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Analysis of High Temperature Monitoring Using Fiber Bragg Grating Sensor

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Abstract— *Measuring the temperature in high temperature industrial application is an important factor and a challenging part where sensors need to withstand high temperature without destruction. Temperature measurement and monitoring in the industries are necessary to ensure correct and accurate operation of the equipment. In these high temperature application conventional electronic sensors like thermocouple, bimetal switches etc cannot withstand high temperature, malfunction due to overheating and also easily pick up Electromagnetic Interference (EMI). In this paper these conventional sensors are replaced by Fiber Bragg Grating (FBG) sensors which is based on the principle of measurement of reflected Bragg's wavelength and the corresponding shift in the wavelength for the temperature sensed. Advantages of FBG sensors for temperature measurement is that its light weight, small size, flexibility, non interfering, low loss, long range sensing(remote sensing), multiplexing capabilities, withstands high temperature. In this paper the simulation of 2D and 3D model is done using the Comsol software and also the experiment is performed for FBG temperature sensors to depict the shift in Bragg's wavelength that can be used in high temperature monitoring in oil wells, high temperature optical sensing in gas turbines, widely used in nuclear reactors which has elevated temperature and high levels of electromagnetic interference (EMI).*

Keywords— ***electromagnetic interference, Comsol software, Bragg's wavelength, Fiber Bragg grating sensor.***

I. INTRODUCTION

Optical fiber based sensing technology have several inherent advantages that make them attractive for a wide range of industrial sensing applications. The conventional sensors like thermocouples, resistance temperature detectors, thermistors cannot be used in high temperature measurement owing to failure at high temperature, EMI coupling, and not appropriate to be used in high microwave fields[3]. The FBG sensors are typically small in size, passive, immune to EMI, resistant to harsh environments and have a capability to perform distributed sensing.

The Fiber Bragg Grating is optical fiber sensor that is created by photo inscribing the core of the silica fiber with the Ultra violet rays by the photomask method. There is a periodic perturbations created in the core refractive index of the optical fiber created by exposure to intense UV radiation. The refractive index of the fiber is permanently altered according to the intensity of light it is exposed. The alteration in the refractive index depends on the photosensitivity of the fiber. The resulting periodic variation in the refractive index is called a fiber Bragg grating. The Fig. 1 shows the expanded view of FBG with the core of the fiber being inscribed and grating is produced with the period Λ.

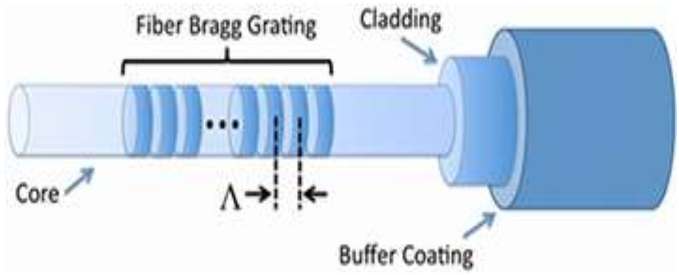

Fig.1 : An expanded view of Fiber Bragg Grating sensors.

The FBG sensors are made of germanium doped silica because of its high melting point 938.2 °C and 1600 °C respectively to withstand high temperature. The FBG reflects a particular wavelength called the Bragg's wavelength and transmits all other wavelength in a broadband source. This property of reflecting the Bragg's wavelength paves way for sensing applications using FBG. The reflected Bragg's wavelength is given as

$$\lambda b=2 \times n \times \Lambda \quad (1)$$

In the equation (1) λb indicates the Braggs wavelength and n for refractive index and Λ is the grating period. The sensing function of an FBG originates from the sensitivity of both the refractive index of the optical fiber and the grating period within the fiber to externally applied mechanical or thermal perturbations. When a external physical parameter like temperature is applied to the FBG there is a shift in the reflected Bragg's wavelength[3]. Based on the shift the amount of variation in the temperature is obtained. In this way the temperature can be monitored and measured regularly in high temperature sensitive regions. The FBG can measure high temperature as 1000 degree Celsius due to the characteristics of the fiber

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material[3]. The shift in the wavelength can be measured from the following equation:

$$\Delta\lambda b = \lambda b\,(1+\xi)\Delta T \qquad (2)$$

The equation (2) λb is the Bragg wavelength, ξ is the fiber thermo-optic coefficient, ΔT is temperature change and $\Delta\lambda b$ is the change in the Bragg's wavelength.

