Quasi-distributed fiber sensor using active mode locking laser cavity with multiple FBG reflections

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ABSTRACT

We have demonstrated a quasi-distributed sensor using an active mode-locking (AML) laser with multiple fiber Bragg grating (FBG) reflections of the same center wavelength. We found that variations in the multiple cavity segment lengths between FBGs can be measured by simply sweeping the modulation frequency, because the modulation frequency of the AML laser is proportionally affected by cavity length.

Keywords: active mode locking laser, fiber Bragg grating, strain sensor

1. INTRODUCTION

Fiber optic sensors are widely used in various industrial fields such as bridges, buildings, and ships [1]. Fiber optic sensor researches are classified broadly into the discrete measurement methods such as fiber Bragg grating (FBG) or Fabry–Perot interferometer (FPI) sensors placed on the optical fiber, and continuous measurement methods such as the use of Brillouin sensors, distributed OTDR (optical time domain reflectometry), or OFDR (optical frequency domain reflectometry). These passive optical fiber sensing methods require a light source located separate from the optical fiber and a sensitive optical receiver to measure the optical signal from the optical fiber. As a result, the optical intensity is decreased owing to the transmission loss from the optical fiber when the measurement distance from the light source becomes longer [1-3].

In this paper, we propose a novel, quasi-distributed fiber laser sensor using an active mode-locking (AML) cavity to overcome the limitations of conventional passive optical fiber sensors. Because the modulation frequency of an AML laser varies with cavity length, the lasing wavelength of an AML laser is determined by the length from the partial reflection points in the laser cavity [4, 5]. When the cavity length is changed by applying a tensile load to the optical fiber between partial reflection parts, the change in fiber length can be detected as a shift in the modulation frequency of the AML laser [2].

2. EXPERIMENTAL SETUP AND PRINCIPLE

Figure 1 shows the experimental setup for the proposed AML laser sensor using three FBG sensors with a center wavelength of approximately 1312 nm. For the multiplecascaded FBGs, the intensity reflection of each FBG is 5.6 % of low partial reflectivity. The optical gain of the semiconductor optical amplifier (SOA) is directly modulated by an RF signal from a function generator. The signal frequency is determined from the modulation frequency required to meet the active mode-locking condition of the specific cavity length, which is determined from the cavity length owing to the position of the partial reflectors. A circulator is used to guide partially reflected light from the FBG into a feedback cavity for an integral multiple of the cycles passed through the SOA.

25th International Conference on Optical Fiber Sensors, edited by Youngjoo Chung, Wei Jin, Byoungho Lee, John Canning, Kentaro Nakamura, Libo Yuan, Proc. of SPIE Vol. 10323, 103235M · © 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2267642

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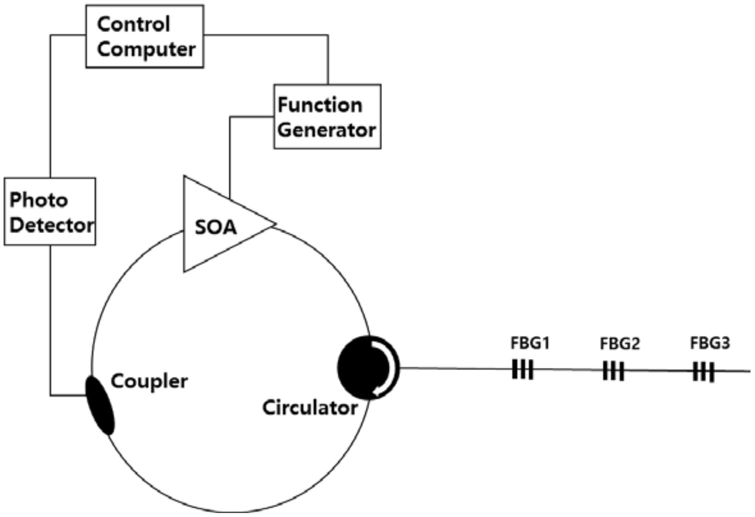

Figure 1. Experimental setup (SOA: semiconductor optical amplifier, FBG: fiber Bragg grating)

Because the SOA is modulated by a function generator, the modulation frequency can be calculated as follows.

$$f_m = N \cdot \mathrm{FSR}. \tag{1}$$

In Eq. (1), f_m is the modulation frequency, N is the mode number, and FSR is the free spectral range, which can be calculated as follows.

$$\mathrm{FSR} = \frac{\mathrm{c}}{n_{eff}\mathrm{L}} \tag{2}$$

where *c* is the speed of light, *L* is the cavity length, and *n* is the effective refractive index.

