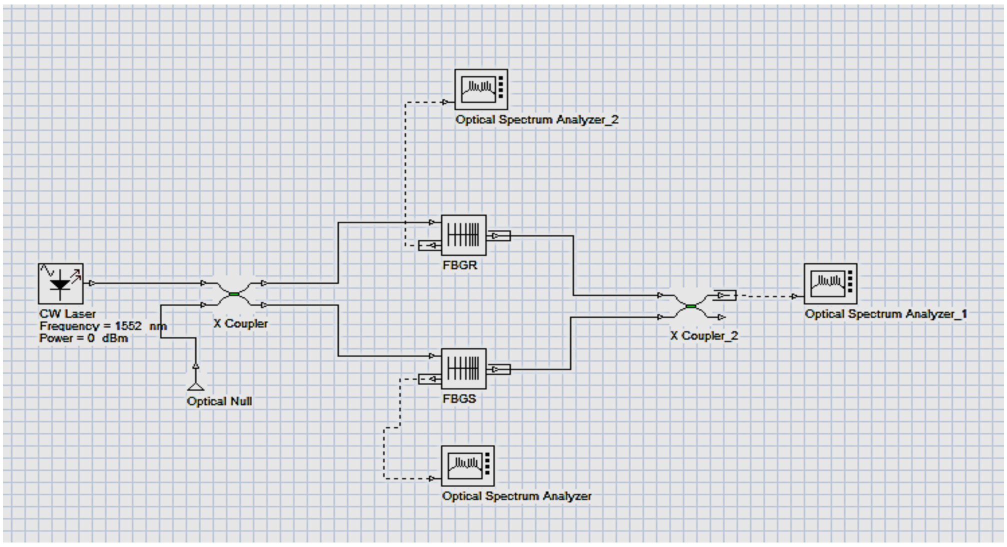


Figure 2. The Schematic diagram of FBG temperature sensor based on MZI technique.

Another interferometric technique had been designed in this work, which is the FPI. Figure 3 shows the schematic diagram of the FBG temperature sensor based on FPI. The same procedure in the MZI technique had been performed, but instead of taken the transmission spectra of FBG’s the reflected spectra had been collected and analyzed.

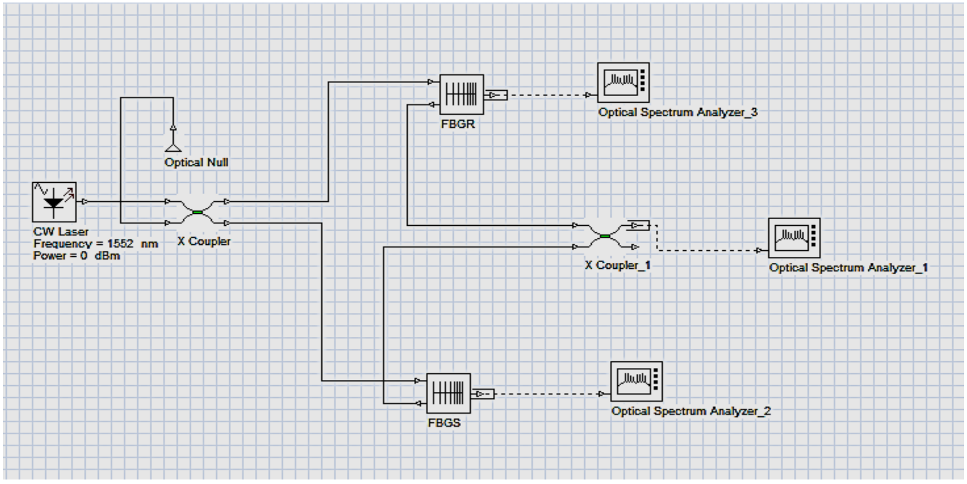


Figure 3. The Schematic diagram of FBG temperature sensor based on FPI technique.

3. Results and Discussions

First, the references spectra of laser source and FBG for both MZI and FPI techniques without applying temperature were collected as shown in figure 4.

