Intensity and Wavelength-Division Multiplexing FBG Sensor System Using a Tunable Multiport Fiber Ring Laser

Peng-Chun Peng, Jia-He Lin, Hong-Yih Tseng, and Sien Chi

***Abstract*—We propose an intensity and wavelength-division multiplexing (IWDM) fiber Bragg grating (FBG) sensor system using a tunable multiport fiber ring laser. The different output powers of a multiport fiber laser are used to address the information reflected from the sensing FBGs, even if the Bragg wavelengths of the FBGs connected at different laser output ports are identical. We describe the operation principle and experimentally demonstrate a three-port fiber sensor. For the IWDM technique, our proposed fiber grating sensor system can enhance the sensing capacity, signal-to-noise ratio, and sensing resolution.**

***Index Terms*—Fiber Bragg grating (FBG), fiber laser, fiber sensor, intensity and wavelength-division multiplexing (IWDM).**

I. Introduction

THE FIBER Bragg grating (FBG) has shown its enormous potential for strain sensing in a smart structure [1]–[4]. One of the attractive advantages of an FBG sensor system is the multiplexing capability. The most popular technique for FBG multiplexing in a sensor system is the wavelength-division-multiplexing (WDM) technique. The simplest light source for a WDM-FBG sensor configuration is a broad-band source, such as an Er^{3+}-doped (Er) fiber amplifier or a light-emmitting diode. The sensor number to be multiplexed is determined by both the operating wavelength range required for each FBG sensor and the total useable bandwidth of the broad-band source. In recent years, using intensity and wavelength-division-multiplexing (IWDM) technique to increase the sensor number has been proposed [5]. An FBG with two specified low-reflectivity peaks has to be fabricated for this IWDM scheme. Such a specific FBG with dual peaks, therefore, can be addressed when its one peak overlaps with that of another single-peak high-reflectivity FBG and its second peak can be used for decoding the wavelength shift. However, an unmeasurable gap would be induced when the bandwidth of the single-peak FBG is slightly broader than that of the dual-peak FBG. Thus, a single-peak high-reflectivity FBG with a narrow bandwidth also has to be fabricated [5]. Furthermore, a signal processing method for the IWDM scheme without using the FBG specifically fabricated has also been reported [6].

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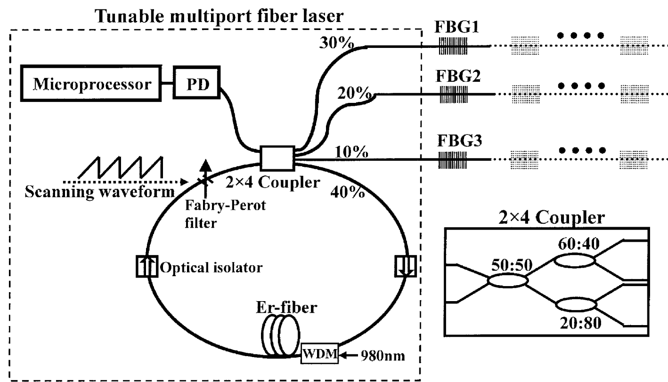

Fig. 1. Schematic diagram of the tunable multiport fiber laser for IWDM sensor systems. (Er-Fiber: erbium-doped fiber; WDM: 980/1550 WDM coupler).

Another simple method for interrogating WDM-FBG sensors is by using a tunable laser source to dynamically sweep the whole FBG's wavelength range. In contrast with the broad-band source, a laser source provides a higher power within a narrow spectral width and, thus, improves the signal-to-noise ratio (SNR) [7]. These merits allow for a larger number of FBG sensors with the same Bragg wavelengths, if we take advantage of a tunable laser incorporated with the IWDM technique. In this letter, we propose an IWDM-FBG sensor system using a tunable multiport Er-fiber ring laser. The output terminals of the fiber laser are constructed by using a 2×4 coupler that comprises three fiber couplers with different coupling ratios. All the sensing FBGs connected at the three different terminals can have the approximately equal peak reflectivities, and it is unnecessary for us to fabricate specified peak reflectivities of FBGs for intensity multiplexing. Consequently, the proposed multiport fiber laser can easily increase the capacity of an FBG sensor system by using the IWDM technique.