From equations (1) and (2), it can be clearly seen that the modulation frequency is proportional to the FSR, and the FSR is affected by the cavity length. Therefore, the modulation frequency changes with the cavity length variation through the light reflected from the FBGs. Based on this relationship, the modulation frequency can be monitored and used to calculate cavity length directly. Thus, the change in the cavity length can be measured to obtain the sensor's performance.

In this experiment, we induced variation in the cavity length by applying strain to the fiber sections between FBGs using a strain stage. We measured the strain by linearly sweeping the modulation frequency. The total cavity length up to FBG3 was 15 m, and the fiber section between FBG2 and FBG3 was 4.65 m. The fiber section between FBG1 and FBG2 was 2.2 m. On the strain stage between these two FBGs, two fiber holders are used to attach the two ends of bare fiber segment of 0.75m length, and pulled them apart to extend the fiber segment by up to 1.4 mm. In addition, the length variation in the FBG1-FBG2 and FBG2-FBG3 sections were measured individually by inversion, demonstrating that the AML laser sensor system can function as a quasi-distributed sensor.

3. EXPERIMENTAL RESULTS

In this experiment, we used two configurations depending on the position of strain stage. Figure 2A shows the first experimental setup and results obtained when the strain stage was installed between FBG2 and FBG3. Figure 2C shows the detector response as a function of the swept modulation frequency in the AML cavity. These results show that only the detector response of FBG3 was affected by the increase in strain steps, while the modulation frequencies of FBG1 and FBG2 remained unaffected. This means that there were no changes in cavity length up to FBG1 and FBG2, and only the cavity length of FBG3 changed. This is consistent with the theoretical results of the experimental setup. We also measured that the modulation frequency, and the graph of the path length variation of FBG3 was linear with an R-squared value of

0.9977. The results from experimental setup 1 show that the FBG sensor system using the AML laser principle can be used as a linear optical fiber sensor system.

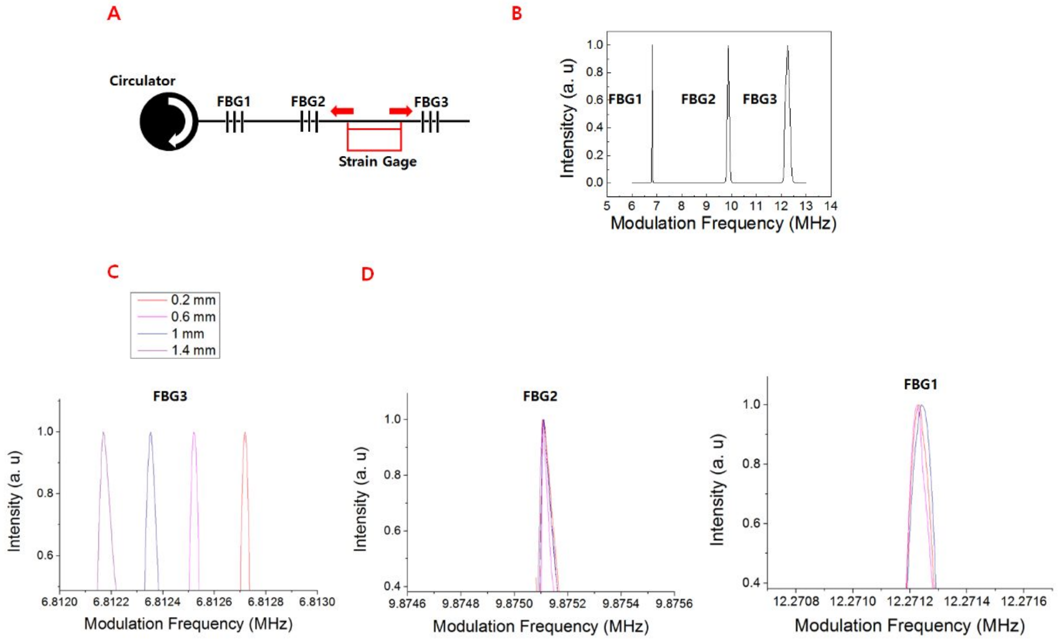

Figure 2 (A) Experimental set-up 1, (B) Response of FBG3, (C) Response of FBG2, (D) Response of FBG1 for various strains between FBG2 and FBG3

