Performance Investigation of Fiber Bragg Grating Temperature Sensor for Industrial Applications

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***Abstract*: Monitoring the high temperature in industrial processes is crucial. Conventional sensors malfunction above 150-degree Celsius temperature. These conventional sensors can be replaced by the Fiber Bragg Grating FBG sensors due to their EMI immunity, compact size and light in weight. In this paper we proposed a model which use FBG sensor to measure temperature for industrial applications. The proposed sensor model measures wavelength to relate it with temperature up to 570 Kelvin. In this paper relation between temperature and wavelength is prepared and result shows FBG sensor has high sensitivity than conventional sensors.**

***Keywords*: Comsol Multiphysics software, Domain probe points, Fiber Bragg grating temperature sensor, Industrial health monitoring.**

1. Introduction

Monitoring the temperature in high temperature industrial application is an important and challenging task where sensors have to withstand high temperature without destruction [1]. Nowadays, the monitoring and control of infrastructure equipment are subjects that have received increasing attention. Conventional electronic sensors like thermocouple, bimetal switches etc. cannot withstand high temperature, easily pick up by electromagnetic interference (EMI) and malfunction due to overheating. That is the reason nowadays conventional sensor has been replaced by Fiber optical sensor [2].

For monitoring the temperature Fiber Bragg Grating (FBG) sensor have been widely used in high temperature industrial applications. Photo engraving the core of the fiber by ultra violet rays create an optical fiber sensor [3]. That optical fiber sensor is known as Fiber Bragg Grating sensor. This method of photo engraving the core with UV radiations is a photo mask method produce periodic perturbations in the core refractive index of the fiber. The refractive index of the fiber is permanently transformed according to the intensity of light it is exposed which depends on the photosensitivity of the fiber. This resulting periodic variation in the refractive index is known as Fiber Bragg grating.

Domain probe points in Comsol Multiphysics are analogous to Fiber Bragg grating sensor. The probe points are used to measure strain, temperature. Probe points are used to monitor the field value over time. K. Vinnarasi and Sundaravadivelu [4] proposed a model in which they used domain probe points to measure the strain to detect the crack in concrete for civil applications. They showed that the value of the strain decreased at a particular point with the help of probe points and hence proved domain probe points are analogous to the FBG sensor. Shyh and Peng [5] proposed a model to improve the temperature sensitivity by using an SOI interferometer sensor with waveguide Bragg reflective grating which enhance the temperature sensitivity. It was emerged as an attractive proposal as its thermal expansion coefficient has larger than grating sensor which shows in this way we can enhance the sensitivity.

FBG proves to be efficient one of the fiber-based sensor. The information sensed by FBG sensor is in the form of wavelength encoded. Parne and Dipankar [6] also demonstrated temperature sensitivity can be enhanced 3 times by using a polymer coated Fiber Bragg Grating sensor. He proposed that coated Fiber Bragg Grating sensor (FBG) by using Teflon coating of 20 to 40 um of thickness.

Thermal expansion has a crucial influence on reliability and working life expectancy of instruments used in industrial applications. To attain the location and value of the temperature, accurate and reliable methods are obligatory. For assessing the hot-spot temperature fiber-optic sensors (FBG) can be used to obtain temperature from the outside or inside of the devices [7].

Thermal expansion is an important factor in all types of high temperature industrial application where differential heating may occur either from environmental effects or from service conditions. The thermal expansion coefficient ξ will be a variable quantity depending on materials [8]. The Bragg wavelength $\boldsymbol{\lambda_B}$ is related to the grating period Δ, and the effective refractive index of the fiber η_{eff} by the following equation [7].

$$\boldsymbol{\lambda_B} = 2\Delta\, \eta_{eff} \quad (1)$$

Subjecting the fiber to a change of temperature will cause Δ

η_{eff} and therefore λ to change. By determining the wavelength of the reflectivity, the temperature to which the fiber is subjected may be found [9]. The shift in the wavelength of the FGB sensor is measured from the following equation [7].

$$\Delta\boldsymbol{\lambda}_{\mathbf{B}} = \lambda_B\,(1+\xi)\,\Delta T \qquad (2)$$

Thermal processes can introduce large non liner optical effects. When incident laser is passed through an optical medium, some fraction of the incident light is absorbed which lead to the origin of thermal nonlinearity. In the similar way when temperature is assigned to a material then the illuminated portion will reflect the heat in form of some parameter, can be in wavelength coded form which can be of a particular band of wavelength. This occurs because the temperature of the illuminated material consequently increases, which produce a change in the refractive index of the material [10].

