IOP Conference Series: Materials Science and Engineering

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To cite this article: D A Resen *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **518** 042029

A New Technique to Sense Humidity Based on Optical Heterodyne detection

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Abstract. A new method of shifting in phase of optical heterodyne detection for humidity sensing have been proposed and demonstrated. In this paper, optical heterodyne techniques by using single source with single Fiber Brag Grating (FBG) were designed and studied. In this work FBG has been used as a light source and sensing element at the same time. FBG used as a laser source to achieve heterodyne detection through combine its reflected light with main laser source. Furthermore a combined lights was generated a beat frequency (F_B). The simulation results proved the ability of the proposed technique to achieve the requires sensitivity about 0.142 GHz / %RH.

1. Introduction

The optical heterodyne technique (OHT) is one of the most commonly used techniques in recent years. It represents two wavelengths mixed to generate F_B. A phase shift due to frequency shift or optical path changes by environmental changes. Moreover OHT technique can be used in many applications like communications and sensing fields [1]. The OHT as a sensor used in many purposes like, voltage, distance measurement, temperature, biosensor, strain, sensors [2-6].

Furthermore, it is used to detect the phase difference between two signals that are guided by reference and sensing arms, which is caused by some environment changes [7]. In 2017 **George Y** was presented a humidity sensor using optical microfiber [8]. In 2017 **Jia Shi** proposed and demonstrated experimentally a Fabry–Perot interferometer (FPI) sensor base humidity, to obtained sensitivity around 0.202 dB/%RH [9].

In 2018 **Yu Shao** presented a PVA-coated fiber SPR sensor for humidity measurement, with sensitivity of about 4.97 nm/RH% [10]. Current work represents a new approach by using one source with single FBG employing optical heterodyne technique. This contribution will help to reduce cost and system complexity with sensitivity of 0.142 GHz / % RH. The outline of this paper consist of section one theoretical concepts of optical heterodyne detection, section two experimental work of system, section three results and discussion and finally conclusion.

2. Theoretical Concepts of Optical Heterodyne Detection

The OHT is a kind of interferometry detection that used to detect phase shift between two waves. While F_B is a new wave generated due to mix reference and sensing signals and represent the difference between them, which is caused by the some environmental changes around the sensing arm.

$$F_B = F_S - F_R \tag{1}$$

Where F_S is the frequency of a sensing arm, F_R is a frequency of reference.

IOP Conf. Series: Materials Science and Engineering **518** (2019) 042029 doi:10.1088/1757-899X/518/4/042029

Both of electromagnetic waves of sensing and reference arms are combined and forwarded to photodetector. The photocurrent of combined signals is given using the total electric field square, as the following [9];

$$I(t) = |A_R \cos(\omega_R t + \emptyset_R) + A_S \cos(\omega_S t + \emptyset_S)|^2 \quad (2)$$

Where A_R & A_s represent the amplitude of reference and sensing waves, ω_R&ω_S are the angular frequencies of them, $\emptyset_R$ & $\emptyset_S$ are the phase of them. The signal phase is given by;

$$\emptyset = \frac{2\pi n_{eff} L}{\lambda_B} \quad (3)$$

Where L & n_{eff} are sensing element length and effective refractive index respectively.

$$I(\emptyset) = A \cos \Delta\emptyset \quad (4)$$

Phase difference represent the sensing signal is subtracted from reference signal as shown in the following equation [11];

$$\Delta\emptyset = \emptyset_R - \emptyset_s \quad (5)$$

$$I(\emptyset) = A \left[\cos\left(\frac{2\pi n_{eff} L(\lambda_B - \lambda_R)}{\lambda_B \lambda_R}\right)\right] \quad (6)$$

Phase difference is obtained by ;

$$\Delta\emptyset = \frac{2\pi n_{eff} L\Delta\lambda}{\lambda_B \lambda_R} \quad (7)$$

Where λ_R is the reference arm wavelength, λ_S is sensing arm wavelength, here $\lambda_S = \lambda_B$ where λ_B is Bragg wavelength, which represent reflected wavelength, taking into account that the Bragg wavelength acts as a laser source and sensing signal.