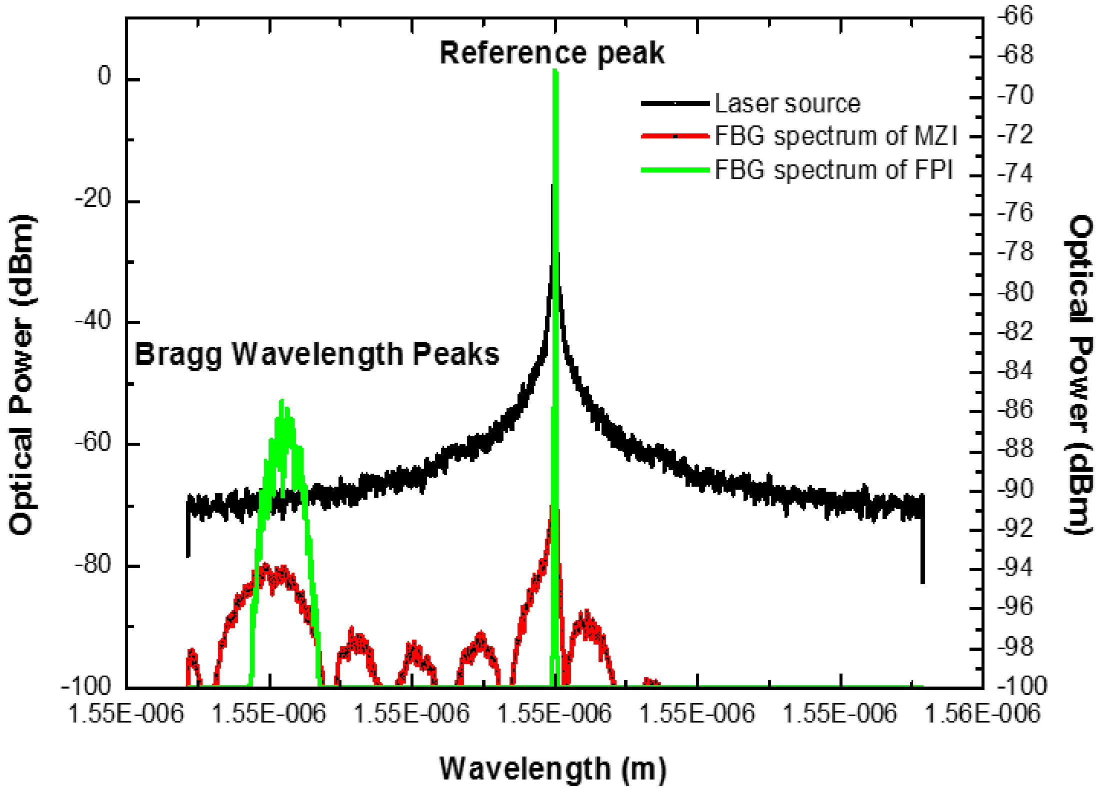
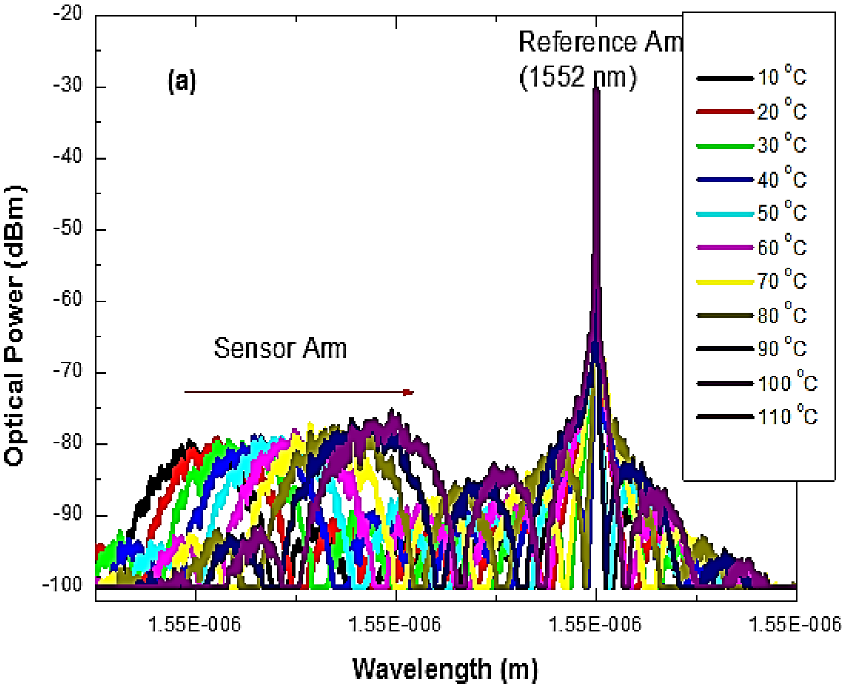