In this paper we developed a model in which domain probe points are analogous to our FBG sensor to sense the temperature at various instances and the temperature can be monitored and measured regularly in high temperature application regions. Therefore, we designed the temperature sensor by adopting domain probe points.

2. Design

A 2D model is designed using COMSOL 5.2 Multiphysics. In this model a rectangle shape slab of length 0.6m and breadth 0.2m is chosen as shown in Figure 1.

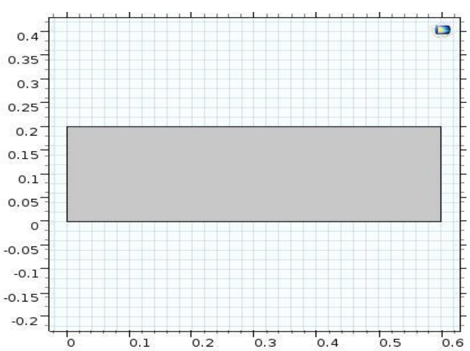

Fig. 1. Schematic of 2D model

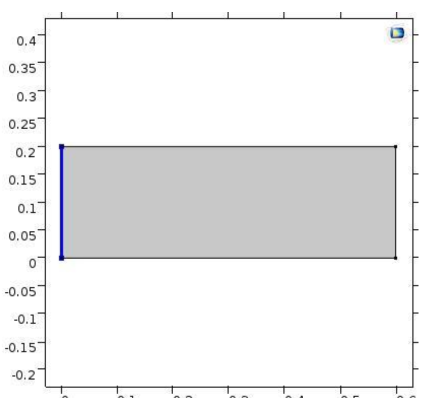

Fig. 2. Schematic of 2D model showing temperature

Mainly in high temperature industrial applications various materials like aluminium, borosilicate, tungsten titanium alloy, silicon etc. are used. Among them aluminium [11] has high thermal conductivity and that is the reason we have chosen this material for our model. The temperature is assigned at one side (left hand side) of the model which is conducted throughout according to the material conductivity as shown in figure 2. The blue line indicates the temperature is assigned to the model.

3. Temperature Measurement

This is a heat transfer model in which temperature is assigned at the left side of the slab as shown in figure 2. Thermal conductivity is assigned to the model according to the material. Thermal conductivity outlines the degree to which a quantified material conducts electricity. Heat flux which states flow of energy per unit of area per unit of time is also defined in the model.

4. Probe Points as Sensor

Domain probe point is selected from Definitions tab which is available in the Comsol Multiphysics 5.2. Domain probe point is analogous to FBG sensor is used to sense the temperature. The probe points are applied at arbitrary positions and temperature is sensed at various time instants as shown in Figure 3. These probe points are analogous to the FBG sensor. We know that change in temperature will produce change in wavelength which has linear relation [7].


Fig. 3. The 2D model showing domain probe point

5. Results and Discussions

A. *Surface Plot*

The heat transfer is defined by the surface plot diagram. Figure 4 shows the surface plot at the 300-degree Celsius temperature that shows the heat transfer along the design model. This clearly shows it has a dependent variable that is temperature (T) which means that may be changed. The maximum temperature reached at the design is 570 (K).

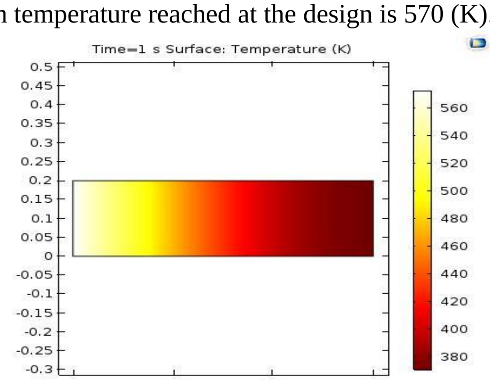

Fig. 4. Surface Plot

B. Temperature versus Time plot at 300 degrees Celsius

Sensor domain point probes are placed at arbitrary instances and plot the change in temperature with time. At same instance of time each probe sensed different value of temperature.