1.1 Design of 2D and 3D models

A 2D model of a furnace in rectangle shape is modeled where the length is 0.6m and breadth 0.2m. The aluminum material is assigned to the model due to its high thermal conductivity. The temperature is assigned at one side of the model which is conducted throughout. The probe points are placed at three different places and the temperature is measured.

Similarly a 3D model is designed with the length 4m, breadth 1m and height 1m. The temperature is assigned to one face of the cube and the edge probes are used to measure the temperature.

1.2 Experiment To Determine Bragg's Wavelength Shift

In the model created using Comsol the temperature is measured using the probe points at different places. These probe points are replaced by the FBG sensors measuring the same temperature that was given in Comsol. If conventional sensors are used at that points it cannot withstand high temperature.

The Fig. 2 shows the block diagram of FBG temperature measurement. Broadband light source is given to the FBG using superluminiscent light emitting diode(SLED). The light passes via the port 1 and 2 of circulator to the FBG pasted on the HOTPLATE. All the connections are made using the fiber pigtails. The FBG reflects the Bragg's wavelength which is obtained at the IMON via port 3of the circulator and then the IMON to the laptop using USB. The temperature of the hot plate in increased in steps and the corresponding shift in the wavelength is noted in IMON software in the laptop.

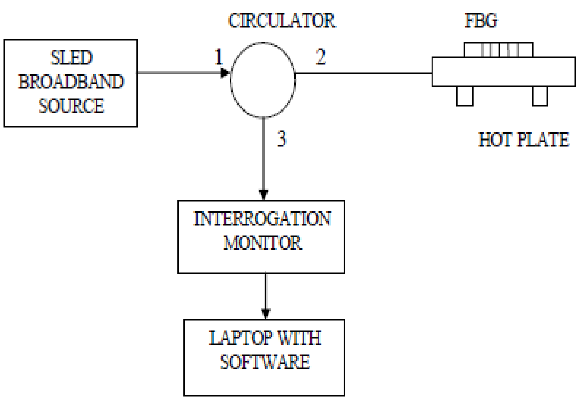

Fig. 2: Block diagram of FBG temperature measurement.

II. HIGH TEMPERATURE MONITORING

2.1 Simulation of 2D and 3D models

The Fig. 3 shows the 2D model for the temperature measurement. The temperature is given at one side of the model which traverses along based on the conductivity of the material. The blue line on the left side indicates the temperature assigned. The Fig. 4 shows the time dependent study is done for the model and the heat is transferred along the model which is shown in different shades.

