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Journal of Electronics Voltage and Application

Application of Sagnac Interferometer for Temperature Monitoring: Experimental Study

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DOI: https://doi.org/10.30880/jeva.2020.01.01.006
Received 00 Month 2000; Accepted 01 Month 2000; Available online 02 Month 2000

Abstract: Temperature sensors have been widely used in industries and they have found applications in food processing units, medical devices, chemical handling processes, automotive and agriculture. In the market, there currently exist many varieties of temperature sensors including thermocouples, resistor temperature detectors, infrared sensor, thermistor, thermometer and optical temperature sensor. Of these technologies, optical temperature sensors have the edge in that they are free from electromagnetic interference, low weight, compact, high sensitivity, high signal-to-noise ratio and excellent stability. In this work, optical temperature sensor based on Sagnac interferometer is experimentally demonstrated. The Sagnac interferometer consists of a 3.5 cm polarization maintaining fiber that acts as a sensor head, a polarization controller and a 3 dB coupler. Experiments are carried out in which an amplifier noise being the input light for the Sagnac interferometer and the transmission spectrum of the output light is observed for the output. Throughout the experiment, the sensor head is placed in an oven for temperature variation. Based on the measurements on the output spectrum, it is found that the spectrum dips shifts to the shorter wavelength from 1554.96 nm to 1528.56nm as the temperature is varied from 30 °C to 45 °C. The spectrum dip is found to be inversely proportional to the temperature with the obtained sensitivity of 1.766 nm/°C. This Sagnac-based optical sensor is promising for detecting temperature especially in the harsh environment.

Keywords: Temperature detection, optical sensor, optics and photonics

1. Introduction

A temperature sensor is a device that is used to gather data about temperature from a particular source and converts the data into understandable parameter for a device or an observer. Temperature sensor exists in many current applications such as in food processing units, medical devices, chemical handling processes, automotive and agriculture. It is significantly needed to satisfy user requirements for specific applications, and the main considerations

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are performance, dimension and reliability. Traditional temperature sensors come in the form of thermocouples and resistance temperature detector (RTD); however they do not always give satisfactory performance especially when the temperature measurement is done in the presence of electromagnetic, radio frequency interference and hazardous environment. Since these thermoelectric sensors may contain intolerable errors if not properly filtered in such condition, an alternative temperature sensor is required. For such applications, optical fiber sensors offer a better alternative since the optical fiber sensors are free from electromagnetic interference, low weight, compact, high sensitivity, high signal-to-noise ratio (SNR) and excellent stability [1][2].In fact, in the major's industry such as biomedicine, environmental monitoring, agricultural engineering, health monitoring and aeronautics, optical fiber sensor are not only limited for measuring temperature but also strain, refractive index (RI), vibration, twist, and gas absorption [3-10]. Fig. 1 illustrates the technologies that have been used for the implementation of temperature sensors.

Recently, optical temperature sensors have gained increased popularity and market acceptance. In comparison to conventional temperature sensors, they offer a number of distinct advantages which makes them unique for certain types of applications. This is where the conventional sensors are difficult and incapable to provide the similar results. In term of temperature measurement, optical fiber as the main materials offer some inherent advantages for measurements in industrial or harsh environments. This is because optical temperature sensor is unaffected by electromagnetic interference (EMI) from large motors, transformers, and welders. Plus, it is also unaffected by radio frequency interference (RFI) from wireless communications and lightning activity. These advantages make optical temperature sensor competent against conventional temperature sensor [11-15].

In recent years, a few types of temperature sensor based on optical fiber have been realized for the temperature measurement. These traditional optical fiber temperature sensors use fiber Bragg grating (FBG), long period fiber grating (LPG) and optical fiber Fabry-Perot interferometers (FPI). In this work, another type of technique using Sagnac Interferometer (SI) is purposed. SI is a common path interferometer, also called fiber loop mirror (FLM) is interesting and very useful component used in optical devices and systems. SI does not only operate as a filter to selectively transmit or reject a wavelength or range of wavelengths but also as a reliable temperature sensor. SI technique implements the polarizing maintaining fiber (PMF) along with polarization controller (PC) for the temperature sensor design. PMF is a section of birefringent fiber that can introduce the optical path difference or phase shift of the two counter-propagating waves, and it is used as a sensing element. PC allows the modification of the polarization state of wave transmission by changing the orientation of the PC plate. Both PMF and PC become the part of sensing head for temperature sensing devices [16-20].

