FBG-based temperature sensor package

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***Abstract*—A fiber Brag grating (FBG)-based temperature sensor accompanying with low cost interrogation scheme and LCD display has been designed and tested. The designed sensor measures the temperature from 20°C to 500°C with 1°C resolution.**

Keywords—temperature measurment; FBG sensor; fiber optic sensor

I. Introduction

Temperature measurement encompasses a wide variety of needs and applications. To meet these requirements, the industry has necessity to develop a large number of sensors and devices [1]. In order to obtain accurate, three-dimensional spatial information regarding the temperature distribution with real-time monitoring, fiber Bragg gratings (FBGs) are the intelligent sensing elements [2]. They have achieved a tremendous growth in sensing, telecommunications, and optical switching applications owing to all the advantages of fiber optics such as compact nature, light weight, immunity to electromagnetic interference, high reliability, etc. as well as fast response, high sensitivity, distribution and multiplexing capability, and multi parameter sensing [3].

FBGs are compact intrinsic optical devices constructed in a small segment of optical fiber. They are obtained by creating periodic variations in the refractive index of the core of a photo sensitive optical fiber from exposure to an intense UV interference pattern [4]. When FBG is illuminated by a broad band light source, it reflects a particular narrow band of wavelength called Bragg wavelength and transmits all others. The Bragg wavelength is expressed as $\lambda_B = 2n_{eff}\Lambda$, where n_{eff} is the effective index of refraction of the fiber core at free space centre wavelength, and Λ is the grating period [5]. Even a minute change in either of the above parameters due to external perturbation, will cause a considerable wavelength shift, and this wavelength shift itself would be a measure of the external perturbation [6]. In this way, FBGs are capable of measuring a wide range of parameters include temperature, strain/stress, pressure, curvature, vibration, displacement, electrical current, voltage, load, and ambient refractive index, etc. [7]. Over the past two decades, FBGs have seen an increased acceptance in variety of sensing applications such as structural sensing and monitoring applications in civil engineering, aerospace, marine, oil & gas, composites and smart structures [8].

The principle of the FBG-based temperature sensor involves the measurement of shift in Bragg wavelength while the other physical parameters (strain, surrounding refractive index) remains unchanged [9]. The wavelength shift for a temperature change (ΔT) is given as

$$\Delta\lambda_{B(t)} = \lambda_B(\alpha + \xi)\Delta T \qquad (1)$$

where $\alpha = (1/\Lambda)(\partial\Lambda/\partial T)$ is the thermal expansion coefficient of the fiber and $\xi = (1/n_{eff})(\partial n_{eff}/\partial T)$ represents the thermo-optic coefficient [10]. Due to the fragility of the bare FBG and to make the surrounding refractive index of the FBG unchanged, it is therefore necessary to encapsulate the FBG and to develop a sensor probe to use them directly in harsh environments [6]. Moreover, the usage of an optical spectrum analyzer (OSA) to extract the wavelength information from FBG significantly increases the size and cost of the system and also limits scanning speed. Therefore a compact and low coast interrogation system with display is to be developed for successful adaption of the technology in engineering applications [11].

In this paper we describe the design of an FBG-based temperature sensor package that includes sensor probe, interrogation system, and digital display to measure up to 500 °C.

II. Design of Sensor Probe

A polyimide coated type-I FBG of Bragg wavelength at 1552.94 nm is encapsulated with a capillary tube of ceramic Aluminum Nitride. The tube is measured 20cm in length and of 2 mm, 3.2 mm inner, outer diameters respectively. Since the ceramic tube is brittle in nature, it is inserted inside a stainless steel tube of diameter, 3.5mm as a safeguard. To avoid the effect of stainless steel tube on response-time of the sensor, aspiratory holes are provided on it at the location of FBG. The FBG inside the probe is fixed at one end and is left free at the other end to ensure that the FBG does get any strain impact neither by ceramic tube nor by stainless steel tube. The sensor probe is then inserted in a steel rod by making use of a brass holder and is sealed with high temperature adhesive. A heat resisting handle made of Nylon is employed for easy and safe handling from thermal hazards as shown in Fig. 1. An optical fiber patch card with FC/PC connector is making the sensor probe portable. The encapsulation not only protects the sensing element, but also makes it easy for installation.