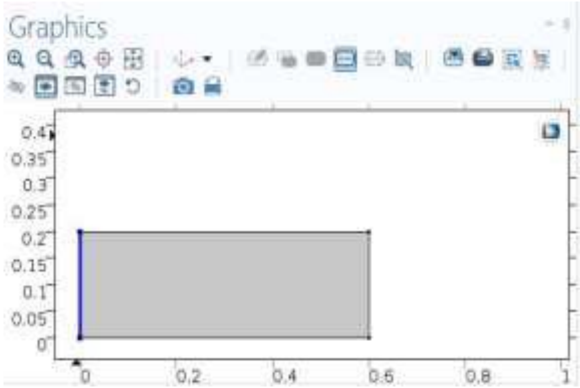

Fig. 3: The 2D model designed using Comsol

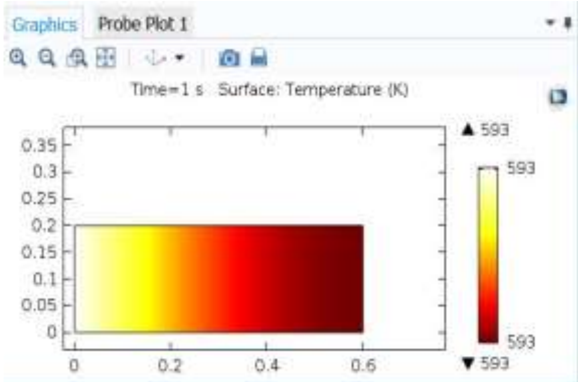

Fig. 4 : The heat transfer along the model

The Fig. 5 shows the 3D model for the temperature measurement where the aluminum is assigned to the entire block and the temperature is assigned to one face of the block which is indicated with blue shade. The Fig. 6 shows the heat transfer in 3D model when a time dependent study is performed in Comsol.

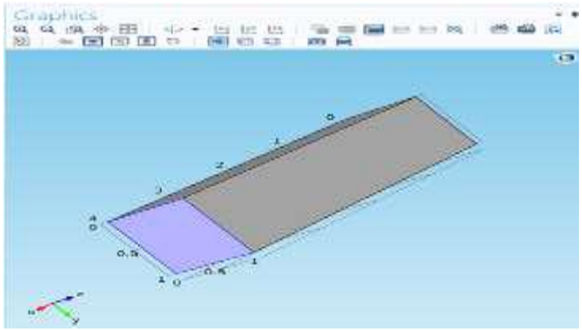

Fig. 5: The 3D model using Comsol

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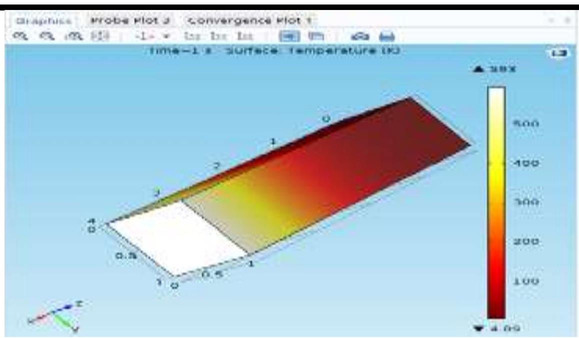

Fig. 6: The heat transfer in the 3D model

2.2 Sensor Location And Temperature Monitoring Waveform For 2D Model

The sensors are placed at three different places to measure the heat transfer. The figures at the top of Fig. 7 shows that the domain probe points placed at the three different places in the model. The probe points are used to measure the temperature at different instants. The bottom part of the figure depicts the respective waveforms or temperature measured for the probe points in the figure. Different temperature values like 300 °C or 573.15 K, 500 °C or 773.15 K is given and measured.

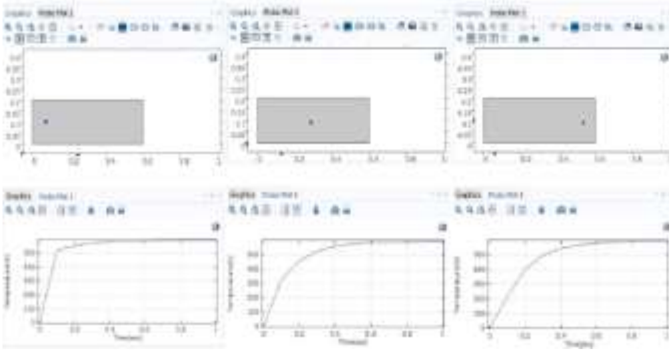

Fig. 7: Domain probe points placement and respective temperature (573.15 K) measured waveforms

The Fig. 8 shows the all the three waveforms of the probe points plotted in the same the same plot. The plots here are temperature (K) versus Time (sec).The blue, green and red lines indicates the waveforms of first, second and third probe points respectively. The difference in the waveforms for same temperature throughout is due to distance from the source of temperature to the probe points. These probe points are replaced by the FBG sensors rather than the conventional sensors.