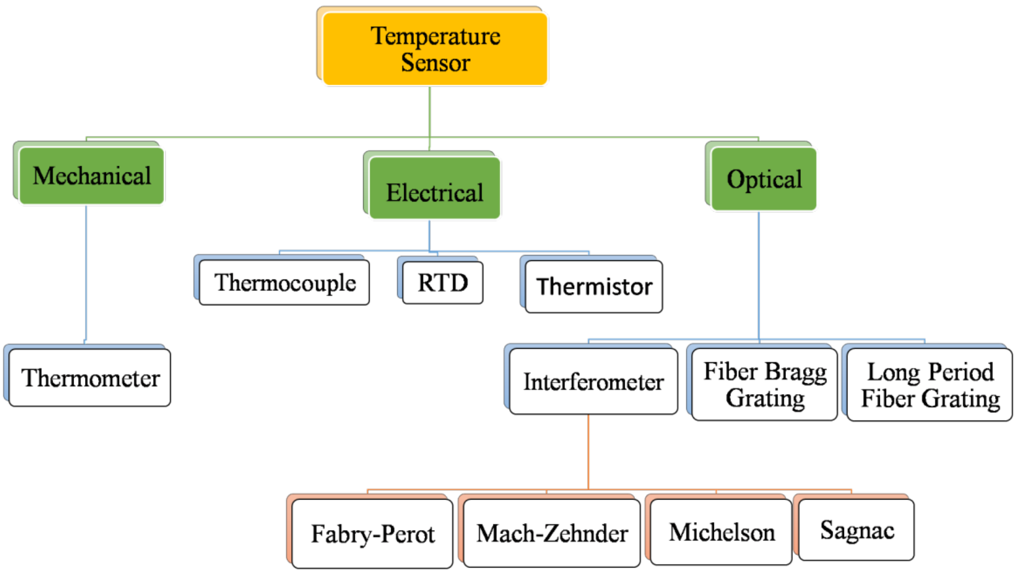

Fig. 1 - Technologies for Implementation of Temperature Sensor

2. Experimental setup

Sagnac interferometer (SI) is recently become a great interest in various sensing applications due to its advantages of simple structure, easy fabrication, and environmental robustness. SI is a common path interferometer as it operates using the counter-propagating beams in a ring path where two laser beams travel in the same path before combining to produce interference. Fig. 2 shows the schematic of an SI as the sensor head which consist of a 3-dB coupler, a PC and a 3.5 cm PMF. When an input light is launched into the 3-dB coupler, the light is split into two directions; clockwise and counter-clockwise. After splitting, these two lights then recombine at the 3-dB coupler to produce interference. The PMF functions as a delay unit for the propagating lights and the PC serves to maximize the interference effect [21-24].

This work is for the development of temperature sensor based on SI. This design can be applied to detect the changes in temperature by using the wavelength shift of the spectrum as the indicator. Figure 3 shows the experimental setup of the optical temperature sensor. The sensing head of 3.5 cm PMF is placed in a temperature chamber. An amplifier noise in the form of amplified spontaneous emission (ASE) is utilized as the input light. The ASE covers a broad spectrum from 1530 nm to 1565 nm. The spectrum of the interference effect is observed using an optical spectrum analyzer (OSA). The output spectrum contains data of transmission intensity as a function of light wavelength for different values of temperature.

Sensing head is a part of SI that consist of 3.5 cm PMF, 3-dB coupler, and PC. These three components are connected by fusion splicing which uses the heating technique. The sensing head operates as the sensor itself and during testing it is placed in a temperature chamber to experience different temperatures. As the temperature of the sensing head increases, the birefringence of the PMF in the SI is also changed, which makes the transmission spectrum of the Sagnac loop shift to shorter wavelengths. As a result, the output wavelength of the Sagnac temperature sensor will also shift accordingly. This shifting of the spectrum wavelength with temperature is the main mechanism for detecting the temperature change in the surrounding environment.