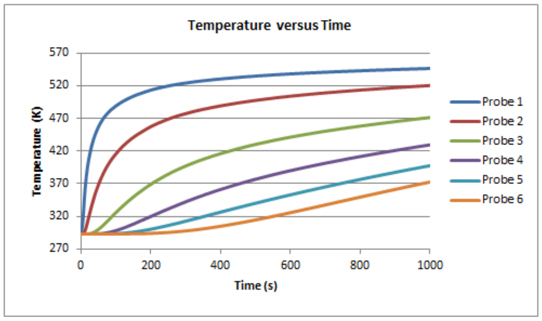

Fig. 5. The Temperature sensed by all the probes

The combined graph of temperature by all the six probes is shown in Figure 5. This shows that the change in temperature is highest at the front end. As the distance increases the temperature value increases as the heat is transferred along the design. Highest temperature is achieved at the right most side and lowest temperature at left most side. This change in temperature is because of the thermal conductivity of the chosen material.

C. Wavelength versus Time at 300-degree Celsius temperature

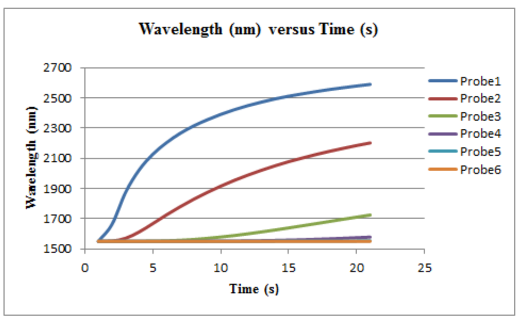

Fig. 6. Wavelength versus Time at 300-degree Celsius temperature

Figure 6 shows the wavelength versus time graph by all the domain probe points. We can have range of wavelength that can be used in different optical fiber communication fields. The dimension of domains probe points is same, the only difference is in their placed locations.

D. Wavelength versus Temperature of last three domain probes at 300 degrees Celsius

In this at every change in value of temperature the probe points reflect a light of a particular wavelength. As the distance increases the change in wavelength achieve is small which means after a particular temperature change it will reflect a particular wavelength. This means that at this temperature we can standardize the probe sensors. Different wavelength that is achieved provides us the sensor range.

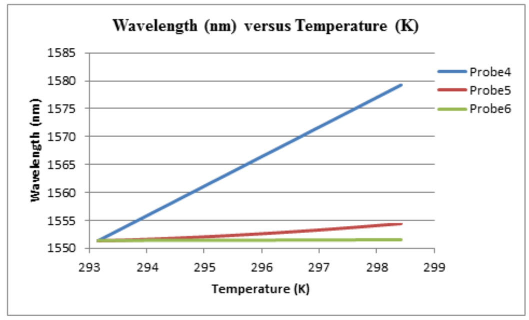

Fig. 7. Wavelength versus Temperature of last three domain probes

E. Wavelength versus Time of last three domain probes at 300 degrees Celsius

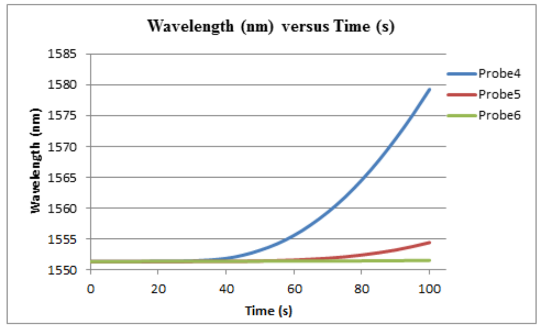

Fig. 8. Wavelength versus Time of last three probes at 300-degree Celsius temperature

Figure 8 shows the graph which states that we have standardized the sensor. At different location of probe points we have achieved a same wavelength. In this we have achieved a particular wavelength of 1551nm with different sensor placing locations. In a way standardization of designing is done. Monochromatic nature appears.

6. Conclusion

A temperature based Fiber Bragg grating sensor is proposed for accurate monitoring of temperature is essential for high sensitive areas for example industrial applications. The conventional sensors like thermocouple, bimetal switches and resistance temperature sensors get damaged beyond 150 degrees Celsius and it will cause instability. To work beyond this temperature, range FBG optical sensors can be used. We have demonstrated it that FBG sensors are stables in the temperature range up to 900 degrees Celsius. They are the best choice for the high temperature industrial applications where stability and sensitivity has to be considered. They have replaced the conventional sensors today due to their compact size, light in weight and EMI immunity. They can be used for oil wells, boilers, nuclear reactors, etc. in the high temperature industrial applications.

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