Cooling System By Using Fiber Bragg Grating As Temperature Sensor

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Abstract— **This paper proposes to design a cooling system by using fiber bragg grating (FBG) as a temperature sensor. The metrology system was developed for detecting temperature by monitoring shifted of bragg wavelength, the movement of bragg wavelength shifted are used to indicate the temperature change at surrounding, when the temperature reach the set maximum surrounding temperature, the cooling system will be turn on and maintain the environment temperature. The optical fiber will provide the broadband light source and FBG will reflect the bragg wavelength and transmit other. The system is based on FBG as a physical quantity sensor, power supply to supply voltage to cooling system and wavelength meter is used as a collecting data instrument. The temperature will be controlled by the intensity of light bulb. The system will be running under the Agilent VEE software. Agilent VEE will be used as a tool to display the data for temperature variation and tool to decide the action of power supply.**

Keywords-component : Fiber bragg grating (FBG), multiwavelength meter.

1. INTRODUCTION

Nowadays there are many type of temperature sensor sold in the market. All of this sensors can be categorized into two major type, mechanical temperature sensor and electrical temperature sensor. The different between both of this types is, the electrical temperature sensor can sent their measurement in the form of electronic signal that can be used for processing and interpretation while mechanical can not. But both of this type use the same principle on the mechanical effects of temperature – typically thermal expansion. Figure 1 show how the temperature sensor can be summarized.

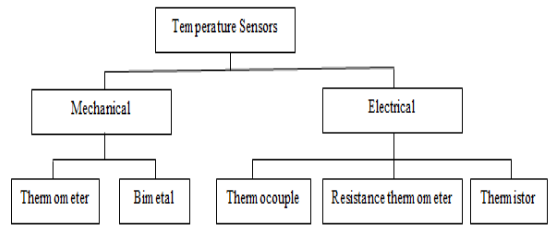

Figure 1: Temperature sensor

Thermometer

A thermometer is a device that measures temperature or temperature gradient using a variety of different principles. A thermometer has two important elements: the temperature sensor in which some physical change occurs with temperature, plus some means of converting this physical change into a numerical value.

Bimetal

A sensor with two unlike metals bonded together. The metals expand at different rates when heated, providing a physical signal that the sensor converts into an electrical signal.

Thermocouple

A thermocouple consists of two dissimilar conductors in contact, which produces a voltage when heated. The size of the voltage is dependent on the difference of temperature at the junction to other parts of the circuit. Thermocouples are a widely used type of temperature sensor for measurement and control. It can also be used to convert a temperature gradient into electrical signal.

Resistance Thermometer

Resistance thermometers, also called resistance temperature detectors (RTDs), are sensors used to measure temperature by correlating the resistance of the RTD element with temperature. Most RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core. The element is usually quite fragile, so it is often placed inside a sheathed probe to protect it. The RTD element is made from a pure material, platinum, nickel or copper. The material has a predictable change in resistance as the temperature changes; it is this predictable change that is used to determine temperature.

Thermistor

Thermistor is a type of resistor whose resistance varies significantly with temperature are widely used as inrush current limiters, temperature sensors, self-resetting overcurrent protectors, and self-regulating heating elements. Thermistors are different from resistance temperature detectors(RTD) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs used pure metals. The temperature response is also different, RTDs are useful over larger temperature ranges, while thermistors typically achieve a higher precision with a limited temperature range

Utilization of optical fiber has made an unprecedented growth in recent years. Such a big progress is caused by high demand for optical fiber used in telecommunication, security and others. Before optical fiber was uses as a main way to sending data from one place to another, copper wire was firstly introduced. A lot of deficiency of copper wire while sending a data. Optical fiber have overcome the copper wire deficiency for example thinner, low power, flexible, less expensive, higher carrying capacity, light signal, digital signals, non-flammable, lightweight, accurate measurement and can be used for interrogation system[1].

Fiber optic sensor can be generally classified in two big groups, extrinsic and intrinsic. Extrinsic fiber optic sensor are basically optical sensor where delivery at light signal is by optical fiber, while the modulation of the light signal occurs outside optical fiber, for example Dopler anemometers and non-contact vibration measurements systems. Intrinsic optical fiber sensor is a sensor where conversion of the modulation of a physic parameter is done by a portion of an optical fiber, these sensor are more difficult to elaborate but have the best performances.

