FBG as a Medical Thermometer

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Abstract

An FBG thermometer was designed for medical applications in human body. In this work, a short period Fiber Bragg Grating (FBG) temperature sensor system were demonstrated and investigated according to the measurement of the Bragg wavelength shift. This FBG designed by using OptiGrating 4.2 software and various temperature where applied according to human body temperature ranging from hypothermia (35 ˚C) to hyperthermia (42 ˚C) and taking into consideration the normal human body temperature as (37 ˚C) which is taken as a reference temperature in the simulation design. There was shifting in Bragg wavelength for each temperature degree. The applied temperature of FBG was so small so the strain effect is neglected.

Keywords: *Fiber Bragg grating; temperature sensor; medical thermometer.*

كمقياس حرارة طبي FBG

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الخلاصة:

في هذا البحث تم تصميم محرار يستخدم للاغراض الطبية باستخدام ليف محزز براغ. حيث تم بناء مجس حراري باستخدام محزز براغ للالياف البصرية ذي الدورة القصيرة بالاعتماد على الزحزحة في الطول الموجي لبراغ باستخدام برنامج النمذجة (OptiGrating 4.2) بتسليط درجات حرارة مختلفة و ضمن حدود حرارة جسم الانسان وهي 35 درجة مئوية كحد ادنى و42 درجة مئوية كحد اقصى للحرارة التي يصلها الجسم وتم اخذ درجة الحرارة 37 درجة مئوية كدرجة حرارة مصدر للقياس، لوحظ ان هناك زحزحه لمقدار الطول الموجي لمحزز براغ بتغير درجة الحرارة مع اهمال تأثير الاستطالة بسبب انخفاض درجات الحرارة المسلطة.

Introduction

Human body temperature comprises temperature of the core and the shell. The core temperature refers to the temperature of the abdominal, thoracic and cranial cavities, and the shell temperature refers to the temperature of the skin, subcutaneous tissue and muscles. The brain is responsible for control the core temperature, while the skin, subcutaneous tissue and muscles affected on the shell temperature. [1] The beginning of optical fiber application in medicine was done using the fiber as illumination environment of the fiber optic endoscopy [2]. Fiber optical sensor is used to monitor variable chemical and physical parameters related to medical field. These sensors are commonly grouped in two classes: in the first class the sensing element represented by the optical fiber itself this called, intrinsic sensors, in the second class which called the extrinsic sensors the optical fiber act as the medium for conveying the light whose characteristics (e.g., intensity, frequency, phase) are modulated by the measurand, in this class the basic component of fiber optical sensor is spreading away from the sensing element, in order to develop small size sensor hybrid solutions. [3], [4].

Sensing There are many inveterate advantages that make them attractive as sensing technologies for wide range of industrial and medical sensing applications. They are typically small in size, passive, immune to electromagnetic interference, resistant to cruel environments and have a capability to perform distributed sensing [5]. Although developed initially for the telecommunications industry in the late 1990's, fiber Bragg gratings (FBGs) are increasingly being used in sensing applications and are enjoying widespread acceptance and use. The FBG is an optical filtering device that reflects light of a specific wavelength and is present within the optical fiber core waveguide. The wavelength of light that is reflected depends on the spacing of a periodic variation or modulation of the refractive index that is present within the fiber core. This grating structure acts as a band-rejection optical filter passing all wavelengths of light that are not in resonance with it and reflecting wavelengths that satisfy the Bragg condition of the core index modulation. A diagram of an FBG is shown in Figure (1) [6].

In the last decade, fiber Bragg gratings (FBGs) have shown a great potential for applications in the field of biomechanics and rehabilitation engineering due to their prominent advantages such as their small size, biocompatibility, chemical inertness, immunity to electromagnetic interference (EMI) , High sensitivity., light weight and multiplexing capability. These characteristics make FBGs suitable for human body uses that adapt to the sensor material so that they can be used for in vivo measurement and can be left for long-term monitoring [7]

