Optical Fiber Thermometer Based on Fiber Bragg Gratings

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Abstract

Fiber Bragg grating has generated much interest in use as sensors to measure strain, temperature, and other physical parameters. It also the most common component used to develop this sensor with the advantages of simple, intrinsic sensing elements, electrically passive operation, EMI immunity, high sensitivity, compact size and potentially low cost [6]. This paper reports the design of an optical fiber thermometer based on fiber Bragg gratings. The system was developed for detecting temperature and strain by monitoring the shift of Bragg wavelength. The shifting of Bragg wavelength is used to indicate the temperature and strain due to the change in the surrounding temperature and strain. When the temperature and strain reach the exact wavelength level of the system, the temperature and strain value will display on the Arduino liquid crystal display (LCD). The optical fiber will provide the broadband light source and after passing the FBG the Bragg wavelength into the optical spectrum analyzer (OSA). The system is based on FBG as a physical quantity sensor. The temperatures measured is taken from the water bath and that of the strain is provided by amount of slotted mass used. The outcome of this project is to characterize the Bragg wavelength shifting from the fiber Bragg grating output. As the conclusion, this project provides an efficient optical fiber thermometer in measuring temperature and strain in order to replace the use of conventional electrical instruments.

Keywords— Fiber Bragg grating (FBG), Optical Spectrum Analyzer (OSA)

1. Introduction

The communications industry has developed rapidly over the past two decades from an orderly and steadily growing enterprise to a chaotic marketplace with continually altered regulations, complex business relationship and explosive optical technology leading to dynamic growth. The installation of optical fibers, which is directly linked to telecommunications or sensors, have grown consistently this decade and it cannot be denied anymore. Just to make sure we can stand with the others in this growth of technology, a research and innovation in this topic need to be done as soon as possible.

Fiber Bragg gratings use light as the medium to send the data and have low attenuation with high security compared to the conventional temperature and strain sensor that can easily have power loss and can be tapped from outside. It is safer and can withstand high temperature and accurate in measuring the temperature and strain. Fiber Bragg grating works by reflecting a specified light wavelength but transmitted the other wavelengths to the detector. When the FBG is heated, the central wavelength will experience a red shift but at room temperature, it will return to its original wavelength instantly [2]. Based on the Fresnel reflection, by varying the refractive index or physical dimensions of the waveguiding core the different periodic modulation of the refractive index can be obtained. This feature varies the reflected light modulation and the reflected wavelength is called
Bragg-wavelength. Wavelength shifting is the main element used in optical fiber Bragg gratings sensor. This shifting affected by manipulating the measurand (e.g. temperature and strain) apply on the fiber Bragg grating. When light guided along the core of the optical fiber, it will be scattered by each grating line.

Finally, suppose the theoretical calculation are good enough to characterize the Fiber Bragg grating, but since many manufacturers do not want to share the fiber Bragg gratings characteristics due to company secrecy or to avoid any competition from other company. So that, the experiment conducted to characterize the Fiber Bragg grating need to be done.

2. METHODOLOGY

Along with this project, a lot of precaution and method need to be followed to complete the project. Before that, the flow chart of the project needs to design to get the exact ways to develop the research. The project starts with research on the Fiber Bragg Grating and Arduino programming technique. The understanding of theory, characteristics, and properties of Fiber Bragg grating need to be studied. Arduino is a system used to design a device to record the temperature of the waterbath. This device is using C programming language to process the data in the microcontroller and send the command throughout the system. It is widely used in the electronic world to interface with the other system with the support of visual basic 6 software.

The second step is to set up the experiment for the characterization of Fiber Bragg grating with the temperature or strain. The Fiber Bragg grating will be placed in the water bath temperature to study the behavior of the fiber Bragg gratings (FBG). The water will be used as the medium to transfer heat onto the FBG. A normal water has the temperature between 0°C up to 100°C in Celsius or 32°F up to 212°F in Fahrenheit. However, to increase the boiling point and decrease the freezing point, the adding of 250g sodium chloride (NaCl) is used to change the water characteristic. By doing this new freezing point is produce which is -10°C and the boiling point is 110°C. To characterize the Fiber Bragg grating, the water bath temperature will be set from -10°C up to 60°C with 10°C range, then the value of Bragg wavelength will be recorded in the optical spectrum analyser (OSA). The data collected was transferred into the Microsoft Excel to be analyzed and plotted a graph. In addition, the small range of temperature also been recorded from 0℃ up to 10℃ with 2℃ increments. Next, for the strain, the experiment will be tested with the copper load and the mass of 0g up to 30g with 5g increment was been used. Same the data will be analyzed in Microsoft Excel.