Fiber bragg grating(FBG) is the most popular type of fiber optic sensor. FBG are made from a section of the fiber in which imprint periodic structure. The structure is formed by illumination with intense UV light during the Fiber drawing process. Each perturbation acts as an partially reflective mirror. The deformations of FBG are determined by the basis spectral properties of the structure. Based on report, FBG can also sense temperature, strain, pressure, displacement, intensity of pressure, torsional angle, torque(torsional stress), acceleration, current, voltage, magnetic field, frequency, concentration, thermal expansion coefficient and vibration. Some of FBG sensing have been applied in reality[4].

Recent paper presents a [2]temporal thermal response of Type II-IR Fiber Bragg gratings. It investigated the effect of optical heating used for optical sensor systems. It used CO2 laser to heat the FBG for temporal thermal response. Based on the result, there is a great chance the Type II-IR FBG could be used in high temperature (>1000 C^0). The experimental result show that the heating phase is 230±25ms and cooling phase is 275±25ms. The experimental result is different from the theoretical calculation. The fiber cross section have no effect on the thermal response and have good potential for daily application.

Another project[3] on Strain-Temperature Discrimination Using Single Fiber Bragg Grating was reported. They presented the way to fabricated Bragg-grating using FabryPerot filter by altering the dopant concentration in the core photosensitive fiber through thermal out-diffusion phenomenon prior to the grating inscription. They use energy dispersive x-ray(EDX) to measure and analyze the data for direct proof of decreased photosensitivity of the fiber. Fabry-Perot FBG was found to be the best measuring sensor for temperature and strain at the same time, due to difference in themo-optic coefficients. For future development of FBG more advanced structure involving photosensitivity modification could be investigated.

From the researches and reviews on the several recent papers [5-6] a new technique can be used to develop FBG, where the optical fiber can continuously electroplated into thicker metallic layer by high temperature processing. The fiber optic sensor gives a little disturbance to the metallic structure. On the experimental result the FBG give almost nothing residues stress. The embedded FBG have almost 100% high temperature sensitivity and 2 ^{0}C accuracy [5]. Since FBG can be used in many type of sensor, it possess many advantages over conventional techniques. It is possible to realize simultaneous measurement or quasi-distribution monitoring [6].

Wavelength reflected by FBG were called Bragg wavelength, λ_b

$$\lambda_b = 2\eta_{eff} \wedge$$

η_{eff} and $\wedge$ is the effective refractive index of the fiber core and the gratting period respectively. The Bragg wavelength λ_b are affected by strain and temperature changes. The wavelength change in the Bragg wavelength is expressed as below:

$$\lambda_b = (\alpha + \xi)\Delta T + (1- P_{e)}\ \Delta\xi$$

Where α is the thermal expansion and ξ is the thermo-optic coefficient and P_e is the effective photo-elastic constant of the fiber core material,[8]. The first part of the equation is the effect of temperature change while the second part is the strain change of FBG wavelength.

Since we only consider temperature change in this paper, we can ignore the strain effect on the equation.

$$\lambda_b = 2\ (\wedge(d\eta/dT) + \eta(\ d\wedge/dT)\ )$$

As the equation being simplified, it will change back $\lambda_b = (\alpha + \xi)\Delta T$ as mention earlier.[6] Where $\wedge$ is spacing between grating plane.

White light source will be used as a light source for this project, with a broad optical bandwidth (usually 100 nm or more), and the propose light source in the range 1520nm until 1570nm. White light is used because it has stabilized optical output power and commonly used for experiment.

2. METHDOLOGY

The System flow diagram is show in figure 2. The Cooling system instrument consist of fiber bragg grating, multi wavelength meter, power supply and blower. The system uses Agilent Vee as base system to control the cooling system either to turn it on or off and to monitor the current environment temperature. As the environment temperature changes the bragg wavelength will be changed as well. The changing of bragg wavelength will be calculated and converted to degree celcius. The cooling system will turn on the blower when the environment temperature reaches 45^{0}C. The system can be monitored and changed the maximum environment temperature through computer, as it display by Agilent Vee.