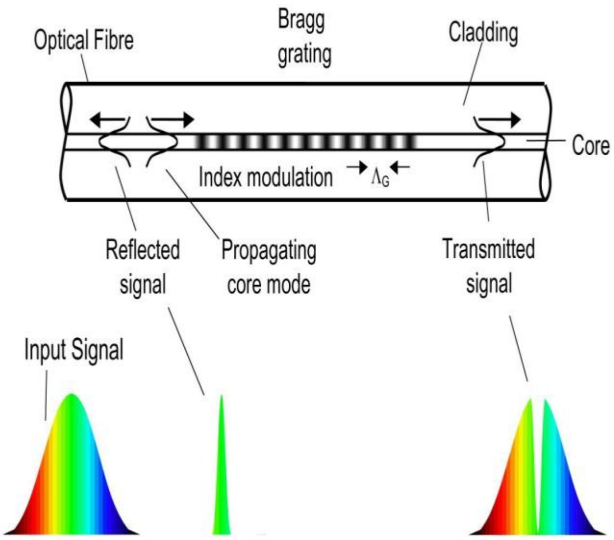

Figure1. Schematic diagram of an FBG having an index modulation of spacing inside a single-mode optical fiber [5]

FBG TEMPERATURE SENSOR

There are many material properties have temperature reliance. In order to utilize temperature effects on measurement is required. Examples of such temperature reliance are density, electrical conductivity, refractive index, rigidity and diffusion. Temperature measurement also plays an important role in health monitoring of electric circuits. There are different types of fiber optic temperature sensors can be used. The most common fiber optic temperature sensors are:

- Fiber Bragg gratings, where the temperature dependence of distributed optical reflection is used.
- Extrinsic interferometric optical structures, which show a temperature dependent behavior.
- Raman scattering distributed temperature sensors, which use the temperature dependence of inelastic scattering on optical phonons [8].

In this paper, we will focus on FBG temperature sensor when broadband light passes through the FBG, the narrowband spectral component at the Bragg wavelength is reflected by the FBG. The basic principle of FBG's is to measure the shift of reflected Bragg wavelength (λ_B), which is related to the effective refraction index (n_{eff}) and the periodicity (Λ) of the index variation of the grating area in fiber core. The Bragg wavelength of FBG is described as: [9].

$$\lambda = 2n_{eff}\,\Lambda \text{ .... } \mathbf{(1)}$$

Any disturbance that can change effective index (n_{eff}) and periodicity (Λ) will result in a shift in Bragg wavelength.

The temperature sensing of Bragg grating occurs principally through the temperature effect on the index of refraction and to a lesser extent through the expansion coefficient. It is remarkable that temperature sensitivity can be enhanced by suitable bonding to other materials. The maximum operating temperature may be around (500 ˚C); however this may depend on the fabrication condition of the Bragg grating [10].

The wavelength sensitivity of Bragg grating is governed by the elastic-optic and thermo-optic properties. From equation (1), a theoretical analysis shows that if there is a short period grating with period Λ under influence change ΔT :

$$\frac{d\lambda_B}{dT} = 2[\Lambda \frac{d\lambda_B}{dn_{eff}} \frac{dn_{eff}}{dT} + n_{eff} \frac{d\lambda_B}{d\Lambda} \frac{d\Lambda}{dT}] \text{....... } \mathbf{(2)}$$

From the above equation, it can be seen that the contribution to the thermal induced shift is a function of change in refractive index with temperature $\frac{dn_{eff}}{dT}$ while the waveguide effect is dependent on the variation in grating period with temperature. From equation 2, we get:

$$\Delta\lambda_B = 2[\frac{1}{n_{eff}}\frac{d\lambda_B}{dn_{eff}}\frac{dn_{eff}}{dT} + \Lambda\frac{d\lambda_B}{d\Lambda}\frac{1}{a}\frac{da}{dT}] \quad \textbf{..... (3)}$$

Where; a core radius, and $\frac{d\Lambda}{dT} = \frac{da}{dT}$

The shift in Bragg wave grating center wavelength due to temperature can be given by:

$$\Delta\lambda_B = \lambda_B(\alpha_\Lambda + \alpha_n)\Delta T \qquad \textbf{........ (4)}$$

Where, $\alpha_\Lambda = (\frac{1}{\Lambda})(\frac{\partial\Lambda}{\partial T})$.

The thermal expansion coefficient for the fiber (approximately 0.55×10^{-6} 1/°C for Silica).

$\alpha_n = (\frac{1}{n_{eff}})(\frac{\partial n_{eff}}{\partial T})$ Represents the thermal – optic coefficient, which is approximately equal to ($8.6*10^{-6}$ 1/°C) for the Germanium – doped, Silica – core fiber [11], [12].

1. Material and Methods

A complex grating is approached by a series of uniform segments, and analyzed by connecting the segments with the well-known Transfer Matrix Method. This will provide the required information about to test and optimize grating designs to the designer.

