Novel interrogation of the multiple FBGs with same Bragg wavelength by using active mode locking cavity

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Abstract: We proposed a new type of fiber Bragg gratings (FBG) interrogator using active mode locking (AML) technique. Since the interrogation mechanism is based on the separated detection of actively mode-locked frequency of each series FBG in the AML cavity, we can successfully interrogate the multiple FBGs with same wavelength. The static strain measurement of FBG sensor shows a high linear response with the R-square value of 0.9990.

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1. Introduction
Fiber Bragg grating (FBG) sensors have been widely used to monitor the structural condition of building, airplane, bridge, and etc. [1] Conventional passive FBG sensors have used a spectrally broadband optical source, such as amplified spontaneous emission (ASE) of erbium-doped fiber amplifier (EDFA) and semiconductor optical amplifier (SOA). However, the scheme of broadband optical source and narrow reflected spectrum of FBG result in a low signal-to-noise-ratio (SNR) and a limited number of FBG sensors in the given spectral width of source [1].

Recently, instead of ASE source, it is intensively studied that the FBG sensor can be interrogated with wavelength-swept laser. By using wavelength-swept laser, the performance of FBG interrogation system shows a quantum leap in terms of SNR and measurement speed. Recently, it is also reported that the high speed dynamic FBG interrogation system can be implemented with 50 kHz measurement repetition [2]. However, most of the wavelength-swept laser suffer the non-linear wavelength sweep operation due to the sinusoidal movement of the built-in mechanical filter in the laser cavity. Because such a non-linear operation causes a downgrade accuracy of FBG interrogation, additional processes or instrument will be needed for compensation of non-linearity of wavelength sweeping [3].

One of advantage of FBG sensor is that a plenty of series FBGs on single optical fiber can be spontaneously interrogated. In the most of FBG sensor system by detecting Bragg wavelength, the limit of measurable number of FBGs is depend on the spectral width of optical source. It has been impossible to distinguish the reflected signal of multiple FBGs with same Bragg wavelength when we use the wavelength swept laser.

For the interrogation of the series FBGs with same Bragg wavelength, instead, the broadband pulse source and pulse picker can be used. As the broadband short pulse from optical source propagate along a fiber, it will be partially reflected back from the each successive FBG. The pulse picker makes the time window, which passes the selected pulse signal, and then the wavelength detection instrument will measure the shifted Bragg wavelength of each FBG. However, this approach has two main problems due to the passive FBG scheme and the same wavelength of FBGs. First, multiple-reflection crosstalk occurs from reflection between FBGs with same wavelength. Because of the optical delay of multiple-reflections, we can monitor the unwanted signal overlap problem in the time window of allotted pulse signal. Second, the reflected signal from backward FBG is decreasing because the signal intensity decays as the light passes through each FBG and returns back [1].

In this study, we demonstrated a novel interrogator for the multiple FBGs with the same Bragg wavelength by using the active mode locking (AML) cavity. The proposed interrogation mechanism is based on the shift of mode-locked frequency detection of FBGs as the AML cavity length is changing at each FBG node. Each FBG has a different mode-locked frequency with the dependence of different AML cavity length. In addition, we add a CFBG to induce a chromatic dispersion in the cavity. It is helpful to increase the amount of the cavity length change when the Bragg wavelength is shifted by applying the strain into the FBG. We can successfully interrogate multiple FBGs with high SNR, no decay of signals along the fiber length, and high linearity response.

2. Experiment set-up and Principle
Fig 1. shows a basic experimental set-up of AML laser sensor using CFBG. The laser cavity consists of an SOA for controlling of the net gain of cavity, a CFBG module, a 10/90 optical coupler, and three FBGs for sensing part. The SOA is directly modulated by applying electrical pulse signal, 4 ns pulse width from an arbitrary function generator (AFG). An AFG is controlled for sweeping pulse repetition rate by a control computer through general
purpose interface bus (GPIB) interface. The dispersion of CFBG is 15 ps/nm and a reflectivity of ~90%. The sensing FBGs have reflectivity of 6%, center wavelength of 1312.22 nm and 3-dB bandwidth of 0.12 nm. The distance between each FBG is 1.2 ~ 1.3 m. The output signal through 10% part of coupler is detected by 80 MHz balanced photo detector (PD, Model 1817) and the detected signal was obtained using a digitizer (NI, PCI-5124) with 1 GS/s oversampling mode. The output intensity as pulse repetition rate can be obtained using a commercial software program, LABVIEW.

![Diagram](image.png)

Figure 1. The experimental set-up of AML laser sensor using CFBG

The active mode locking can be clearly occur when the external modulation frequency corresponds with the free spectral range (FSR). This frequency is called as mode-locked frequency. A number of cavities are composed by each FBG and each cavity has different cavity length or mode-locked frequency. In condition of the applying strain to one of FBGs, the wavelength shift (Δλ) of mode locking laser results in FSR change (ΔFSR) or mode-locked frequency shift due to chromatic dispersion of CFBG. The relationship between lasing wavelength shift and FSR change can be described as follows:

\[
\Delta FSR = \frac{c}{n \cdot L_i} \cdot \Delta L = \frac{1}{2} \cdot FSR_i^2 \cdot D \cdot \Delta \lambda
\]

where \( L_i \) is initial cavity length with no strain on FBG, \( FSR_i \) is initial free spectral range with \( L_i \), \( D \) is the chromatic dispersion of CFBG.

3. Experimental Results

![Figure 2](image.png)

Figure 2. The mode-locked frequency spectrum of five FBGs with same wavelength
Fig.2 shows the mode-locked frequency spectrum of three FBGs with same center wavelength of 1312.12 nm and reflectivity of 6%. The measured SNR and intensity ripple of each peak were ~40 dB and ~1 dB, respectively. The measured mode-locked frequency and calculated cavity length (in silica) of FBG1~FBG3 was 13.42, 11.63, 10.14 (MHz) and 15.23, 17.57, 20.16 (m), respectively. The calculated distances of each neighboring FBG were 1.29, 1.17 (m) and were largely correspond with real distance of ones, 1.2 ~ 1.3 m.

Fig.3 shows the mode-locked frequency shift of FBG3 at 0 ~ 5109 με strain. (5 steps). According to Eq. (1), the mode-locked frequency shift and Bragg wavelength shift have linear relationship. Hence, the applied strain to FBG can be directly measured from mode-locked frequency shift. The measured R-square value of first-order fitting was 0.9990. The measured slope coefficient was determined to be 2.653 kHz/με, which is in good agreement with the calculated value 2.733 kHz/με.

![Figure 3. The mode-locked frequency shift of FBG3 at 0 ~ 5109 με strain. (5 steps)](image)

### 4. Conclusion

A new concept of FBG sensor interrogation is successfully demonstrated based on the AML cavity. The interrogation mechanism is based on the mode-locked frequency detection of each FBG separately. The three FBGs with the same Bragg wavelength were interrogated successfully. The measured SNR and intensity ripple is ~40 dB and ~1 dB, respectively. The static strain measurements of FBG sensors were characterized with high linearity of R-square value of 0.9990.

### 5. References


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