3. Experimental Work

The F_B shift is a function of shifting in wavelength in this work. The system consist of laser source 1552 nm, optical couplers C_1, C_2 and C_3, avalanche photodiode (APD) receiver, Fiber Bragg Gratings FBG and Oscilloscope (OSC) as shown in Figure 1. Here FBG has two functions, the first is a sensing element and the second it work as another source in order to achieve heterodyne in output wave. The first coupler C_1 split the launched light into two beams along reference and sensing arms. This interferometer achieved due to different wavelengths through reference and sensing arms. The reference arm signal and reflected signal of FBG via C_2 will be combined using C_3, finally the output waves process used APD.

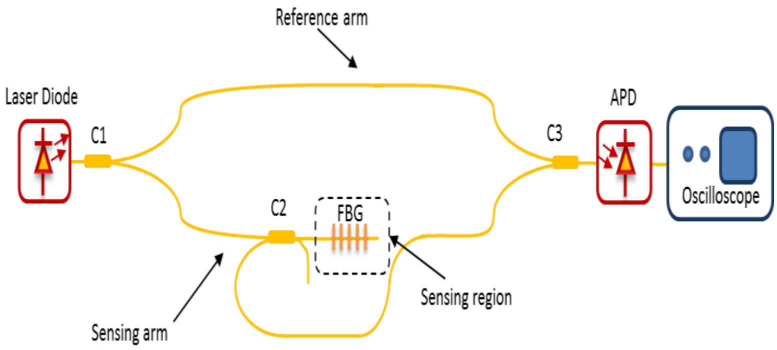

Figure 1. Humidity sensor based heterodyne technique.

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The whole system is shown in figure (2) using OptiSystem. Here OSA used to show the difference between the two signals that represent F_B. The difference between them was clear by using APD and OSC.

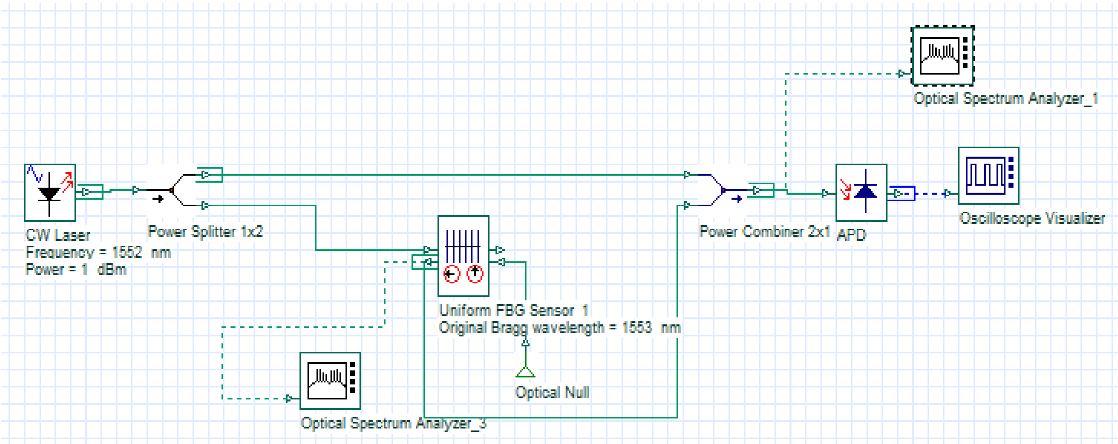

Figure 2. Humidity sensor based Heterodyne detection system

4. Results and discussion

The system has been achieved utilizing OptiSystem take into account the previous results was obtained by other researchers in this field. Figure 2 shows both of (a) main source wavelength and (b) shifting in λ_B for three.