The data from Bragg wavelength against temperature or strain will be used as a reference to decide which Fiber Bragg grating will be more suitable to be used as optical fiber thermometer sensor. There are 4 selections for this experiment, four bare fiber Bragg grating with different center wavelength will be used. By creating a straight-line graph, the best optical fiber thermometer can be choose. The smoother the graph straight-line, the sensitive the Fiber Bragg Grating. Lastly, to create a system that can be a monitor on the place, all the instrument use need to interface with the computer. For this project, there are 2 instruments that need to be interfaced, which is optical spectrum analyzer (OSA) and Arduino Mega 2560. The system uses Arduino Mega 2560 as a base system to control the system to display the output temperature of the waterbath. As the waterbath temperature changes the Bragg wavelength will be changed as well and the output data sent to Arduino to be processed. The changing of Bragg wavelength will be analysed.

Design selection need be done first by listing the hardware and software choice that most suitable for this purpose optical fiber thermometer. For hardware design, it is divided into four
categories which are Fiber Bragg grating, Power supply, Wavelength Analyzer and Materials for medium tested. There are many types of fiber Bragg grating used in the industries because Fiber Bragg grating is a multi-purpose sensor and quite sensitive to the stimulus. It also saves from any interference. Since this system is focused on the optical fiber thermometer, two type of fiber Bragg grating being selected, which bare Fiber Bragg grating and shield Fiber Bragg gratings. Bare fiber Bragg grating has been used because it is more sensitive and directly contact to the material tested compare to the shielded that may slightly change the temperature based on shielded materials used.

Next, to turn on the Arduino system, it needs a power supply. Two choices already are chosen either to use triple output DC power supply or AC to DC adapter. For this project, AC to DC adapter is used because it has fixed voltage and current for the Arduino microcontroller. In addition, the supply used only for the Arduino board. So, AC to DC adapter was most suitable to be used. For Bragg wavelength analyzer, laboratory equipment is needed to be used. Only optical spectrum analyzer are being selected for wavelength reader because of the waveform display and more precise to collect the data.

Moreover in this project, two types of the testing to be done which are temperature and strain. Firstly, the temperature is divided into two conditions which are hot air and water bath. The reason water bath has been chosen because of the ability of water that easier to control either in hot condition or cold condition. The characteristic of the water can be changed by adding the impurities in it. It also can change the boiling point and the freezing point better than the hot air that hard to control. The results may be varied due to a different level of air temperature. So, for this project, the water bath is suitable to see the Bragg wavelength change when the fiber Bragg grating makes a contact with the medium tested. Secondly, for the strain, the choices are divided into two which are fixed copper load and plasticine. Plasticine has an ability to change its mass by weighing it on the weighing balance. But for this experiment, fixed copper load is more suitable to be used due to firm shape compare to plasticine that may slightly change in mass.

Move on to software, it is divided into three categories which are LabVIEW, Agilent VEE Pro, and Arduino programming. This three software commonly being used to interface between computer and instrument. For this project, Arduino programming is being selected to process the data in the Arduino Mega 2560 microcontroller.

3. RESULT AND DISCUSSION

The optical fiber thermometer prototype is setup as in fig. 1. The comparison of the four fiber Bragg grating is tested to see the behaviour of the FBG. To characterize fiber Bragg grating and water bath temperature of an experiment, the instrument is arranged as shown in fig. 1. The results of the eight temperature for four different FBG were stated in Table I.

a. Characterization of FBG in every 10°C increments (large range).

To record the water bath temperature, 18B20 temperature sensor (waterproof) is used. While running the temperature sensor, fiber Bragg grating was immersed together with the temperature sensor in the water bath. So, that the real temperature can be measured. The used of IR thermometer sensor is used to make sure the temperature used exactly as in the objective.

In order to control the temperature, hot plate machine have been used as a heating element to maintain the temperature. The hot plate temperature will be adjusted so that the water temperature will be maintained at certain degree Celsius. The data of the Bragg waveform have been collected and
the center wavelength has been used to construct the graph to see the sensitivity of the fiber Bragg behaviour. The graph for four FBG results has been constructed as shown in fig. 2. The linear graph has been formed and proves the theory of the fiber Bragg gratings as the temperature increased, the Bragg wavelength also increased. Means the shifting occurs on the Bragg grating of the FBG when the temperature applied on it. With this results, the project can be carried out to make the fiber Bragg gratings as an optical fiber thermometer.

![Figure 1. Set-up for characterization of fiber Bragg grating to measure temperature](image1)

![Figure 2. Plot of temperature against Bragg wavelength](image2)

![Figure 3. Waveform for FBG 1549.31 at different temperature](image3)

**TABLE I.** The comparison between water bath temperature (large range) with different types of fiber Bragg grating.

| Temp(℃) | Types of Fiber Bragg gratings |
|---------|------------------------------|
|         | FBG 1553.72 | FBG 1554.1 | FBG 1549.31 | FBG 1551.59 |
| -10     | 1548.60     | 1549.48    | 1549.04     | 1546.64     |
| 0       | 1548.68     | 1549.50    | 1549.16     | 1546.66     |
| 10      | 1548.76     | 1549.56    | 1549.24     | 1546.80     |
| 20      | 1548.88     | 1549.64    | 1549.34     | 1546.86     |
| 30      | 1549.04     | 1549.78    | 1549.52     | 1547.04     |
| 40      | 1549.20     | 1549.92    | 1549.60     | 1547.12     |
| 50      | 1549.28     | 1550.00    | 1549.72     | 1547.24     |
| 60      | 1549.32     | 1550.06    | 1549.84     | 1547.32     |

Based on the graph plot from fig. 2, the graph is linear, and it proves that the bare fiber Bragg grating (FBG 1549.31) have the good efficiency. The straight line of the graph is $y=0.0115x + 1549.1$.