III. Interrogation Scheme

A simple and low cost interrogation system is developed by employing a long-period fiber grating (LPG), photodiode

Fig. 1. Photograph of FBG sensor probe

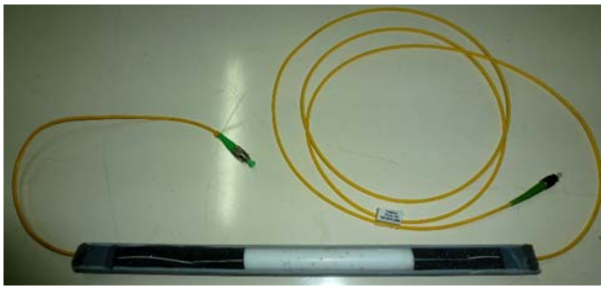

Fig. 2. Photograph of athermalized LPG

(PD), transimpedance amplifier, analog to digital convertor, and field programmable gate array (FPGA) with LCD display. The LPG is athermalized using a novel encapsulating technique by means of creating opposite effect of temperature induced strain attributed by encapsulating it appropriately in a specially designed Teflon tube, shown in Fig. 2, which is presented in our previous work [12]. This athermalized LPG is used to convert the wavelength information from the sensor probe into its equivalent intensity modulated signal, which can be easily detected by the simple PD instead of bulk optical spectrum analyser (OSA).

IV. Experimental Details

The sensor probe is inserted into a tubular furnace and subjected to the temperature ranging from 20 to 500 ^{o}C, and the corresponding response is recorded using OSA. Temperature related shift of Bragg wavelength is converted into an intensity modulated signal using the LPG as an optical edge filter. In order to make the system compact and cost effective, the OSA has been replaced by a PD.

The schematic of the sensor package is shown in Fig. 3. The reflected peak power of FBG at Bragg resonance wavelength is redirected to a PD using a three port optical circulator. Now the intensity modulated signal is converted into electrical current signal, and then converted into a voltage signal by making use of transimpedance amplifier. Further steps; signal conditioning, analog to digital conversion, calibration, addressing are followed respectively and the output is displayed in ‘^{o}C’, shown in Fig.4.

V. Results and Discussion

Fig. 5 shows temperature response of the FBG sensor probe. In comparison to the bare FBG, encapsulated FBG seems to be slightly lagged in Bragg wavelength shift, but maintained the linearity, shown in Fig. 5. The resonance peak power has been stabilized significantly at high temperature, which is desirable in further interrogations. The FBG sensor probe has shown fine temperature characteristics with a linearity of ~99.979 %, and sensitivity of 14.03±0.02 pm/^{o}C.

Fig. 6 shows temperature response of the sensor probe after being modulated by the LPG. Here the wavelength encoded signal from FBG is converted into intensity modulated signal using the LPG as an optical edge filter. The shift (redshift) in Bragg wavelength is found to be 13.04 pm/^{o}C with linear coefficient of 0.9999, whereas the intensity modulation is 3.56 nW/^{o}C with linear coefficient of 0.9997. Fig. 7 shows the spectral response of the reflected light from sensor probe after being modulated by LPG, over the span of applied temperature 20-500 ^{o}C. This intensity modulation is attained by using LPG as an optical edge filter, and hence a low cost interrogation system is attributed to the FBG sensor by replacing the bulk OSA with a simple PD with electronics.