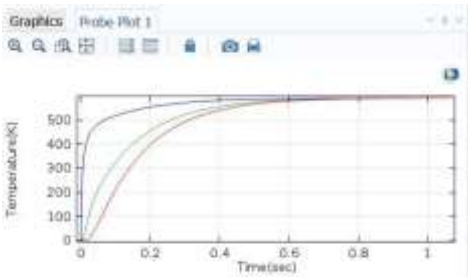

Fig. 8: Waveform for all the three probe points

2.3 Sensor Location And Temperature Monitoring Waveform For 3Dmodel

The Fig. 9 shows the domain boundary probe points to measure the temperature given at the one face of the model. The probe is kept at the boundary of the sides of the 3D model designed.

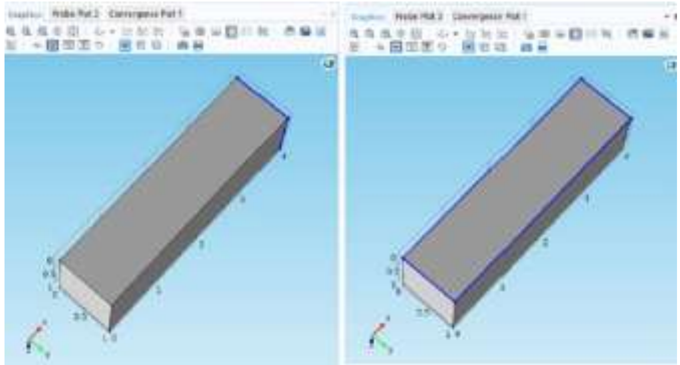

Fig. 9: The domain boundary edge probe points assignment

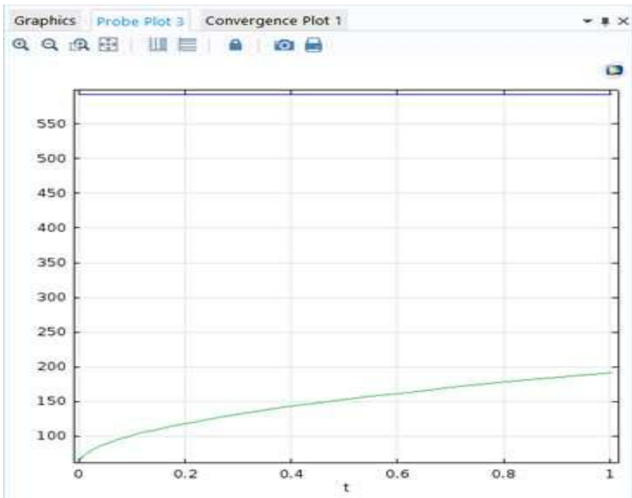

Fig. 10: Plot for temperature (573 K) measurement

The Fig. 10 shows the time dependent study made for the 3D model and also the waveforms for temperature measured using the boundary domain probe points. The temperature of 573 (K) is given and plots are obtained. The first picture gives the heat transfer in the 3D model where it gradually reaches the end. The waveforms are temperature (K) versus time (sec).The two plotted line indicates the measured values at the instant of the boundary probes. As the heat traverses through the model gradually, the waveforms obtained is also different based on the placement of the probes. The probes at the edge face measure less due to low heat reached at the end.

III. EXPERIMENTAL SETUP

The Fig. 11 depicts the practical experimental setup performed at IIT MADRAS of the FBG senor to measure the temperature which is given as the perturbation to the

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FBG. The temperature to FBG placed on the ceramic hotplate is measured by increasing in steps.

