A STUDY OF FIBER BRAGG GRATING AS A TEMPERATURE SENSOR

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Abstract

Fiber Bragg gratings (FBGs) became one of the elegant sensor components for static and dynamic parameter measurement, for instances, temperature, strain and pressure. FBGs are based on the principle of Bragg reflection. Their Bragg wavelength shift is proportional to the temperature and strain variations which are experienced by the gratings. In this study, a fiber Bragg grating sensor is proposed to detect the temperature on the surface of mechanical structures. In particular, we point out that the method is well suited for measuring very small temperature because they are able to withstand in a high temperature environments, where standard thermocouple methods are failed. The sensing principle is based on tracking of Bragg wavelength shifts caused by the temperature change. In this work, fiber grating is dipped into partially filled water beaker that place on a hotplate for the heating process. The Bragg wavelength shifts are observed using optical spectrum analyzer (OSA). The sensitivity of this sensor due to temperature variations is 0.0138 nm/ °C almost equal to common FBG. The correlation of theoretical calculations and experimental results show the capability and feasibility of the purposed techniques. It will be useful for monitoring the flow allocation on production wells, fire detection, steel building, tunnels, leak detection and temperature monitoring of reactor vessels, flare stacks, power line. Therefore, it is expected that the fiber Bragg grating sensor, because of its uniqueness in many aspects and being at an affordable cost, has an excellent prospect in temperature measurements.

Keywords : Fiber Bragg grating, optical sensing, temperature sensor, Bragg wavelength shift.

Traditionally, the semiconductor sensor, platinum resistance sensor, thermistor and thermocouple are most commonly used for temperature measurement. The semiconductor sensor measures the leakage current through a semiconductor, which is proportional to the absolute temperature. This is not much used in general data gathering. It is not very small and has no particular advantages. The platinum resistance sensor changes resistance according to the temperature, calibrated by a very well defined equation. It is often used as an accurate reference but this accuracy is seldom needed in our trade. Thermocouple and thermistor devices have been commercialized available in the market for many years [1]. The sensor are widely utilized due to their small size, reliable and inexpensive, however, these temperature sensors are not satisfied thoroughly due to the lack of intrinsic safety, their characteristics of electrically active, and not durable at the extravagant heating [2]. The two main drawbacks of these sensors are: 1) local heating of the sensor head due to metallic conductor; 2) the electromagnetic interference (EMI) of voltages and currents in metallic conductor [1].

FBG sensors overcome these problems as they are dielectric and virtually immune to electromagnetic interference [3]. FBG offers a series of advantages including small size and weight, high multiplexing potential, high dynamic range, fatigue and corrosion resistance, inherent strength of fiber, immunity to electromagnetic interference (which reduces the cost for shielding the ruggedness of environment), and low cost due to the complementary developments in the telecommunication and optoelectronics industry [4,5]. In addition, the embedded optical fiber which contains the Bragg grating does not degrade the static mechanical characteristics of the host. The combination of fiber optic technology and smart structures enables the multiplexing of the arrays for fiber optic sensors, meanwhile, interconnected to other fibers to convey the signals and implement as a quasi-distributed sensors [5].

Fiber Bragg grating (FBG) can be obtained by creating a periodic change in the refractive index along a certain short length of the fiber core [6]. The magnitude of ambient perturbations in an environment experienced by the grating is ascertained from the resulted Bragg wavelength shift [7]. FBGs operate as sensors when changes in a particular environmental variable are correlated with shifts in the reflected wavelength of the FBG, such as temperature and strain variation. As the light source pass through the optical fiber which contains the FBG, a certain percentage of the incident light will be reflected at the Bragg wavelength [8] which can be expressed as:

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

where λ_B is the Bragg wavelength, n_{eff} is the effective refractive index of the fiber core, and Λ is the period of grating [9].

MATERIALS AND METHODS

The whole testing system utilized Tunable Laser Source (TLS), Optical Spectrum Analyzer (OSA), electrical oven, thermocouple wire, and a fiber Bragg grating. Fig. 1 shows the schematic experimental setup for temperature measurement using fiber Bragg grating in the air. The optical fiber containing the Bragg grating is exposed to an increase in temperature when the water inside the beaker is heated using the hot plate progressively.

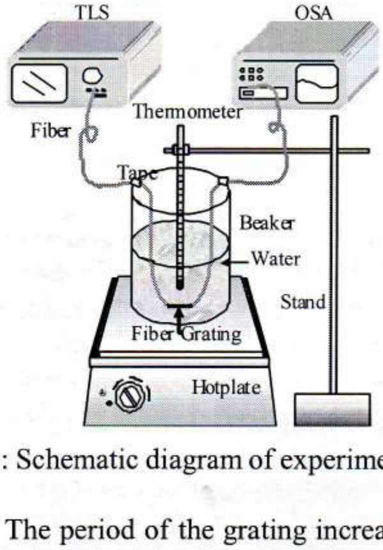

Fig. 1: Schematic diagram of experimental setup.