As shown in Fig. 8 the intensity modulated signal from LPG followed by FBG sensor probe, is converted into an

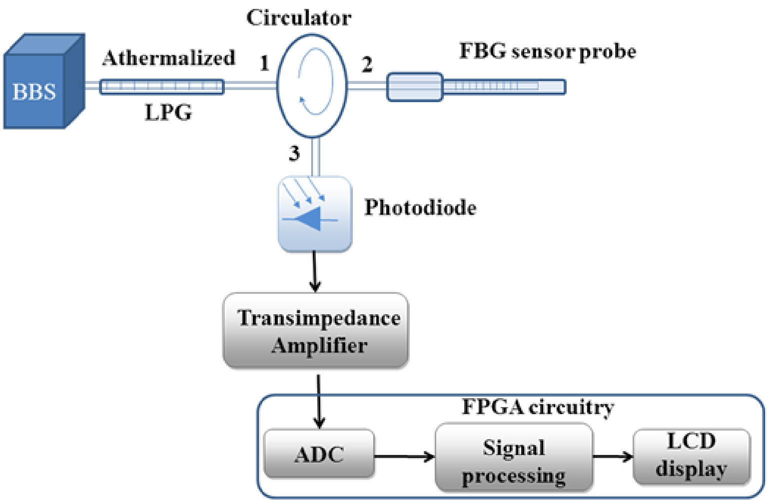

Fig. 3. Schematic of sensor package

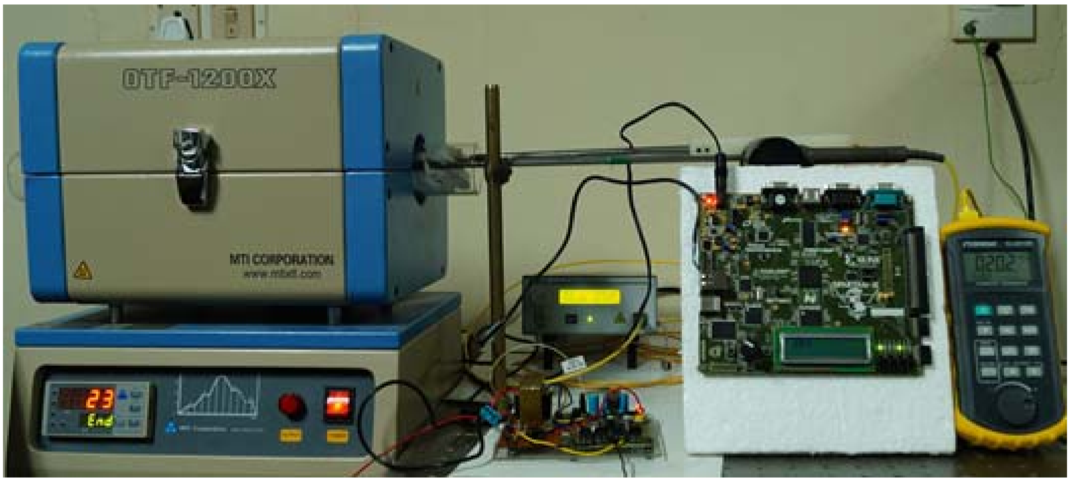

Fig. 4. Photograph of the experimental setup

electrical signal by making use of PD with transimpedance amplifier. In order to meet the requirements of ADC for further processing the signal is manipulated appropriately. Based on this graph the temperature calibration of the sensor is performed, and the output is displayed directly in '°C' using a Spartan 3-E FPGA starter kit.

The experimental results reveal that the system measures and displays the temperature from 20 °C to 500 °C, and it accomplishes good repeatability with negligible error bar (<4 °C). The resolution of the system is found to be 1 °C.

The important aspects that are involved in this design of the sensor package are; i) design of a rigid sensor probe by encapsulating bare FBG without compromising its sensitivity and response time, ii) making the measurement system cost effective by replacing the OSA with PD accomplished by a simple electronics, by employing the LPG as an edge filter and iii) displaying the sensor output directly in degree Celsius.

VI. Conclusion

An indigenous FBG based temperature sensor package which includes rigid sensor probe accompanied by the compact and low cost interrogation system, and digital display is designed, developed, and tested successfully. The test results are evident that the sensor measures the temperature from 20 °C to 500 °C with 1 °C resolution.