The optical FBG used in this work is designed by OptiGrating 4.2 software Short period FBG designed with grating length (l= 50000µm), and periodicity (Λ =0.5338 µm), refractive index of the core (n_{core} =1.46) and for the cladding ($n_{cladding}$=1.45) and difference of refractive index (Δn_{eff}=0.0030) as shown in figure (2) then we obtain the grating spectrum reflection and transmission at different applied temperature. The inverse scattering solver is only used on the reflection at zero temperature to create a reference spectrum.

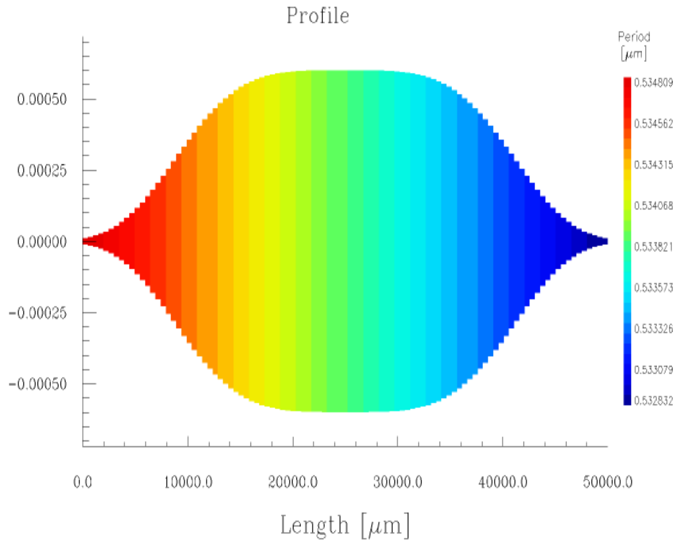

Figure 2: Profile of changing of refractive index along grating length.

2. Result and Discussion:

According to eq. 1 the Bragg wavelength of FBG is 1.55 μm. Figures 3 and 4a, b showed the spectrum of FBG, transmission of Bragg wavelength at 37 ˚C, reflection of Bragg wavelength at 37˚C respectively.

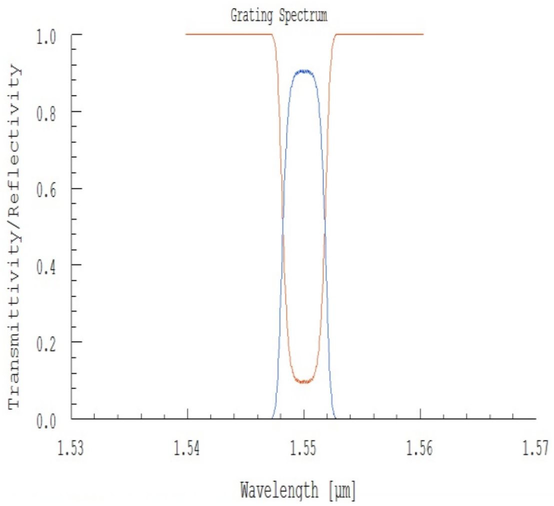

Figure (3): Spectrum of Grating.

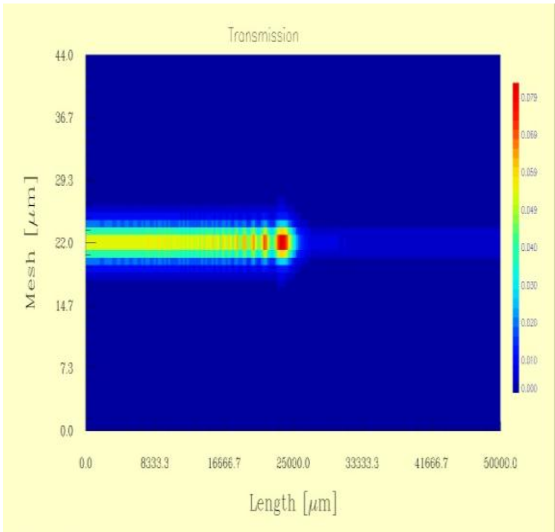

Figure (4a): transmission of Bragg wavelength at 37 ˚C (reference temperature)