From fig. 3, shows the shifting of the Bragg wavelength with different temperature. Among four FBG, only FBG 1549.31 is the best FBG to be used as an optical fiber thermometer in large range due to high sensitivity compared to other FBG. The different between the temperature tested on the FBG 1549.31 has a small different and almost constant with each other. The shifting of the Bragg wavelength move from left to right and this proves another theory as mention in the introduction part.
b. Characterization of FBG in every 2°C increments (small range).

Move on to small measurement to see the sensitivity of the FBG within the small range of the temperature. Six temperature has already been used to see the consistency of Bragg wavelength produced.

TABLE II. THE COMPARISON BETWEEN WATER BATH TEMPERATURE (SMALL RANGE) WITH DIFFERENT TYPES OF FIBER BRAGG GRATINGS.

| Temp(℃) | FBG 1553.72 | FBG 1554.7 | FBG 1549.31 | FBG 1551.59 |
|---------|--------------|-------------|--------------|--------------|
| 0       | 1548.68      | 1549.50     | 1549.16      | 1546.66      |
| 2       | 1548.72      | 1549.52     | 1549.16      | 1546.72      |
| 4       | 1548.72      | 1549.54     | 1549.20      | 1546.72      |
| 6       | 1548.76      | 1549.54     | 1549.24      | 1546.76      |
| 8       | 1548.76      | 1549.56     | 1549.24      | 1546.76      |
| 10      | 1548.76      | 1549.56     | 1549.28      | 1546.80      |

TABLE III. THE COMPARISON BETWEEN MASS) AND BRAGG WAVELENGTH OF BARE FIBER BRAGG WAVELENGTH.

| Mass (g) | Types of Fiber Bragg gratings | FBG 1553.72 | FBG 1554.7 | FBG 1549.31 | FBG 1551.59 |
|----------|------------------------------|--------------|-------------|--------------|--------------|
| 0        | 1549.24                      | 1549.68      | 1549.44      | 1546.88      |
| 5        | 1549.28                      | 1549.69      | 1549.48      | 1546.96      |
| 10       | 1549.32                      | 1549.69      | 1549.52      | 1547.00      |
| 15       | 1549.32                      | 1549.73      | 1549.56      | 1547.04      |
| 20       | 1549.36                      | 1549.73      | 1549.60      | 1547.08      |
| 25       | 1549.36                      | 1549.76      | 1549.64      | 1547.08      |
| 30       | 1549.40                      | 1549.76      | 1549.68      | 1547.12      |

From the graph above, the result shows the linear graph of the Bragg wavelength increased but only FBG 1554.7 manage to show the sensitivity of the FBG within small range value and the waveform shown as in fig. 6.
c. Characterization of FBG in every 5g increment of mass.

Seven different mass have been used to see the Bragg wavelength changes on the four different types of FBG and the graph has been plotted as shown in fig. 6. The graph above shows the linear graph of the increment of the Bragg wavelength due to the elongation of the FBG in the stimulus of the mass added to the system. As the mass increase, the length on the FBG also increases cause the change of refractive index in the fiber.

Lastly, from the graph plotted in fig. 6, the deduction for the best FBG for strain can be concluded. FBG 1549.31 already been chosen because the sensitivity and the waveform produced on the OSA. The graph result as shown in fig. 7 shown the strain graph to support the theory research. The shifting of the Bragg wavelength to the right gives the picture of the elongation of the FBG due to the mass applied on it. The length of the grating to another grating is increasing and the refractive index in the FBG also changing. The author still trying to interface the Arduino with the optical spectrum analyzer and the research still continues to make the system connected between OSA and Arduino.

4. CONCLUSION

Based on the results obtained, there is a good linear relationship between temperature applied on FBG to the Bragg wavelength shift using FBG as an optical fiber thermometer. The sensitivity of wavelength shift to the changing of temperature is suitable for FBG to monitor the temperature because of its precision on the temperature change. The issue of strain effect on the FBG sensitivity has been solved. Bare fiber Bragg grating sensor is the most suitable approach to replace the conventional electrical sensor in measuring temperature and strain of the substances. The convenience of fiber Bragg grating gives a lot of benefits to be used in the various environment.

For future recommendation, the author like to recommend the testing of fiber Bragg grating at high temperature and strain because of the unique characteristic of the optical fiber. Further enhancement in optical fiber sensor may expand the use of the fiber optic and replace the conventional electrical sensor in future. Plus, reduce the use of metal in the sensor appliances.

5. REFERENCES

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