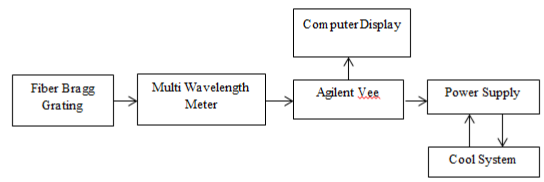

Figure 2: Cooling system flow diagram

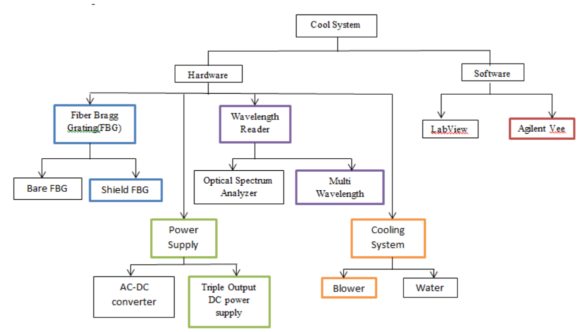

Figure 3: Design Selection of Cooling System

Before the final design is made design selection must be done first in order to list out what hardware and software most suitable for this proposed cooling system. The design selections of cooling system are divided into two categories which is hardware and software as show in figure 3. The detail about hardware and software selection is described below.

A. Hardware Design

The Design for hardware are divided into four categories which are Fiber bragg grating, Power supply, Wavelength reader and Cooling system. The detail of hardware selection of this design is described below.

1. Fiber Bragg Grating
   There are many type of fiber bragg grating sold in the market, because fiber bragg grating is a multi-purpose sensor. Since this system is focused on temperature, two type of

fiber bragg grating being selected, which are bare fiber bragg grating and shield fiber bragg grating. Bare fiber bragg grating has many disadvantage in this system for example it is easily broken, the wavelength shifted may be affected by the outside pressure and the ambient temperature taken may fluctuate due to external factors. So shield fiber bragg grating being use to minimize errors of using bare fiber bragg grating.

2. Power Supply
   To turn on the blower for cooling system, it need a power supply. There are 2 choices either to use ac-dc converter or triple output DC power supply. To use ac-dc converter it need to connect to microcontroller so that it can be controlled the triple output DC power supply have already built in controller to control the output current. To reduce the cost of this system, triple output DC power supply have being selected, because it will be quite expensive to set up the microcontroller just for power supply.

3. Wavelength Reader.
   To read the output wavelength of the fiber bragg grating a laboratory equipment are needed. Optical spectrum analyzer and multi wavelength meter are example of the wavelength reader. Multi wavelength meter are being selected as a wavelength reader for this system because the system only want to read the current wavelength not the power. Multi wavelength meter only read the wavelength while optical spectrum analyzer read wavelength and power.

4. Cooling System
   There are many way to cool down the ambient temperature, but since this system being use at low temperature, so there is no need to use the extreme cooling device. Blower have been chosen for the cooling system because it safe, cheap and can be easily controlled, rather than using liquid for the cooling system, if there is a leakage on the system, it will damage the equipment and lead to disaster.

B .Software Design

There are 2 softwares commonly being used to interface between computer and instrument they are LabVIEW and Agilent VEE pro. Both of these softwares use graphical system design to create this codding. Agilent VEE had being selected for the system code. The flow chart of the cooling system is shown in figure 4. When the light transmitted to the fiber bragg grating, it will reflected a certain value of wavelengths and transmit the others. The reflected wavelength will be read by the multi wavelength meter.

The value recorded by multi wavelength meter, will be sent to computer through general purpose interface busses (gpib) cable. At the computer, a set of formula will be used to convert wavelength to degree Celsius. After the conversion process, the value was then compared to the maximum temperature set points. For this system, a the maximum temperature was set at 45^0C.

When the temperature have reach the maximum value it will sent a signal to power supply through gpib cable. The outputs of power supply have being set at 12volts and 0.25amperes. Which is the maximum input of the blower.

The blower will push out the heat from the close space and maintain the temperature. The blower will turn off when the ambient temperatures are below the maximum temperature. So it will save the electricity cost, because it will not be turned on when it is not needed.

The system will continue to read the ambient temperature as long as it not turns off.