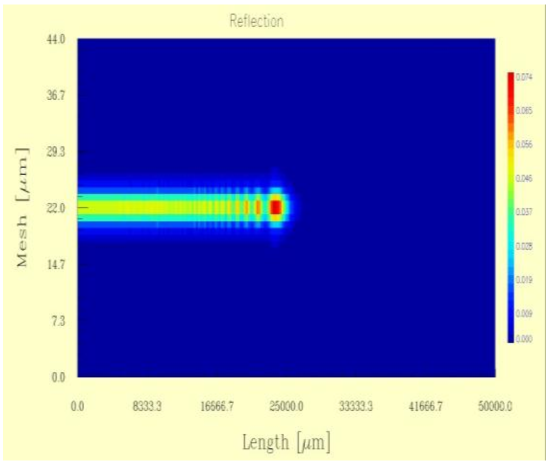

Figure (4b): reflection of Bragg wavelength at 37˚C (reference temperature)

By taking natural temperature of human body as a reference temperature which is 37 ˚C and apply different values of temperature from hypothermia (35 ˚C) to hyperthermia (42 ˚C) with interval of (1 ˚C). The peak wavelength of FBG sensor was recorded at different temperature as shown in figures (5, 6, 7, 8, 9, 10, 11 and 12). The relation between the applied temperature and shifting Bragg wavelength is linear as it clears in figure (13).

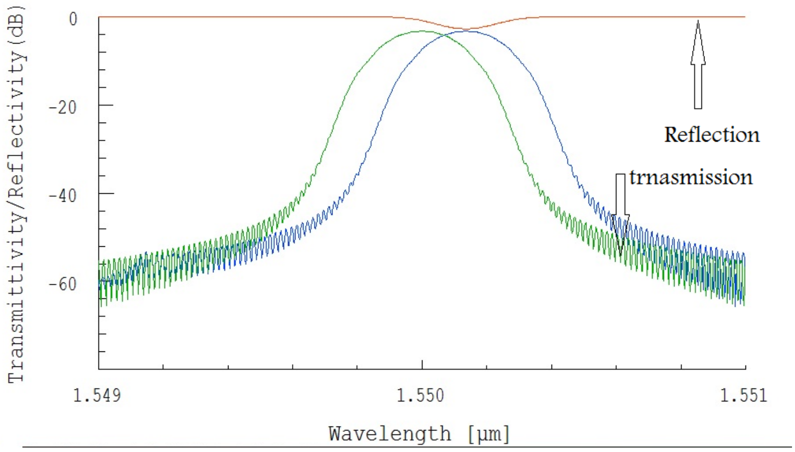

Figure (5): transmission and reflection spectra for shifted Bragg wavelength at 35 ˚C

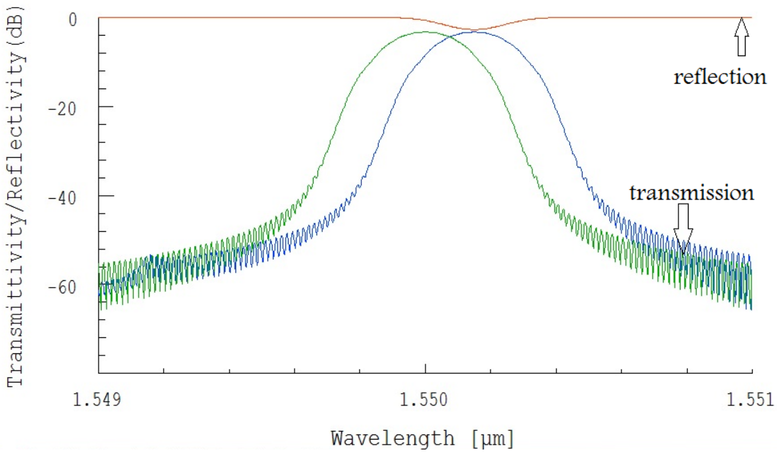

Figure (6): transmission and reflection spectra for shifted Bragg wavelength at 36 ˚C

