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Authors: Şerif Ali SADIK, Fırat Ertaç DURAK, Ahmet ALTUNCU

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Fiber Bragg Grating Sensor Interrogation Using Tunable Erbium-Doped Fiber Ring Laser Source

Şerif Ali SADIK*[1], Fırat Ertaç DURAK[1], Ahmet ALTUNCU[1]

Abstract

Fiber Bragg gratings (FBG) are ideal sensors for temperature, strain or vibration sensing applications with their advantages over conventional electronics sensor systems. In this paper, two different FBG sensor interrogation schemes based on broadband ASE source and tunable EDFRL source are demonstrated and compared. With both interrogator configurations, the response of the FBG sensor to temperature change is found to be linear and the sensitivities are measured as 11 pm/°C and 10.5 pm/°C, respectively. The experimental results have revealed that the optical power reflected from the FBG sensor is almost 20 dB higher with tunable EDFRL source than broadband ASE source. Thus, an interrogation method with tunable EDFRL can be suitable for remote, quasi-distributed sensor applications requiring high output power and OSNR.

Keywords: Fiber Bragg grating, broadband ASE source, tunable erbium doped fiber ring laser source, optical sensor interrogation

1. INTRODUCTION

Optical fiber based sensor systems have been studied extensively with their advantages of compactness, stability, durability, immunity to electromagnetic interference, high multiplexing capacity and suitability for remote sensing [1–7]. Among these studies, fiber Bragg grating (FBG) sensors have attracted great attention with its unique capabilities. In addition to advantages mentioned above, FBGs have the benefits of low-cost, wavelength coded linear response, quasi-distributed and embedded sensing ability [1,8]. With quasi-distribution several FBGs can be multiplexed in wavelength and/or time domain on a single optical fiber link to acquire responses from same or different parameters (e.g. temperature, strain, vibration etc.) and interrogated with a single system [8–14].

Since the response of a FBG to a measured quantity is a shift at the peak wavelength, the amount of the wavelength shift must be observed to quantify the sensor response. There are two main types of optical sources presented in the literature used for FBG based sensor interrogators. First group consist of broadband

*Corresponding author: serifali.sadik@dpu.edu.tr
[1]Kütahya Dumlupınar University, Faculty of Engineering, Electrical and Electronics Engineering Department, 43100, Kütahya, Turkey.
E-Mail: serifali.sadik@dpu.edu.tr; firat.durak@dpu.edu.tr; altuncu@dpu.edu.tr
ORCID: https://orcid.org/0000-0003-2883-1431; https://orcid.org/0000-0002-4278-6561; https://orcid.org/0000-0002-3753-9515

optical sources, such as amplified spontaneous emission (ASE) source, which is commonly used [4,7,15–17], or superluminescence light emitting diodes (sLED) [18-20]. An interrogator with a broadband light source is easy to install and has a compact structure. However, the ASE source has low output power and optical signal to noise ratio (OSNR). Thus, the maximum distance for long range quasi-distributed sensing may be limited. Also sLEDs have comparatively narrower spectral bandwidth which is usually some tens of nanometers, that limits the multiplexed sensor count [1,15,20].

The second group of optical sources for FBG sensor interrogator is based on tunable laser sources (TLS) [3,8,21–23]. The tunable laser sources offer wider spectral range, higher output power and OSNR which enable long distance remote sensing [14,21–23]. Among these, tunable erbium doped fiber ring lasers (EDFRL) are widely used for optical fiber sensor interrogation systems[1,24,25]. They offer many advantages such as high output power, high OSNR, wide tuning range, narrow linewidth and high stability [26,27]. These advantages may also moderately be offered by the bulk type solid state TLSs. However, EDFRLs have also more advantages over a bulk type tunable laser system which are a better beam quality, easy heat dissipation, compact in-line device, no need for bulk type optics, easy and low coupling loss to an output fiber, coupling a higher pumping power to the laser cavity and consequently low cost [28]. Therefore, EDRFLs have recently become a very promising and economical solution for FBG based and non-FBG based sensor interrogation systems.

In this work, we have realized FBG sensor interrogation with both a broadband ASE light source and a tunable EDFRL. In the experiments, firstly a broadband ASE signal obtained using a C-EDFA was used as the broadband light source and we have analyzed the spectral response of the FBG sensor to temperature variation as the measured physical quantity. Later, a tunable EDFRL was used as an FBG based temperature sensor interrogator. The results obtained for both interrogation schemes were compared and discussed. This paper is organized as follows. In Section 2, the experimental setup is introduced. Section 3 presents the experimental results. Finally, the results are discussed in the Section 4.