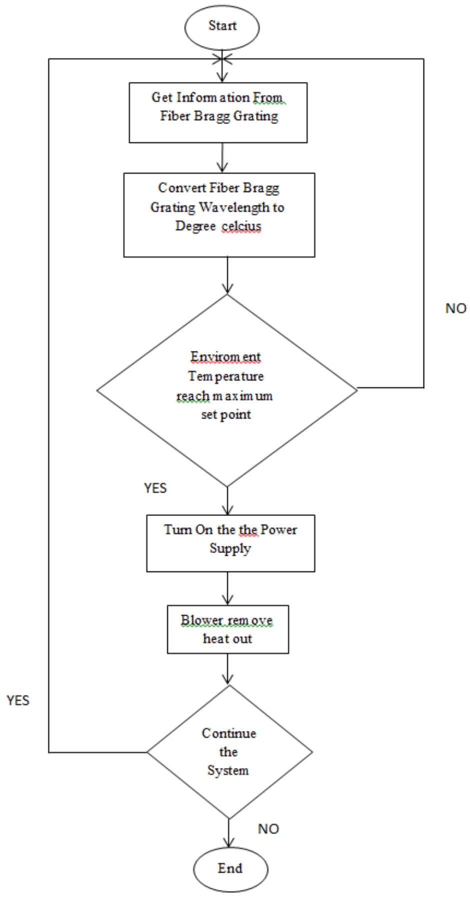

Figure 4: system flow chart

3. RESULT AND DISCUSION

The prototype of this cooling system in this paper is shown in the figure 5. To characterize fiber bragg grating and temperature an experiment need to be done, figure 6 is the arrangement of the experiment for the characterization of fiber bragg grating. Table 1 is Table of comparison between ambient temperature and bragg wavelength of bare Fiber Bragg grating and table 2 is table of comparison between ambient temperature and bragg wavelength of shield Fiber Bragg grating.

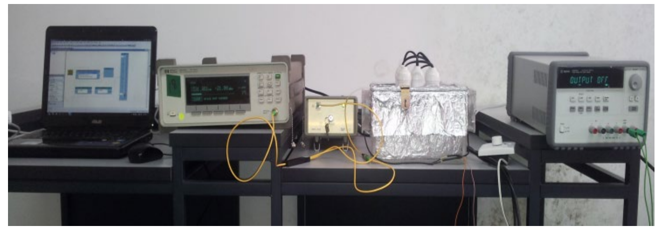

Figure 5: Cooling System by using fiber bragg grating

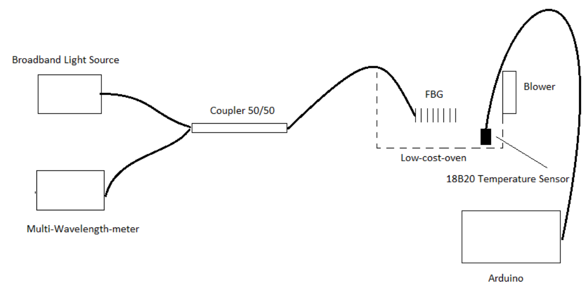

Figure 6 : Characterization of Fiber Bragg grating arrangement

	fiber bragg grating (bare)	
	Temperature(degree)	Wavelength(nm)
1	28.44	1561.881
2	42	1561.939
3	45	1561.94
4	50	1561.968
5	55	1561.97
6	60	1561.999
7	65	1562.027
8	70	1562.056
9	75	1562.057
10	80	1562.086

Table 1: Table of comparison between ambient temperature and bragg wavelength of bare Fiber Bragg grating.

	fiber bragg grating (shield)	
	Temperature(degree)	Wavelength(nm)
1	31.75	1546.076
2	40.81	1546.192
3	45	1546.278
4	50	1546.336
5	55	1546.365
6	60	1546.422
7	65	1546.48
8	70	1546.509
9	75	1546.567
10	80	1546.624

Table 2: table of comparison between ambient temperature and bragg wavelength of shield Fiber Bragg grating.

To record the ambient temperature, 18B20 temperature sensor is used. While running the temperature sensor, fiber bragg grating was placed together with the temperature sensor so that the real time ambient temperature can be measured.

To control the temperature light bulb have been used as a source of heat and the blower is used to maintain the temperature. The light bulb intensity will be adjusted, so that the ambient temperature will be maintained at certain degree celcius.