Figure 4.The spectra of laser source, FBG spectra of MZI and FPI techniques.

The performance of FBG as a temperature sensor studied utilizing OptiSystem simulation software, the temperature range chosen to simulate the radiation effect on fiber was (10-110) ˚C. Figure 5 (a, and b) show the transmission of Bragg wavelength due to application of temperature based on MZI and FPI techniques respectively.



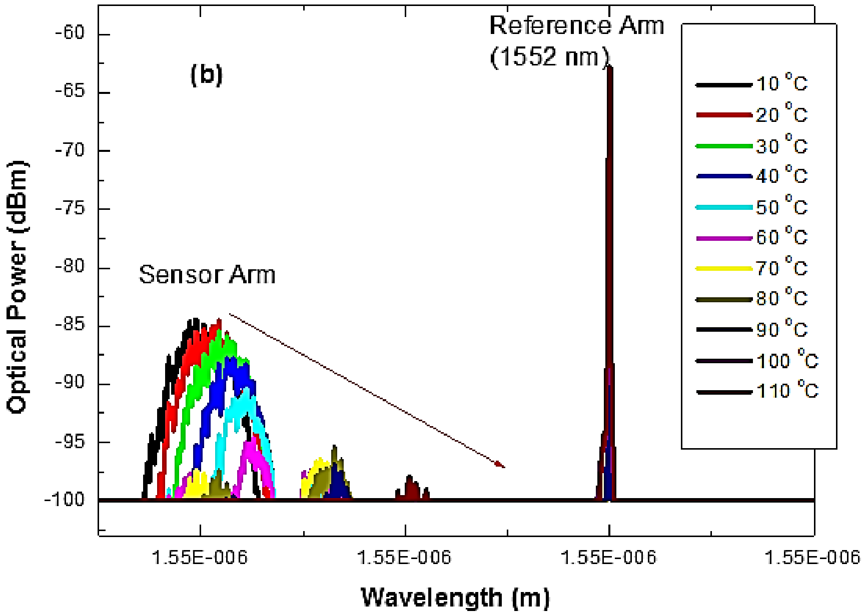


Figure 5. The transmission spectra of Bragg wavelength due to application of temperature based on (a) MZI technique, (b) FPI technique.

From the above spectra, it could be noticed that shifting in Bragg wavelength towards the longer wavelength (Red-shift) occurred due to the application of temperature. Due to equation 1 the wavelength shift of the FBG spectrum is directly related to temperature or strain/ stress changes. When the temperature applied both changes in effective refractive index and spacing between grating will be resulted. So a shifting in Bragg wavelength achieved.

A fiber coupler splits an incident light into two arms, which are subsequently recombined by another fiber coupler in the MZI process. According to the Optical Path Difference (OPD) between the two arms, the recombined light has an interference component. Only the sensing arm is susceptible to variation in sensing applications because the reference arm is maintained segregated from external variation.Then, temperature_induced variations in the sensing arm modify the MZI's OPD, which may be easily observed by studying the variation in the interference signal. As a result, the Bragg wavelength simply shifts.as clear in figure (5 a).

The reflection spectrum of an FPI, on the other hand, can be characterized as the wavelength-dependent intensity modulation of the input light spectrum, which is primarily caused by the optical phase difference between two reflected beams. This lead to both changing in Bragg wavelength and intensity of the reflected spectra as clear in figure (5 b).