Fig. 11: Experimental setup for temperature monitoring

3.1 Experimental Results

When the experiment is performed as shown in the Fig. 11, there is a external perturbation i.e. the temperature to the FBG given by the ceramic hotplate over which the FBG is placed. The range of the hotplate is 40-500 °C. The temperature is increased in the hotplate in steps and readings are taken. The wavelength shift in the Bragg's wavelength is noted in the IMON evaluation software in the laptop.

The initial reflected Bragg's wavelength is 1551.54 nm. The Fig. 12 shows the example of reflected wavelength for temperature of 340 °C that is obtained in the IMON software and there is a shift noted in the wavelength which is 1555.0 nm.

Fig. 12: Example waveform for 340 °C in IMON software

These values i.e. the readings obtained for the different wavelength shift due to temperature change in the IMON software is tabulated in the excel sheet. For each temperature increase the readings are tabulated. The tabulation includes the wavelength shift and the power in pixel. Then these counts are converted into power in watts using MATLAB and the plot for power (watts) versus wavelength (nm).

The Fig. 13 shows the waveform for the initial reflected Bragg's wavelength when no temperature is given to the FBG and it is at 1551.43 nm. Only the input broadband light source is present in the fiber.

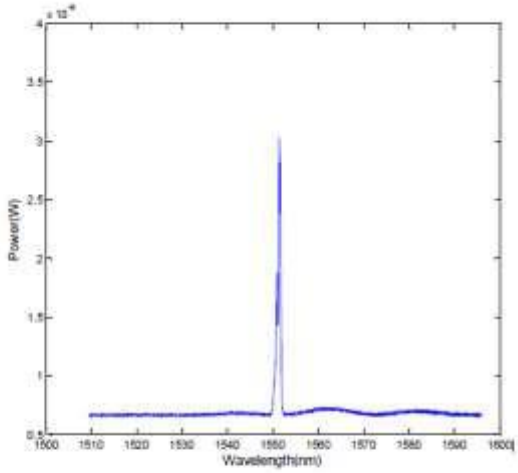

Fig. 13 : The reflected FBG spectrum .

The Fig. 14 depicts the wavelength shift plotted for 43.5°C from initial 0°C and its shifted to 1551.60 nm. The plot is done for power (watts) versus wavelength (nm).

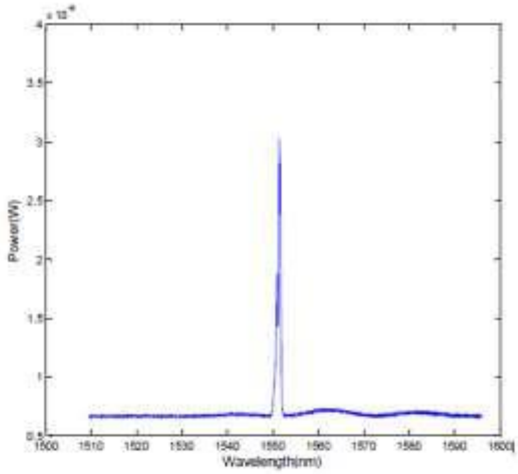

Fig. 14: The wavelength shift at 43.5°C

Similarly Fig. 15 depicts the wavelength shift for 500°C and it is 1557.0 nm. Now from initial reflected Bragg's wavelength 1551.43 nm has shifted to 1557.0 nm

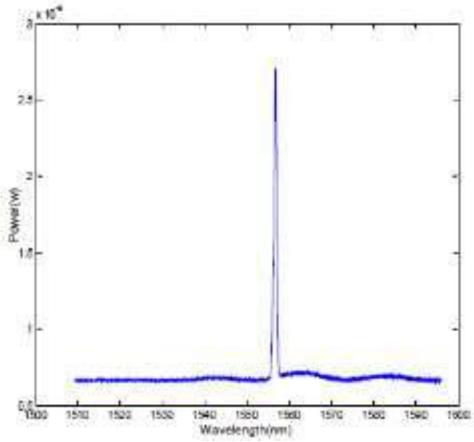

Fig. 15. The wavelength shift at 500°C

The Table I shows the tabulated values for different temperature raised in steps and the respective wavelength shift of the reflected spectrum that is noted in the IMON evaluation software and the readings are also plotted in MATLAB, which is shown in *Fig. 15*.