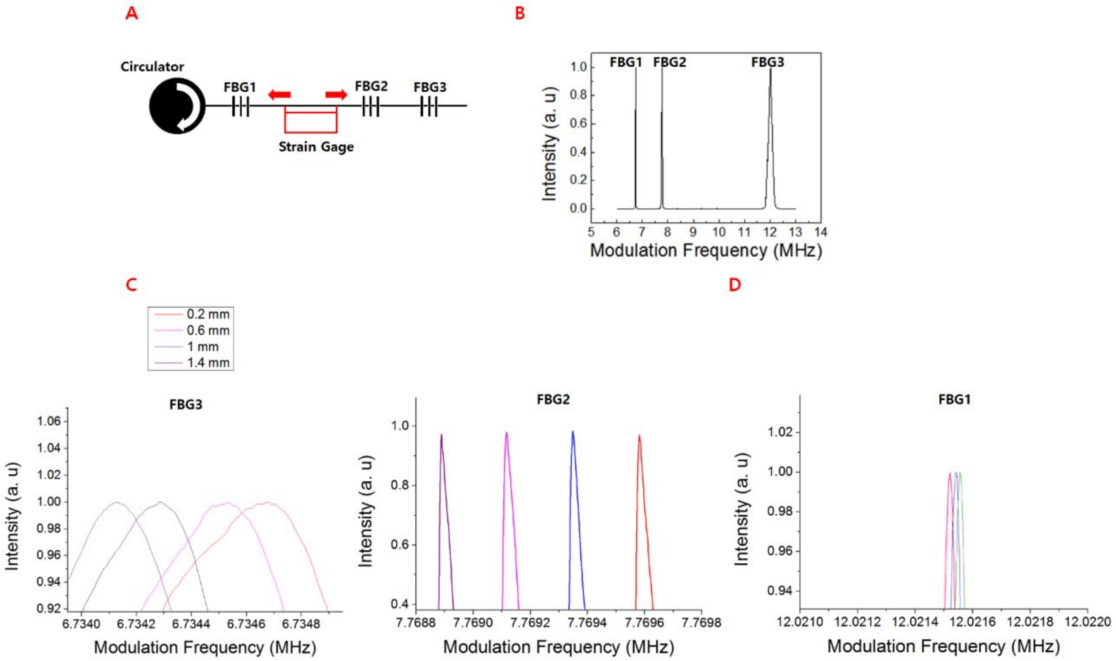

Figure 3 (A) Experimental set-up 2, (B) Response of FBG3, (C) Response of FBG2, (D) Response of FBG1 for various strains between FBG1 and FBG2

Figure 3 shows the second experimental setup with the strain stage installed in the FBG1-FBG2 section. In this configuration, the detector response of FBG2 changed linearly according to the change in the path length of FBG1-FBG2.

The variation in the path length of the FBG1-FBG2 section affected the detector response of FBG3 with the same change in path length. Therefore, the detector responses of FBG2 and FBG3 are similar, as shown in Figure 3C. Therefore, the experimental results are consistent with the theoretical values for this experimental setup.

The relation between the modulation frequency and path length of FBG2 and FBG3 were also measured. Both results showed good linearity with R-squared values of 0.99. The changes in path length measured using the modulation frequency changes of FBG2 and FBG3 were in agreement with each other. Therefore, we can clearly see that no path length change occurred between FBG2 and FBG3, and the path length changed only between FBG1 and FBG2. These results show that the FBG sensor system using an AML laser principle is useful as a quasi-distributed sensor with multiple sections.

4. CONCLUSION

We have demonstrated that an FBG sensor system using an AML laser cavity can be used as a precision strain sensor with a quasi-distributed sensor network. We proposed a simple strain sensor design and demonstrated the performance of the quasi-distributed sensor using multiple FBG experimental data. We expect that such a novel quasi-distributed AML laser sensor system can be implemented as a low-cost alternative for precision distributed fiber optic sensors.

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