2. EXPERIMENTAL SETUP

The experimental setup of the FBG temperature sensor interrogator with a broadband ASE source is shown in Figure 1(a). For the broadband ASE source design, a laser diode operating at 976 nm with a pump power of 120 mW was used as the forward pump laser source. An EDF (LIEKKI Er30-4/125) with length of 3 m was used as the active medium. The broadband ASE signal generated in C-EDFA is shown in Figure 2. It can be seen from Figure 2 that the ASE signal source has low output power (< -15 dBm) and a limited bandwidth in C band (1525-1575 nm). Also, the power level is not constant in the entire C band.

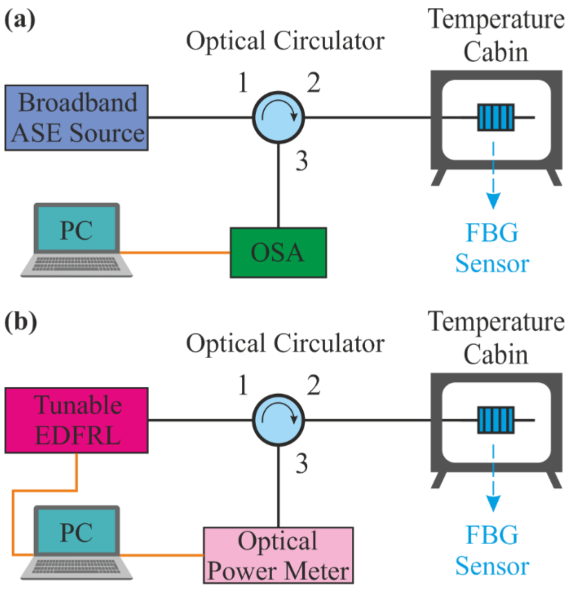

Figure 1 Experimental setup of FBG temperature sensor interrogator (a) with broadband ASE source (b) Tunable EDFRL source.

Figure 1(b) shows the FBG interrogation system with a tunable EDFRL. The tunable EDFRL source was designed, characterized and optimized for wideband operation between 1525 nm-1605 nm in a previous work [26]. The measured output power spectra of the tunable EDFRL used in this study is shown in Figure 3. One can see from Figure 3 that the tunable EDFRL used has 60 nm

(1525-1585 nm) (-3dB) tuning range and ~5.5 dBm output power in entire tuning range.

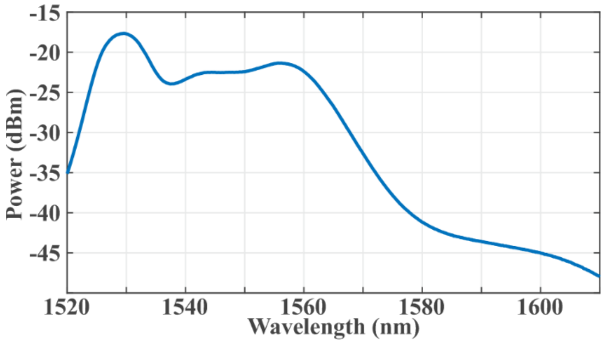

Figure 2 The output spectrum of the broadband ASE signal generated in C-EDFA.

In both configurations, the source signal (broadband ASE signal or narrow linewidth tunable EDFRL output signal) was directed to an FBG temperature sensor through a wideband optical circulator (1520-1625 nm). The center wavelength of the FBG temperature sensor is 1533.45 nm at room temperature, the reflectivity of FBG is 95% and and its 3-dB bandwith is 0.1 nm. The FBG sensor was placed inside a climatic test cabinet (NUVE TK120). The reflected signal was observed with an optical spectrum analyser (OSA, Antritsu MS9710B) and the acquired sensor data were processed and stored on a computer.

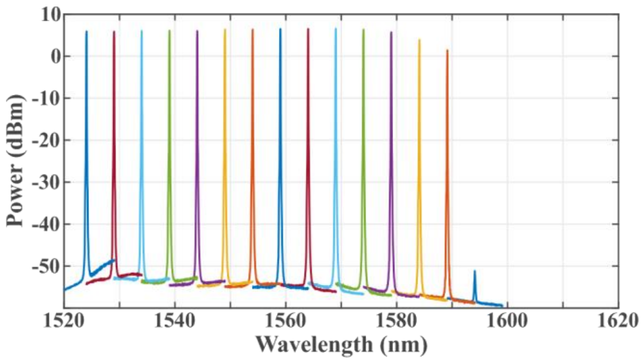

Figure 3 The output spectra of tunable EDFRL.

3. EXPERIMENTAL RESULTS

Using the measurement setups presented, we have measured the response of the FBG sensor to temperature variation. The temperature inside the climatic test cabinet was increased from 0°C to 40°C. At each measurement step, the temperature of the cabinet was kept constant for 15 minutes to achieve a uniform stabilized temperature distribution in the cabinet.