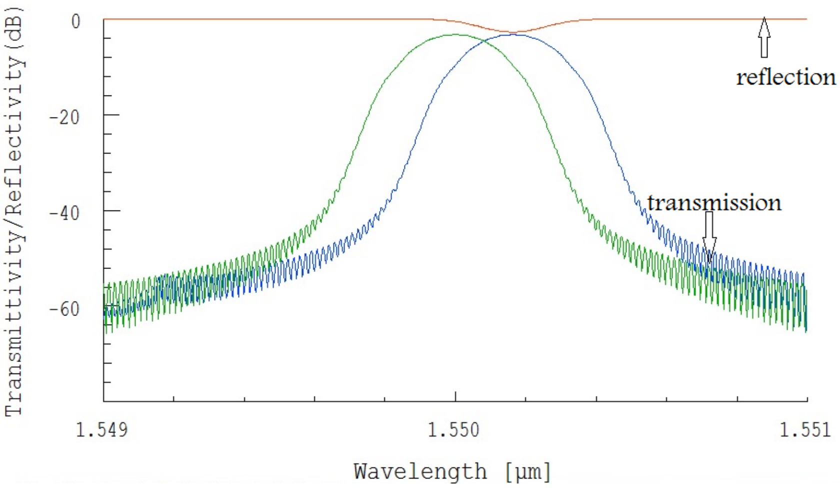

Figure (7): transmission and reflection spectra for shifted Bragg wavelength at 37˚C

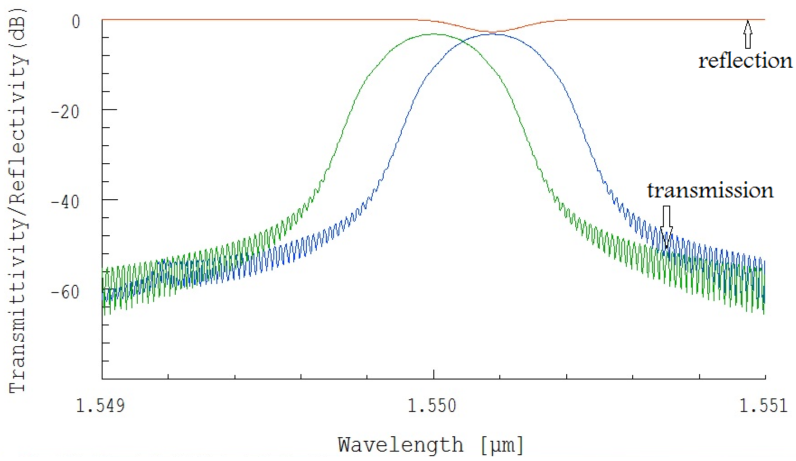

Figure (8): transmission and reflection spectra for shifted Bragg wavelength at 38˚C

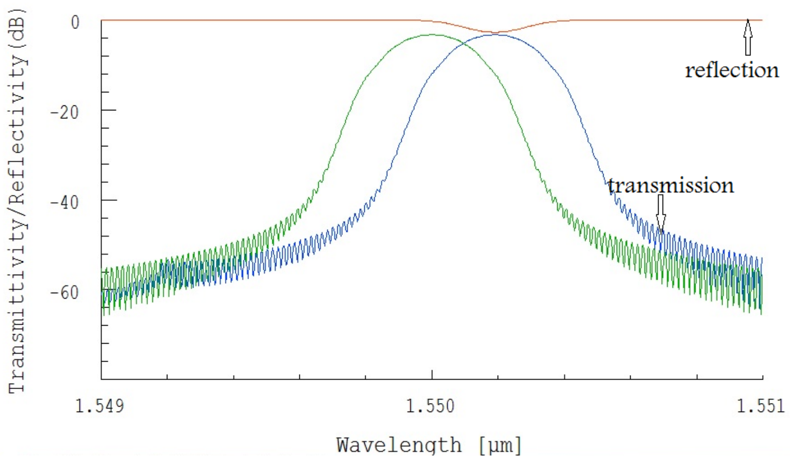

Figure (9): transmission and reflection spectra for shifted Bragg wavelength at 39˚C

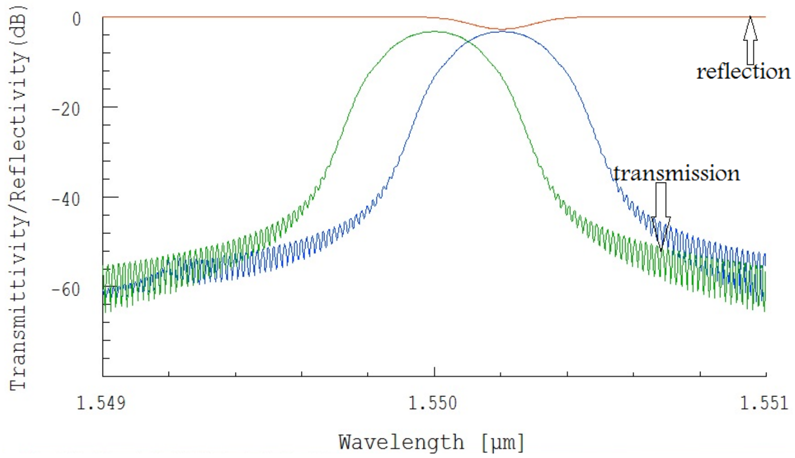

Figure (10): transmission and reflection spectra for shifted Bragg wavelength at 40˚C