II. Principles

Fig. 1 schematically shows the IWDM-FBG sensor system. The light source of this sensor system is a tunable fiber ring laser with a Fabry–Pérot filter for wavelength selection. For the IWDM technique, the laser output consists of three ports of a 2×4 coupler that is connected by three fiber couplers with different coupling ratios. The output ratio between the different lasing branches can be designed according to the coupling ratios of the three fiber couplers. The lasing light from each output port

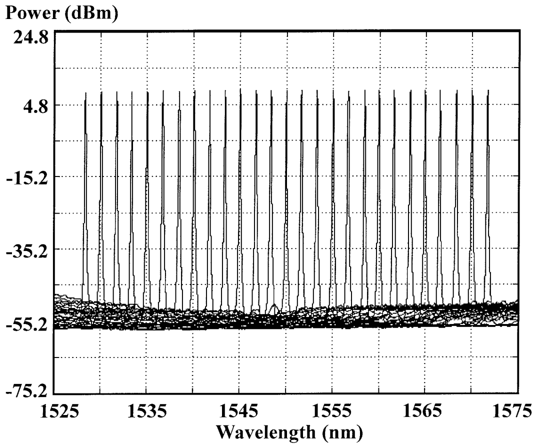

Fig. 2. Output spectra at 30% lasing port within the working range from 1528 to 1572 nm.

is launched into a branch of sensing FBG chain. In the WDM technique, the multiplexing number of the sensing gratings is limited by the reflective band of each FBG sensor and the whole bandwidth of the light source. Therefore, the wavelengths of sensing gratings cannot cross each other. On the contrary, our proposed scheme for the IWDM technique allows for the peak reflectivity of each grating at different lasing branches crossing each other. When spectral overlap occurs between two sensing gratings, the output intensity is the sum of each grating's output intensity. As a result, the overlap output still can be used to address the sensing information without the unmeasuable gap.

III. Experimental Results

The fiber laser was constructed by a 2×4 coupler, a Fabry–Pérot filter with 44-nm tunable range, and a commercial Er-fiber amplifier. The 2×4 fiber coupler comprised a 2×2 fiber coupler (50 : 50), 1×2 coupler (40 : 60), and 1×2 coupler (20 : 80). The lasing light traveled through the 2×4 fiber coupler and split into three FBG branches (FBG1 $= 1545.32$ nm, FBG2 $= 1548.32$ nm, FBG3 $= 1550.28$ nm) for experimental demonstration of our proposed multiplexing technique. Because of the 2×4 coupler, the power ratio launched into FBG1, FBG2, and FBG3 was 30% : 20% : 10%. The peak reflectivity of each FBG was 99%. The backreflected light from each FBG finally propagated through the 2×4 coupler and into the photodetector (PD). The output signal from each PD was fed into a microprocessor to accurately calculate the backreflected wavelength.

Fig. 2 shows the output from the 30% lasing port when we turned the Fabry–Pérot filter by using a voltage controller from 0 to 12 V. This operating voltage range can select the lasing wavelength within the working range from 1528 to 1572 nm. The average power from this 30% output port is 9.16 dBm. Fig. 3 shows the laser stability from this 30% lasing port within fifteen minutes. When the central wavelength of the laser is 1533.19 nm, the average wavelength variation is 0.04 nm. In addition, the variation of the output power is $(P_{\max} - P_{\min})/\bar{P}_{\text{out}} = 0.64\%$, where $P_{\max}$ is the maximum output power, $P_{\min}$ is the minimum output power, and $\bar{P}_{\text{out}}$ is the average output power. The system stability of this IWDM system is determined by these two parameters and the adopted method for electronic signal processing, which will be discussed in Section IV.

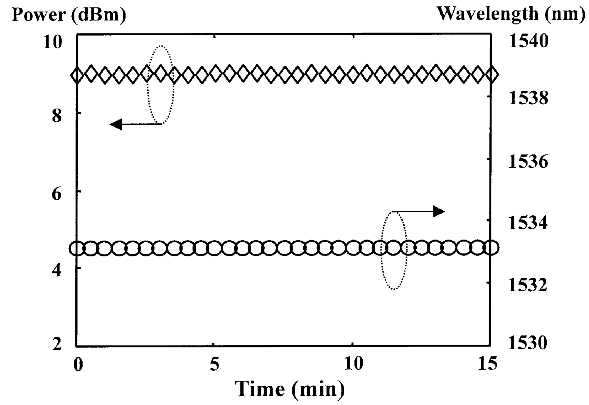

Fig. 3. Laser stability regarding output power variation and wavelength drift at 1533.19 nm.

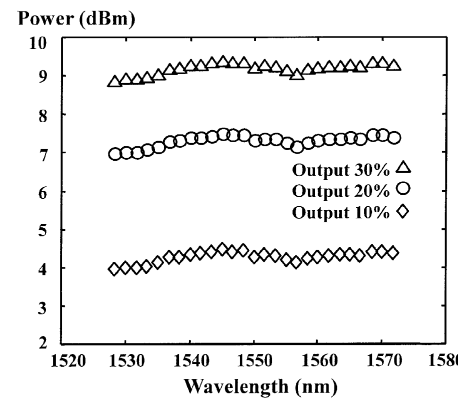

Fig. 4. Output powers of the 30%, 20%, and 10% lasing ports at different lasing wavelengths.