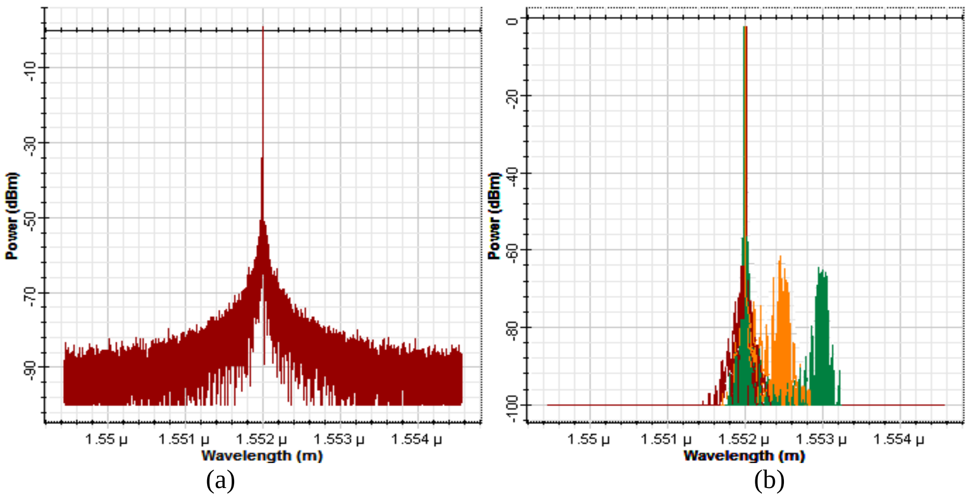

Figure 3. (a) main source wavelength (b) shifting in λ_B

Where F_B was generated due to the difference between main source wavelength and λ_B. The difference between two signals is measured utilizing heterodyne detection.

When the humidity applies on the FBG the λ_B will change and cause shifting in F_B. The beat frequency shift is due to the shifting in λ_B caused by humidity changes.

Figure 4 shows the beat frequency shift due to Bragg wavelength shift, which caused by applied humidity.

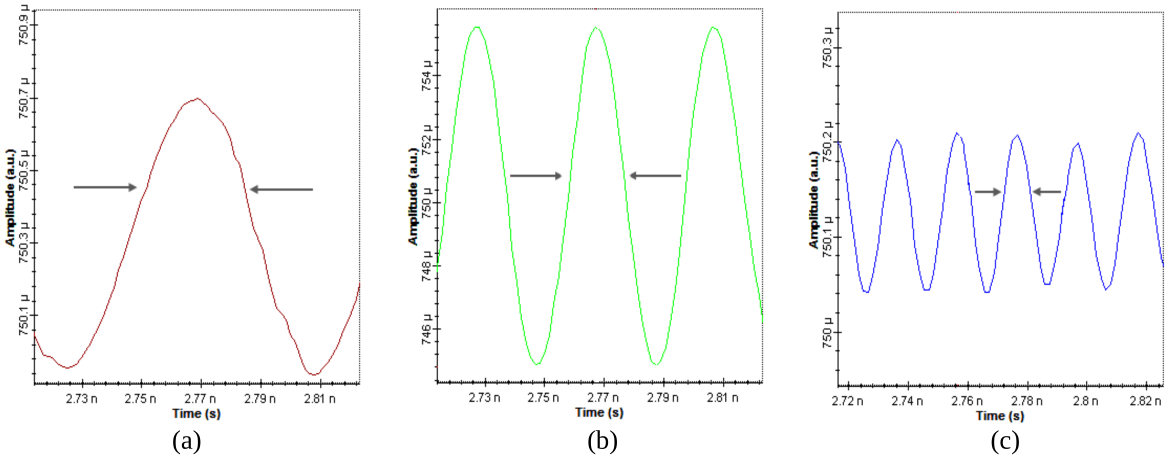

Figure 4. (a) F_B at $\Delta\lambda_B = 0.1\ nm$, (b) F_B at $\Delta\lambda = 0.\lambda_B\ nm$, (c) F_B at $\Delta\lambda_B = 0.3\ nm$.

The wavelength shift over the humidity range from 23.8%RH to 83.4%RH at room temperature is linear, and $\Delta\lambda_B$ increases with the rate of about 1.134 to 1.832 pm/%RH [10]. In this work the heterodyne technique plays the main role, where the F_B here is as a function of %RH. In this case the Bragg wavelength shift with the rate of 1.134/%RH is used. Figure 5 shows the relationship between F_B and RH%, where the F_B is generated by mixing a different wavelength and represents the subtraction of them. As a result, the beat frequency shift over the range of the humidity from 23.8% to 83.4%RH was 0.1416 GHz/%RH