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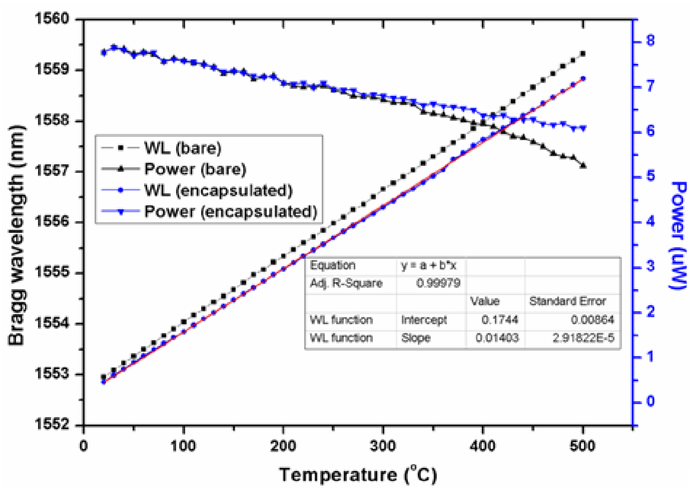

Fig. 5. Temperature response of FBG before and after encapsulation

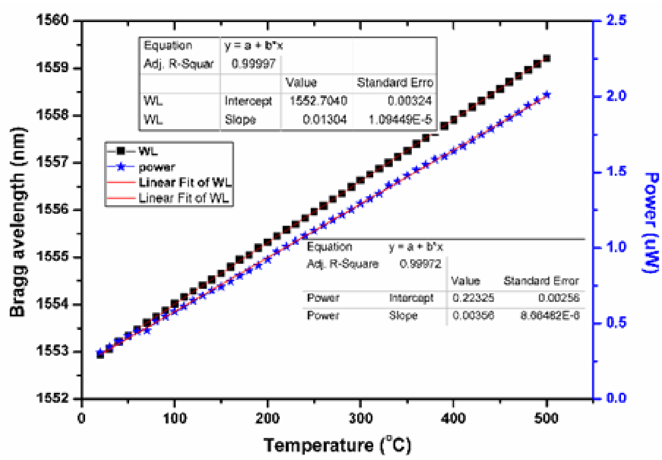

Fig. 6. Temperature response of the sensor probe after being modulated by LPG

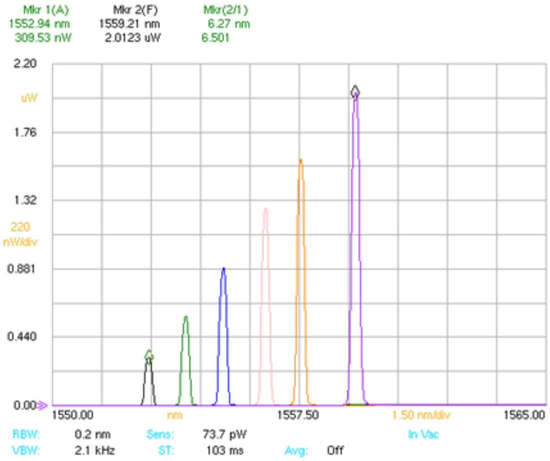

Fig. 7. Temperature response of FBG modulated by LPG

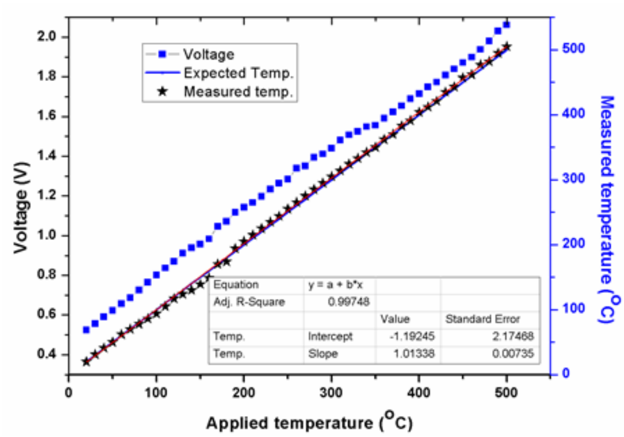

Fig. 8. Final output of the sensor in terms of voltage, and temperature

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