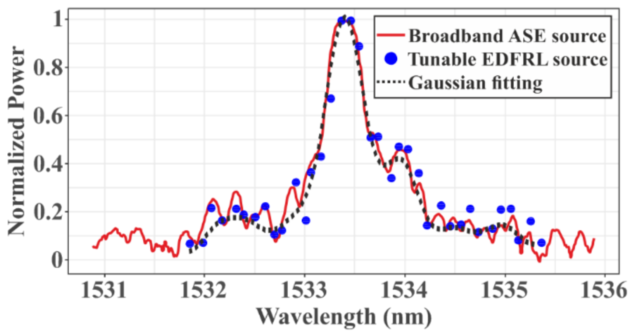

Figure 4 Measured reflection spectrum of the FBG sensor at room temperature (25°C) with a broadband ASE source and a narrow linewidth tunable EDFRL source as interrogator and Gaussian fitting curve of the points.

Firstly, the reflection spectrum of the FBG sensor was measured at room temperature (25°C). In Figure 4 solid red line shows the reflection spectrum obtained with broadband ASE source and the blue dots shows the discrete measurement points taken with 0.1 nm steps from reflection spectrum with narrow linewidth tunable EDFRL source. Also, the dashed black line shows the Gaussian fitting curve of the points obtained by the EDRFL interrogation system. Studies have shown that Gaussian fitting method is a precise peak detection method with a low detection error for the detection of FBG sensor peak reflection wavelength [29], [30]. It can be clearly seen from Figure 4 that, the reflection spectrum of the FBG sensor can be reconstructed from the peak points of discrete reflection spectra obtained with narrow linewidth tunable EDFRL source and Gaussian fitting algorithm. Also, one may increase the spectral resolution of discrete points to obtain a more precise reflection spectrum of FBG sensor.

3.1. Interrogation with a broadband ASE source

At the first measurement, we have employed an FBG temperature sensor interrogation system with a broadband ASE source which has been used for temperature sensing.

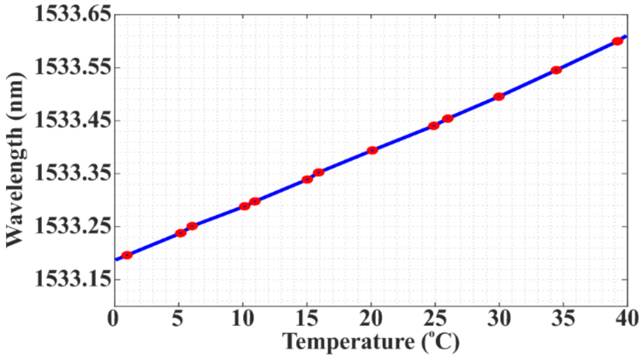

Figure 5 Linear response of the FBG sensor to temperature variation from 0°C to 40°C with broadband ASE source interrogator.

The shift at the center wavelength of the FBG sensor for varying temperature values from 0°C to 40°C is shown in Figure 5. The wavelength shift shows a linear response to temperature variation and the sensitivity of the FBG sensor was obtained as 11 pm/°C.