Both approaches have a linear relationship between the applied temperature and the shift in Bragg wavelength as it clears in figure (6).

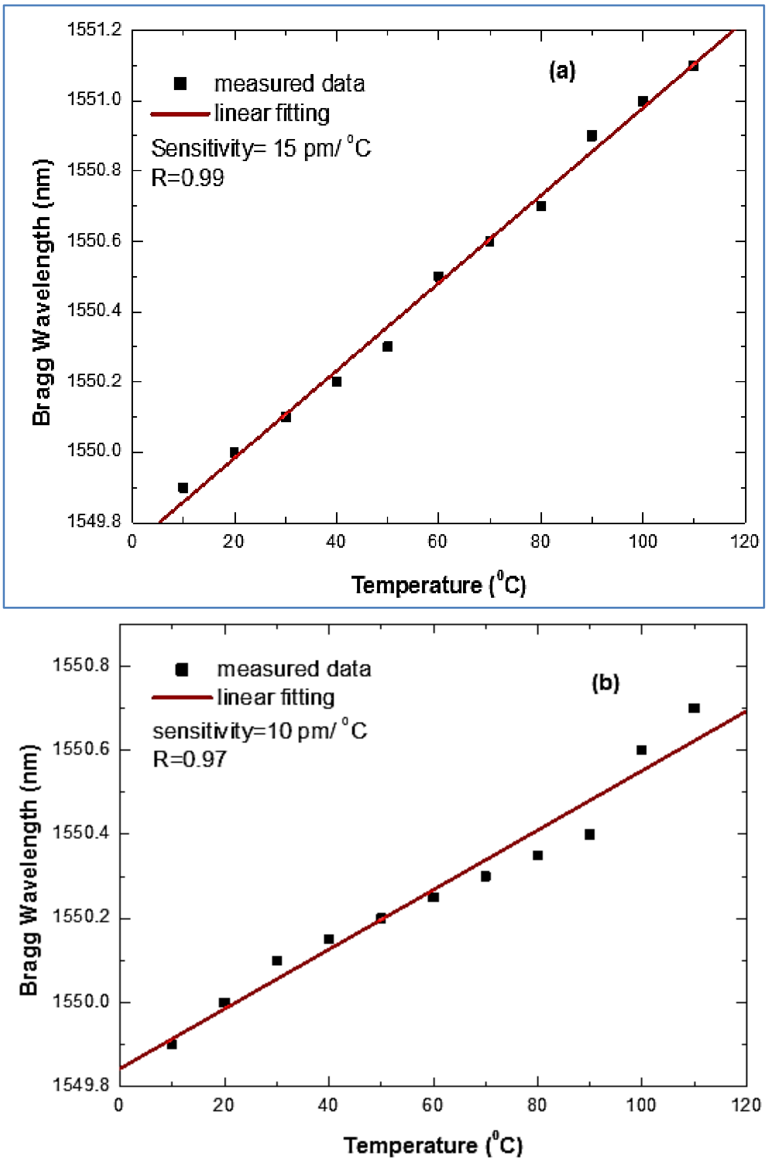


Figure 6. **The relationship between the Bragg wavelength applied temperature for (a) MZI technique, (b) FPI technique.**

From this linear relationship, the sensitivity could be calculated. From figure 6 it could be noticed that both sensors have a high correlation factor (R) and the sensitives were equal to 15 pm/ ˚C and 10 pm/˚C for FBG temperature sensor based on MZI and FPI techniques respectively.

4. Conclusions

Fiber Bragg temperature sensors had been designed and simulated in this work using OptiSystem simulation software. The submitted design based on the interferometry technology which is MZI and FPI. The application of temperature leads to changes in the effective refractive index of FBG and the spacing between the gratings which are lead to shifting in Bragg wavelength. Both designs exhibit very good sensitivity and linearity. But the MZI sensor is more intensity stable than the FPI design. The submitted design could have important applications in the field of industry and medicine.

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