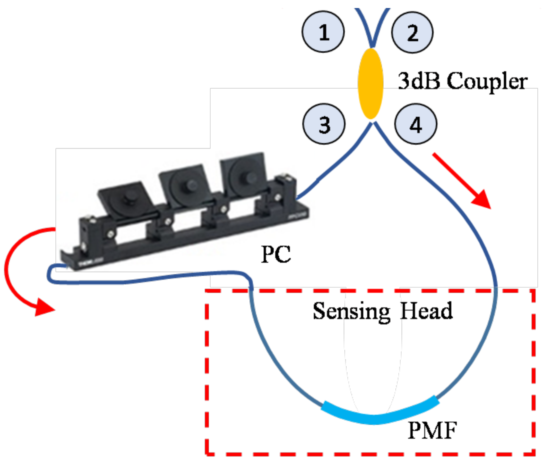

Fig. 2 – Sagnac interferometer as sensor head

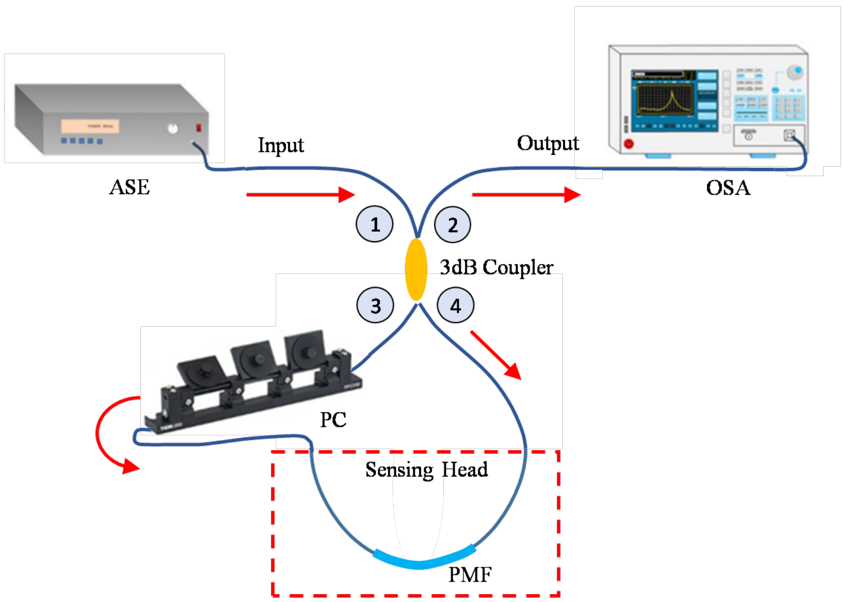

Fig. 3 - Experimental setup of Sagnac based optical temperature sensor

3. Experimental Results

The input light for the experiment comes from an ASE source. Basically, ASE light is amplifier noise where the noise is a result of spontaneous emission process in an erbium-doped fiber. Fig. 4 shows the spectrum of ASE light. It is found that the ASE light covers over the C-band region from 1530 nm to 1565 nm. As the input current for the ASE source is varied from 100 mA to 500 mA, the ASE light intensity becomes larger but such increase in intensity gets saturated as the input current is increased. The spectrum is also found to be not flat, resulting from the spontaneous emission in the erbium-doped fiber. Throughout the experiment, ASE source with the input current of 200 mA is utilized. The justification is that for higher input currents, the output light intensity is saturated. Therefore, the ASE source with 200 mA input is the most optimized after considering a trade-off between the input current and light intensity.

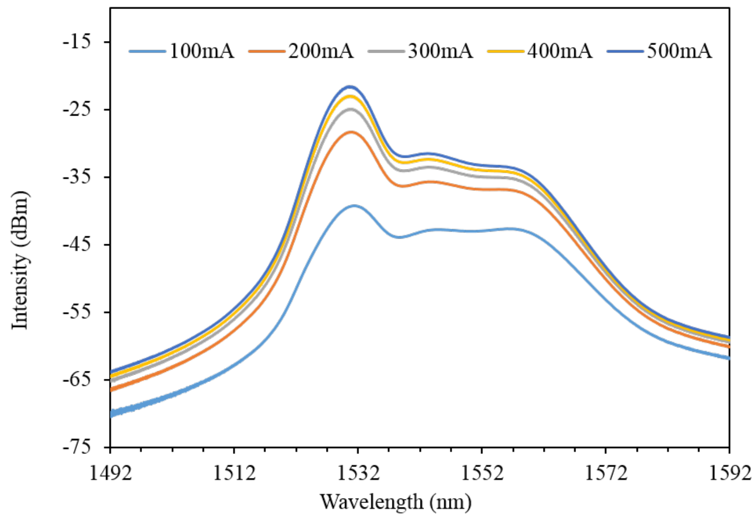

Fig. 4 - Spectra of input ASE light

The impact of temperature change on the output spectrum is then investigated. Fig. 5 shows the output light spectrum as the temperature of the sensor head varies from 30°C to 45°C with an increment of 1°C. Based on the spectra, there exist spectrum peaks and dips. The existence of such peaks and dips result from the interference effect in the sensor head. As the temperature of the sensor head increases, the birefringence of the PMF in the SI is also changed. Consequently, it causes a change of phase for clockwise and counter-clockwise lights that recombine at the 3-dB coupler, producing unique interference for each temperature. For that reason, spectrum dips change with the surrounding temperature. With increasing temperature, the spectrum dip shifts to the shorter wavelength.