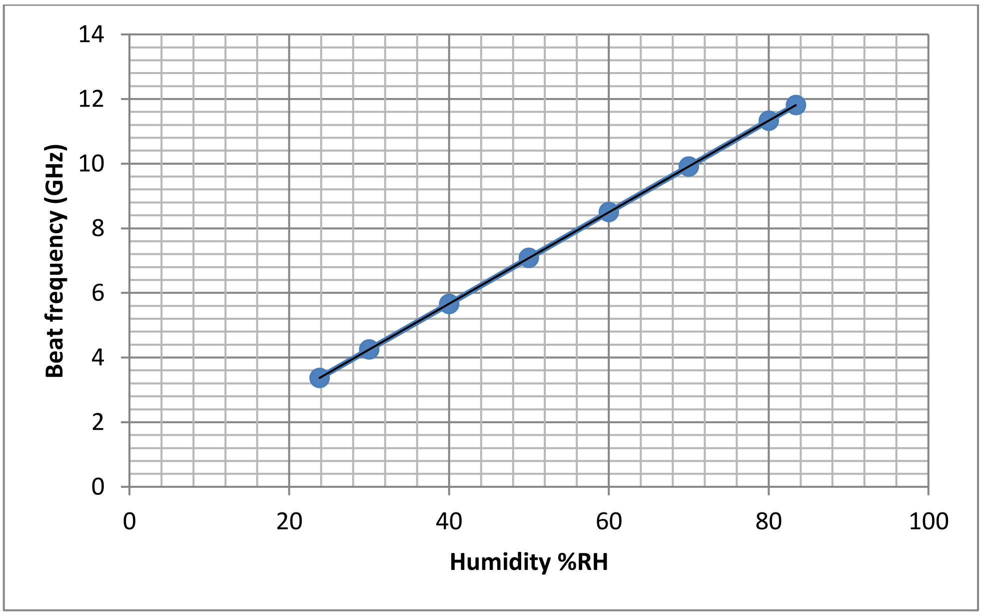

Figure 5. relationship between F_B and %RH.

5. Conclusions

The proposed approach was presented in current work by using a single CW laser and single FBG with a heterodyne technique based humidity sensor. The interferometry has been used utilizing single mode fiber as a reference arm and FBG along sensing arm. OTH provides an optical sensors with conventional receivers likes photodiode, furthermore the FBG used as a secondary source and sensing element at the same time. The results has been demonstrated, which possess many unique advantages over conventional techniques, it is help to reduce cost and system complexity and obtained sensitivity about 0.142 GHz /%RH. The results shows the propose technique can make improvement respect to other conventional technique. The beat frequency shift is measured in (GHz). This will gives the ability to measure output using conventional detectors, like photodiodes. While the conventional technique needs OSA in order to read output signal, this will leads to more cost and complexity.

References

[1] Yufei U, et al. 2017 Modified heterodyne efficiency for coherent laser communication in the presence of polarization aberrations *Optical Society of America* **25** 7567-7591.

[2] José H, et al. 2017 Polarimetric Optical High - Voltage Sensor using Synthetic - Heterodyne Demodulation and Hilbert Transform with Gain Control Feedback. I*EEE Journal of Selected Topics in Quantum Electronics* **23** 3275-3283.

[3] Zhaowu L, et al. 2017 Two-color heterodyne laser interferometry for long-distance stage measurement with correction of uncertainties in measured optical distances *Scientific Reports* **7** 1–10.

[4] Ruey-Ching T, et al. 2010 A Comparison between Two Heterodyne Light Sources Using Different Electro-Optic Modulators for Optical Temperature Measurements at Visible Wavelengths *Sensor* **10** 9609–9619.

[5] Antonio G, et al. 2018 Surface-plasmon optical-heterodyne clock biosensor *Sensors & Actuators: B. Chemical* **273** 336-341.

[6] Mingjia S, et al. 2017 Brillouin optical time domain re fl ectometry for fast detection of dynamic strain incorporating double-edge technique *Opt. Commun.* **398** 95–100.

[7] Haochen T, et al. 2018 High-detectivity optical heterodyne method for wideband carrier-envelope phase noise analysis of laser oscillators *optics letters* **43** 3108-3111.

[8] George Y 2018 Optical Microfiber Technology for Current, Temperature, Acceleration, Acoustic, Humidity and Ultraviolet Light Sensing *Sensors* **18** 1-25.

[9] Jia S, et al. 2017 Humidity Sensor Based on Fabry – Perot Interferometer and Intracavity Sensing of Fiber Laser *IEEE* **35** 4789 - 4795.

[10] Yu S, et al. 2018 Mechanism and Characteristics of Humidity Sensing with Polyvinyl Alcohol Coated Fiber Surface Plasmon Resonance Sensor *Sensors* **18** 1-9.

[11] Hely G, et al. 2017 Micrometric displacement sensor based on the strain of a fiber Bragg grating with heterodyne detection of intensity in a MachZehnder interferometer *IOPJournal of Physics: Conf. Series* **792** 1-6.