3.2. Interrogation with a narrow linewidth tunable EDFRL source

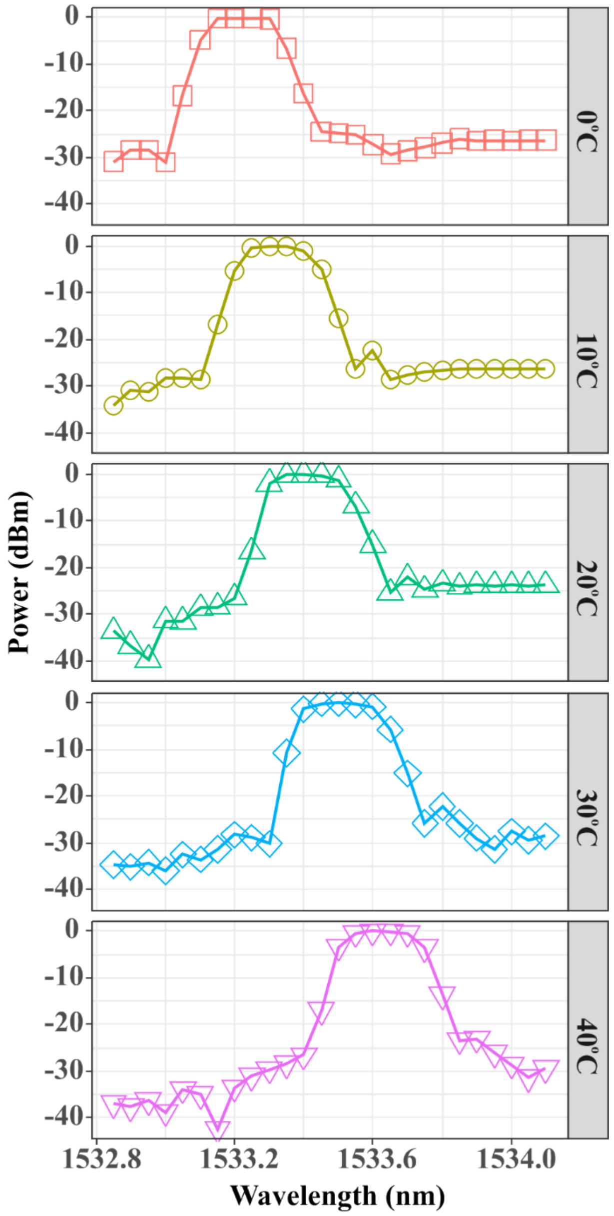

Figure 6 Reflection spectra of the FBG temperature sensor for different temperature values. Here, the interrogator is a narrow linewidth tunable EDFRL source.

As a second type of FBG temperature sensor interrogator, a narrow linewidth tunable EDFL source was utilized. The wavelength of the tunable EDFRL source was tuned from 1532.85 to 1534.10 with 0.05 nm steps and the reflection spectrum of the FBG temperature sensor was reconstructed from the peak powers of the reflections measured at each step.

Figure 6 shows the reconstructed spectra of the FBG temperature sensor for temperature values from 0°C to 40°C. It can be seen from the Figure 6 that, the peak wavelength of the reflection spectrum shifts towards to longer wavelengths as the temperature in the cabinet increases.

The linear relationship between the center reflection wavelength of the FBG sensor and the temperature is shown in Figure 7. It can be seen that, the wavelength shift response of the FBG sensor to temperature variation is linear and the experimental sensitivity is found to be 10.5 pm/°C. Our experimental sensitivity results for both interrogator schemes are highly consistent with the results given in the literature [3,31].

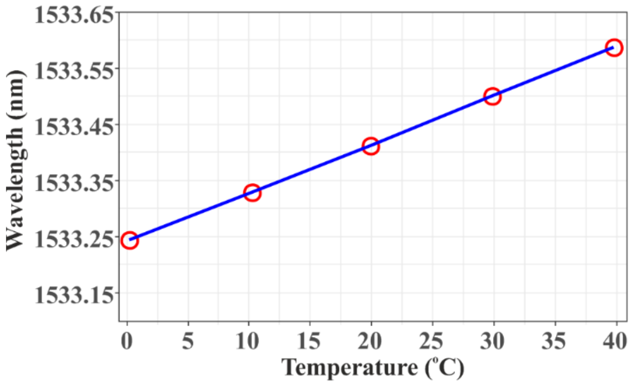

Figure 7 Linear response of the FBG sensor to temperature variation from 0°C to 40°C with tunable EDFRL interrogator.

4. CONCLUSION

In this work, the applications of a broadband ASE source and a narrow linewidth tunable EDFRL source as a FBG temperature sensor interrogator were demonstrated. From 0°C to 40°C, a positive linear response of the FBG sensor to temperature increase was successfully obtained with both interrogator configurations. The sensitivity of the FBG sensor is found to be 11 pm/°C and 10.5 pm/°C with broadband ASE source and narrow linewidth tunable EDFRL source interrogators, respectively.

With the broadband ASE source, the reflected optical power from the FBG temperature sensor was relatively low (~ -20 dBm) and its spectrum is not flat compared with the tunable EDFRL source. Therefore, a narrow linewidth tunable EDFRL source interrogator may be preferred to a broadband ASE source interrogator as it can support long range and multipoint quasi-distributed sensing systems due to its high output power, flat tuning spectrum and high OSNR. In addition, tunable EDFRL source interrogator has low cost advantageous due to lack of an expensive OSA or a wideband spectrometer in the system.

Further studies will be focused on multi-point, quasi-distributed sensing with FBG sensors using a narrow linewidth tunable EDFRL source interrogator. Also, further studies will be conducted in order to achieve simultaneous temperature and strain sensing with WDM and/or TDM techniques using narrow linewidth tunable EDFRL interrogator.

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The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

This study was the Ph.D. thesis of Şerif Ali SADIK, and the idea of the studies belongs to supervisor that is Ahmet ALTUNCU. Fırat Ertaç DURAK had a great contribution in providing support for the experiments.

The Declaration of Ethics Committee Approval

The authors declare that this document does not require an ethics committee approval or any special permission.

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