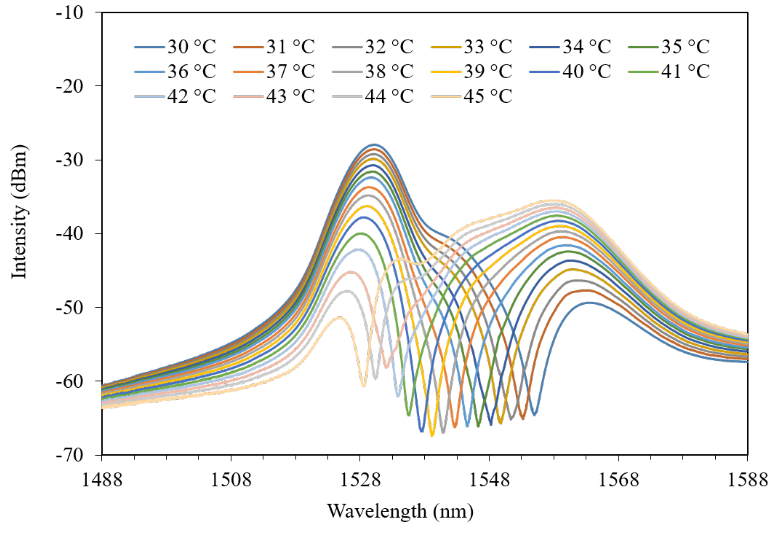

Fig. 5 - Spectra of output ASE light for varying temperature of sensor head

Fig. 6 plots the spectrum dip wavelength as a function of temperature, varying from 30°C to 45°C with a step of 1°C. The dip wavelength is found to be inversely proportional to the temperature. When temperature increases, the spectrum wavelength dip shifts to the shorter wavelength. The relationship between the wavelength dip and temperature can be fitted linearly, represented by a straight line with R^2 equal to 0.999 as shown in Fig. 6. The wavelength dip shifts linearly from 1554.96 nm to 1528.56nm when the temperature changes from 30 °C to 45 °C. The proposed Sagnac based temperature sensor has temperature sensitivity of -1.766 nm/°C, obtained from the slope of the fitted straight line.

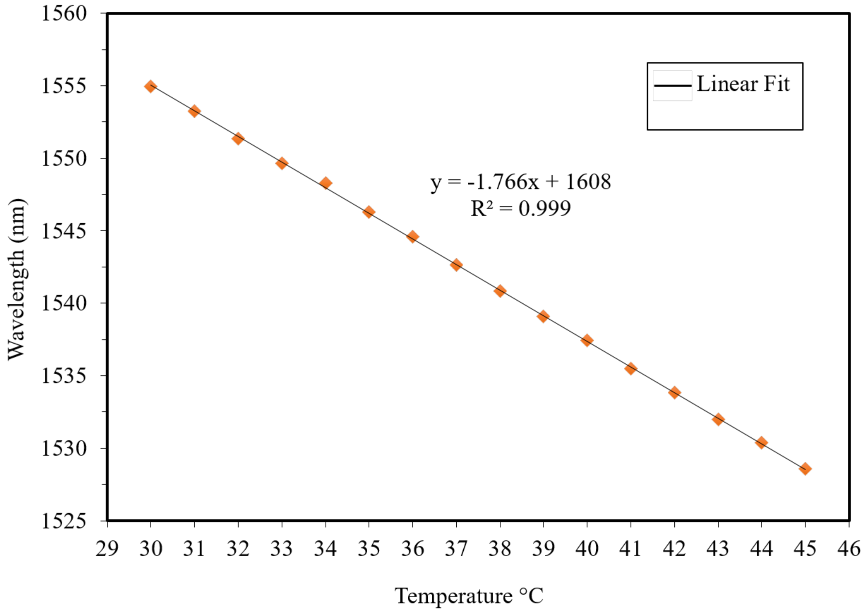

Fig. 6 - Wavelength dips as function of temperature

4. Conclusion

In conclusion, a Sagnac temperature sensor is experimentally demonstrated. The design starts with the development of Sagnac interferometer that consists of a 3.5 cm polarization maintaining fiber that acts as a sensor head, a polarization controller and a 3 dB coupler. In experiments, an amplifier noise that covers over the C-band region from 1530 nm to 1565 nm acts as the input light. For the output, the output spectrum after recombination of clockwise and counterclockwise lights in the Sagnac interferometer is observed. For temperature variation, the sensor head is placed in a temperature oven. Based on the experimental measurements, spectrum dip is found to have linear relationship with temperature. As temperature is varied from 30 °C to 45 °C, the spectrum dip shifts to the shorter wavelength from 1554.96 nm to 1528.56nm with the obtained sensitivity of 1.766 nm/°C. This Sagnac-based optical sensor is useful for temperature detection especially in the harsh environment.

Acknowledgement

This work was supported in part by the Ministry of Education (MOE) Malaysia under Fundamental Research Grant Scheme (FRGS) FRGS/1/2018/TK04/UTHM/02/5 Vot K062 and by the Universiti Tun Hussein Onn Malaysia (UTHM) under Post-Graduate Research Grant (GPPS) Vot H307 and TIER 1 Grant Vot H162.

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