The period of the grating increases due to an increase in length of the fiber from thermal expansion. This change in period of the grating causes a change in wavelength of the light being reflected. When the broadband light source from Tunable Laser Source (TLS) is sent down the fiber, the light which its wavelength match the Bragg condition is reflected, while the rest are transmitted through the optical fiber and monitored using an Optical Spectrum Analyzer (OSA) to deduce the relationship between wavelength shifts in respect to the changes in temperature of the environment.

RESULTS AND DISCUSSION

A small amount of incident light is reflected at each periodic refractive index change and thus created the dip of power which represented the power of reflected light. The value of the power dip is essential to determine the reflectivity using the equation below:

$$R = (1 - 10^{-\frac{r}{10}}) \times 100$$

where R is the reflectivity and r is the dip of power. The average reflectivity of the fiber Bragg grating sensor used is 51 %. This means 51 % of the light source is back-reflected at the certain Bragg wavelength [10].

The temperature response of a Bragg grating is related to the coefficient of thermal expansion, α of the fiber (typically fused silica) and the temperature dependence of the effective refractive index. The normalized wavelength change is related to the temperature change by

$$\Delta\lambda_B = \lambda_B(\xi + \alpha)\Delta T$$

where $\Delta\lambda_B$ is the Bragg wavelength shift, λ_B is the Bragg wavelength or center wavelength of the fiber Bragg grating, ξ is the thermo-optic coefficient and is the thermal expansion coefficient. In this case, the center wavelength of commercialized fiber Bragg grating utilized is 1555.006 nm. For germanium-doped silica core optical fiber, is 8.6 x 10^{-6} C^{-1} and α is 0.55 x 10^{-6} C^{-1}. The Bragg wavelength shift ($\Delta\lambda_B$) resulted by the elevated temperature (ΔT), thus can be calculated. The experimental and theoretical results are displayed in Fig. 2.

We observed that the Bragg wavelength behaved in an almost linear response to the temperature changes, where the Bragg wavelength shift, $\Delta\lambda_B$, is proportional to the temperature increases.

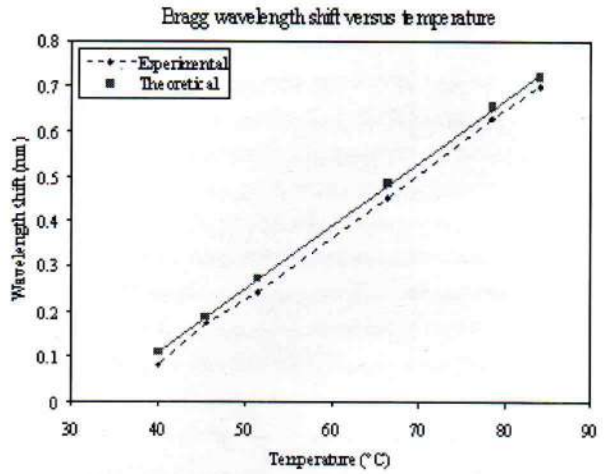

Fig. 2: Graph of comparison for experimental and theoretical results for temperature measurement

The graph shows that the experimental result is matched to the linearity of the theoretical results. However, deviation occurred between the experimental and theoretical results. The experimental wavelength-temperature sensitivity is 0.0139nm/°C whereas the theoretical wavelength-temperature sensitivity is 0.0142nm/°C.

Standard deviation =

$$\frac{\text{(Theoretical value - Experimental value)}}{\text{Theoretical value}} \times 100$$

$= [(0.0142 - 0.0139)/0.0142] \times 100$
$= 2.1\ \%$

There are some reasons which lead to the deviation, such as the uncertainty of the instruments involved in the experiment, displacement readings uncertainty, unsuitable optical fiber length, deviation of gratings temperature sensitively at different wavelength and other technical problems.

CONCLUSION

The fiber Bragg grating sensor has been shown to be useful and brilliant as a temperature sensor with sensitivities 0.0139 nm/ °C (experimental). The result obtained from this work indicated a rational deviation between the outcomes of experimental and theoretical, with a standard deviation of 2.1%. The use of the fiber Bragg grating is able to retrieve the temperature profile of a heating element. Such a device may find applications in a huge amount of application, for instances, medical areas, to detect the size and temperatures of inflamed areas within a body or within industry to accurately detect non-uniform heating of a miniature device. A possible application would be as an analytical tool to detect heat leakage from prototype computer chips in order to discover design flaws. The outstanding and unique advantages enable fiber Bragg grating plays a breakthrough role over other sensors as the most promise and sophisticated sensing element in a vast numbers of applications in aerospace, civil infrastructure, medical, oil exploration sensing fields and more. \

To conclude, the future of the fiber Bragg grating sensor is looking very promising and certainly has the potential to finally push optical fiber sensors to the forefront, resolutely challenging conventional forms of electromechanical sensors.

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