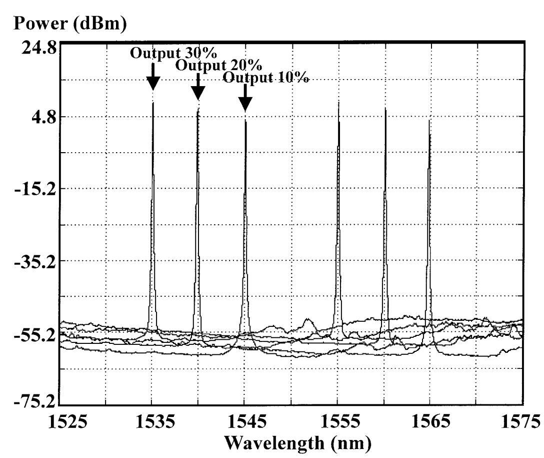

Fig. 5. Output spectra of the 30%, 20%, and 10% lasing ports at different lasing wavelengths.

Fig. 4 shows the output power of the 30%, 20%, and 10% output ports at different lasing wavelengths. The average output power from the 20% and 10% lasing port are 7.30 and 4.26 dBm, respectively. The maximum power variation is 0.55 dB from 1528 to 1572 nm. Fig. 5 shows the output spectra of the 30%, 20%, and 10% output ports at different lasing wavelengths. For

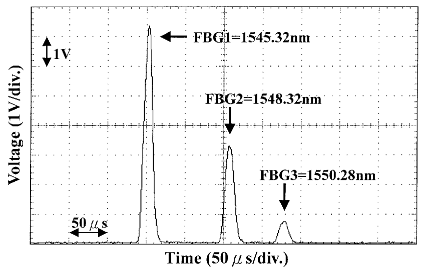

Fig. 6. Output signals from the PD under the scanning Fabry–Pérot filter operation. (Vertical scale is 1 V/div. Horizontal scale is 50 μs/div).

quasistatic strain sensing, we drove the Fabry–Pérot filter by using a scanning sawtooth waveform to sweep the wavelength range of the sensing FBGs. Fig. 6 shows the output signal from the PD under the scanning Fabry–Pérot operation. Finally, in contrast with a broad-band source, the light source of our proposed sensor system is a tunable fiber laser, which can enhance the SNR and the sensing resolution for the system. These advantages facilitate the accurate measurement that is sufficiently reliable against the noisy environments, especially for the long-distance remote sensing in a smart structure.

IV. Discussion

In this letter, we focus our attention on the IWDM laser source for a high-capacity and long-distance sensor system. Nevertheless, how to distinguish the reflected signal encoded via IWDM has been reported previously [6]. In the previous study, the technique of a minimum variance shift (MVS) has been proposed for the discrimination of IWDM signals. The MVS technique is based on the construction of a variable spectrum from the original uncontaminated spectra of the FBGs. According to the MVS technique, if there is wavelength overlap due to two or three FBG sensors from different ports, the reflected power will be accumulated. Such accumulated intensity information must also be encoded. Moreover, our proposed fiber laser with lasing range from 1528 to 1572 nm is capable of supporting 22 WDM channels with 2 nm per channel. The measurement range for each sensing FBG on the identical sensing branch, therefore, has to be smaller than $[0, 1760]\mu\varepsilon$. Because there are three intensity-coded branches, the allowable number of FBGs is $22 \times 3 = 66$. The IWDM system can support only few intensity-coded branches because the MVS technique is time-consuming. In addition, the scanning rate of the tunable filter always limits the dynamic range of the sensor system if the FBGs undergo the noise perturbation from the environments. For this problem, we should use the MVS technique in conjunction with a time-interval counting method, which is usually used for the perturbation problem in a conventional WDM scheme [8]–[10]. Nevertheless, the IWDM scheme can easily double or triple the sensing number based on the WDM technology and maintain the measurable range for each sensor.

Another problem when wavelength overlap occurs is the coherence related problems which could be overcome by using the following methods: 1) We can add long fibers between the three-port coupler and the FBGs such that our proposed system could be used for long-distance sensing. 2) We can use a phase modulator to degrade the coherence of the lasing light.

V. Conclusion

An IWDM-FBG sensor system using a tunable multiport fiber ring laser has been proposed and experimentally demonstrated, in this letter. Such a multiplexing technique can easily increase the capacity of an FBG sensor system. In the experiment, a three-point sensor system was shown. The experimental results show that our proposed fiber ring laser can simultaneously lase three outputs with different intensity for the information addressed by the IWDM technique. Moreover, the laser source can enhance the SNR and resolution of the IWDM sensor system.

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