TABLE I. Tabulation For Temperature And Wavelength

Temperature(°C)	Wavelength(nm)	Temperature(°C)	Wavelength(nm)
0	1551.43	320	1555.0
108.8	1552.40	370	1555.54
151.2	1552.81	420	1556.06
212.1	1553.50	460	1556.00
270.5	1554.36	500	1557.00

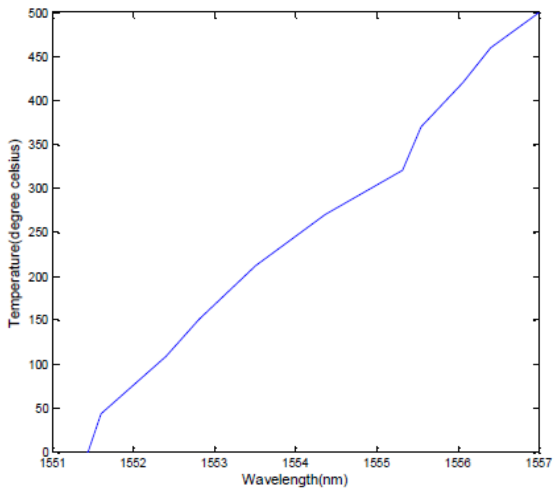

Fig. 15: Plot for temperature (°C) versus wavelength (nm)

From the Fig. 15, it can be inferred that the wavelength shifts linearly with the temperature as it is increased. The temperature is increased in steps to obtain the variations and increase in the reflected Bragg's wavelength. The stability of FBG to high temperature can also be analyzed.

IV. CONCLUSION

A temperature sensor based on Fiber Bragg gratings is analyzed both theoretically via simulations and experimentally. The response of the grating to changes in temperature is very linear and this makes the FBG a rugged device for sensing applications. Here the experiment is performed to measure temperature is up to 500°C using the FBG. If the conventional sensors like resistance temperature detectors ,bimetal switches and thermistors are used, it will malfunction at 150°C[1] causing instability in the measurement of the temperature at high sensitive areas where temperature needs to be monitored regularly. The fragile nature and its small size with stable characteristics have helped to sense temperature in sensitive region. These FBG's can replace conventional sensors in remote applications like oil wells, nuclear reactors, boilers etc...withstanding high temperature range.

REFERENCES

[1] Grzegorz Fusiek, Pawel Niewczas, James R. McDonald, "Design of a highly accurate optical sensor system for pressure and temperature monitoring in oil wells", IEEE Sensors Journal, Vol. 12, No. 1, January 2009.

[2] Stephen J. Mihailov , " Fiber Bragg Grating Sensors for Harsh Environments" , Sensors 2012, 12, 1898-1918.

[3] Ogério M. Cazo, Carmem L.Barbosa, HaroldoT. Hattori,Renato C.Rabelo,Osni Lisbôa, Jorge L. S. Ferreira, "Fiber Bragg Grating Temperature Sensor " , Sensors 2009, 9, 8377-8381.

[4] Yun-jiang Rao, David J. Webb, David A. Jackson, Lin Zhang, and I. Bennion, "In-Fiber Bragg-Grating Temperature Sensor System for Medical Applications", Journal Of Lightwave Technology, Vol. 15, No. 5, May 1997.

[5] David Barrera, Vittoria Finazzi, Joel Villatoro, "Packaged Optical Sensors Based on Regenerated Fiber Bragg Gratings for High Temperature Applications" , IEEE Sensors Journal, Vol. 12, No. 1, January 2012.

[6] S. Gingras, C. Hudon, C. Guddemi, paper titled as 'Rotor Temperature Monitoring Using Fiber Bragg Grating Sensors' Sensors 2011, 12, 1880- 1886