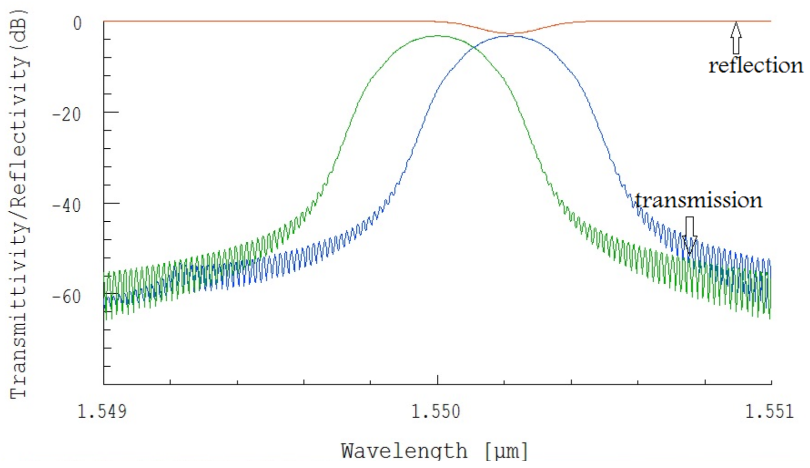

Figure (11): transmission and reflection spectra for shifted Bragg wavelength at 41˚C

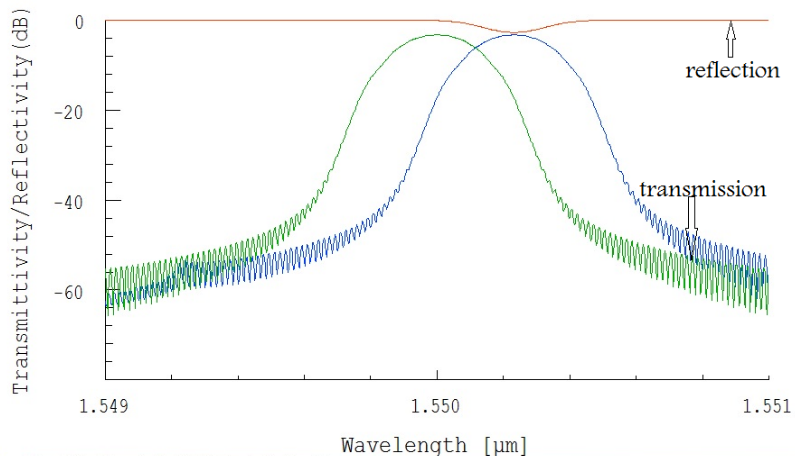

Figure (12): transmission and reflection spectra for shifted Bragg wavelength at 42˚C

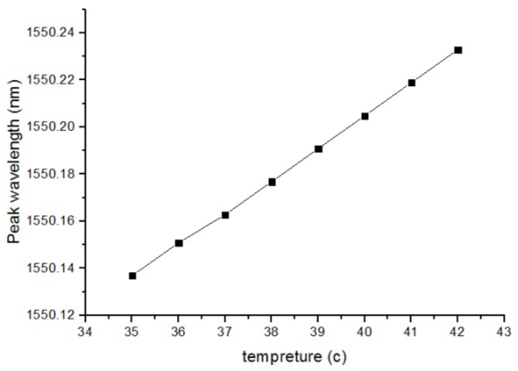

Figure (13): The Relation between shifting in Bragg wavelength with applied temperature

Conclusion

An important application of FBG technology was sensing. The sensitivity of the Bragg wavelength to temperature arises from the change in the refractive index of the optical fiber. The used FBG in this work is very sensitive to the variation of the temperature degrees; the sensitivity was (0.014 nm/°C). The relation between the applied temperature and shifting Bragg wavelength is linear. There was a little shifting in wavelength of FBG which indicate it is sensitive to temperature arise so this simulation result will help to improve this work to practical area and synthesized an implantable thermometer used for emergent cases which include sudden temperature shift.

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