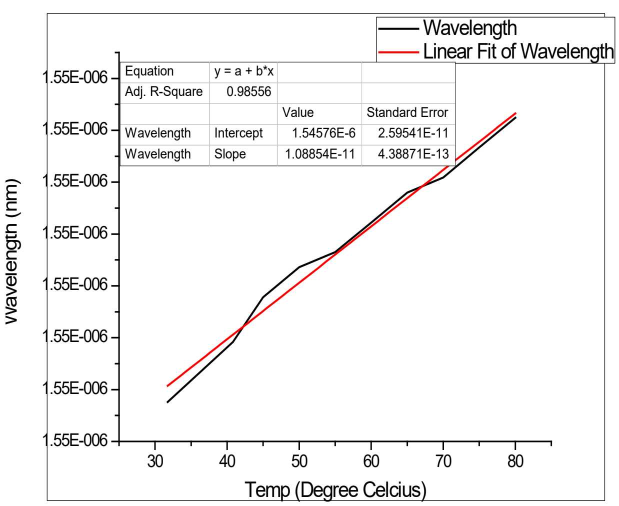

Figure 7: Straight line graph to convert Bragg wavelength to Degree Celcius

Based on the plot, the graph is almost linear, and it proves that the shield fiber bragg grating have the good efficiency. The straight line graph is Y = 1.54576E-6 + (1.08854E-11 X).

The arrangement of cooling system by using fiber bragg grating as temperature sensor show in figure 8. The broadband light sources give out the light source to Fiber Bragg grating. The light source are interprets in term of wavelength. Coupler then divides the light source into two parts, one to the Fiber Bragg grating, and another to the Multi-Wavelength meter. Fiber Bragg grating reflects the constructed wavelength and by pass the others. The reflected wavelength will be return to coupler and go straight to Multi-Wavelength meter. The Multi-Wavelength meter only read the highest power of wavelength, and in this project, the Multi-Wavelength meter will display the Fiber Bragg grating wavelength, which is call Bragg wavelength.

The value of Bragg wavelength needs to be transferred to the control system, which in this case, the computer that have Agilent VEE pro. The data from Multi-Wavelength meter are transfer to the computer through general purpose interface busses (GPIB). The Agilent VEE will display the Bragg wavelength. Agilent VEE then transfers the Bragg wavelength to Degree Celsius. Bragg wavelength convert the degree Celsius based on the data collected in the experiment earlier. The Output temperature starts from 30^0C until 95^0C in the steps of 5^0C.

After the command on Agilent VEE converts the wavelength to degree Celsius, the output temperature will be used as parameter to turn on the triple output DC power supply. Firstly the user needs to set the maximum temperature for the system, for example 45^0C. When the output temperature already reach the maximum set temperature, Agilent VEE will sent a signal to triple output DC power supply to give a voltage supply to the cooling system.

Triple Output DC power supply give the maximum voltage and current that can handle by the cooling system, so that the cooling process will occur in short period. The cooling system will cool down the ambient temperature at the Fiber Bragg grating being place. The system will be continues read the ambient temperature on the Fiber Bragg grating being placed until the user stop the system.

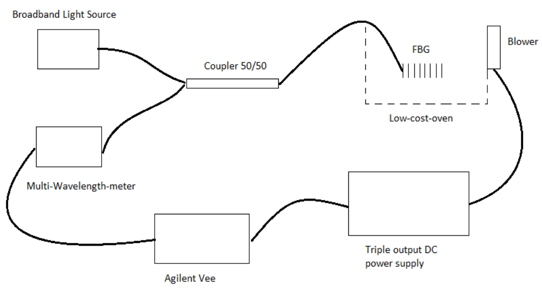

Figure 8 : Cooling System By using Fiber Bragg grating set up arrangement

4. CONCLUSION

Based from the test result, this proposed cooling system by using fiber bragg grating as temperature sensor is considered successful. From the test result it proof that this cooling system can be used and safe for the user.

The cooling system design to show that fiber bragg grating can be used for temperature sensor. It is beyond capable of the tester to test the fiber bragg grating for temperature more than 200^0C because the source of heat can only produce maximum ambient temperature of 130^0C. Perhaps the author can show the fiber bragg grating can use for temperature more than 1000^0C and it is free from electromagnetic field problem.

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