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Optics Communications 252 (2005) 127–131

OPTICS COMMUNICATIONS

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Long-distance fiber grating sensor system using a fiber ring laser with EDWA and SOA

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Received 17 January 2005; received in revised form 15 March 2005; accepted 30 March 2005

Abstract

This investigation presents and demonstrates the feasibility of a novel fiber Bragg grating (FBG) sensor system using a fiber ring laser with a hybrid amplifier. The hybrid amplifier comprises an erbium-doped waveguide amplifier (EDWA) and a semiconductor optical amplifier (SOA). Experimental results demonstrate that the hybrid amplifier has a higher amplifier spontaneous emission power and gain spectrum. Moreover, this novel fiber ring laser provides a stable multiwavelength output with an optical signal-to-noise ratio over 50 dB, even when FBGs are located at a 25 km remote sensing position. The primary feature of the proposed fiber laser is that it facilitates a long-distance or a large-scale sensor system.

Keywords: Fiber sensor; Fiber Bragg grating; Fiber laser; Erbium-doped waveguide amplifier; Semiconductor optical amplifier

1. Introduction

Fiber Bragg gratings (FBGs) are effective optical devices for multipoint sensing in smart structures. In general-use FBG sensor systems, a broadband erbium-doped fiber amplifier (EDFA) or light-emitting diode is employed as the light source. Recently, FBG sensor systems employing fiber laser schemes have been the focus of a significant amount of research due to their high power output, high resolution for wavelength shift, and high optical signal-to-noise ratio (SNR) in noisy environments [1–4].

Because the homogeneous broadening of an erbium-doped fiber is dominant at room temperature,

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doi:10.1016/j.optcom.2005.03.036

it is difficult to obtain multiwavelength lasing in an erbium-doped fiber laser [5]. Therefore, multiwavelength fiber lasers employing an EDFA at room temperature have received considerable attention. For example, a technique that inserts variable attenuators into the erbium-doped fiber laser cavity for multiwavelength oscillations has been developed [2]. However, the cavity loss corresponding to each wavelength has to be balanced carefully in such techniques.

Multiwavelength oscillations in a fiber laser source that uses a semiconductor optical amplifier (SOA) has been reported [3]. An interesting technique developed recently employs two SOAs in the laser cavity to increase both the lasing bandwidth and the average output power [6]. However, SOAs have a relatively high noise figure. Addition of an extra SOA in the laser cavity decreases the optical SNR of the fiber laser. To overcome this limitation, an EDFA rather than an SOA can be inserted into the multiwavelength laser cavity to increase gain and broaden the lasing bandwidth. Moreover, the optical SNR is higher than that of the two SOA systems [7].

Erbium-doped waveguide amplifiers (EDWAs) are now very attractive for used in metro networks due to their compactness, low processing cost, and compatibility with other optical devices. Furthermore, the EDWAs have the advantage of the fundamental qualities of the EDFAs, such as a low noise figure, negligible polarization dependence, and the absence of inter-channel crosstalk. Moreover, they have potential to be integrated with pump lasers and other optical devices [8,9]. In this study, a FBG sensor system in the fiber ring laser scheme with a hybrid amplifier as gain medium is proposed. The ring cavity comprises a series of FBGs and a 25-km single mode fiber (SMF); both EDWA and SOA are employed as the gain medium. In this experiment, this multiwavelength fiber laser scheme provided a high optical SNR over 50 dB, even when FBGs were located at 25 km remote sensing points. Additionally, the peak power of each lasing wavelength was stable, even when different strains were imposed on the FBG. These features could facilitate a long-distance or large-scale fiber sensor system and could be easily extended for multipoint sensing applications.

2. Experiment and results

Fig. 1 shows the schematic diagram of the proposed long-distance FBG sensor system. The fiber ring laser comprises a hybrid amplifier with an EDWA and an SOA, a circulator (OC), a 1×2 optical coupler with a coupling ratio of 90:10 (C), a 25 km section of SMF, and a series of FBGs simultaneously acting as cavity mirrors and sensors. The lasing wavelength is derived by the sensing FBG chain. The EDWA is manufactured by Teem Photonics (France) via a two-step ion-exchange process. The EDWA driven by a 150 mA current source has a saturated output power of about 10 dBm and an amplified spontaneous emission (ASE) power of 3 mW. The SOA is manufactured by Kamelian Limited (United Kingdom). The SOA has a saturated output power of about 13.7 dBm and an ASE power of 3.4 mW. In the fiber-laser-based sensor system, the principal limitation on the maximum distance separating the sensors and number of sensors is the gain medium. To evaluate the performance of this proposed hybrid amplifier, a tunable laser and an optical spectrum analyzer (OSA) are used to measure its gain spectra. Fig. 2 shows the gain spectra of the amplifiers. Input power was set at −25 dBm. The maximum gain of the hybrid amplifier was 36.71 dB at 1532 nm. In contrast to the single EDWA or SOA, the hybrid amplifier had a higher gain. Furthermore, this hybrid amplifier can facilitate a long-distance or large-scale fiber sensor system. Moreover, for a long-distance sensor system, the light source with high output power is

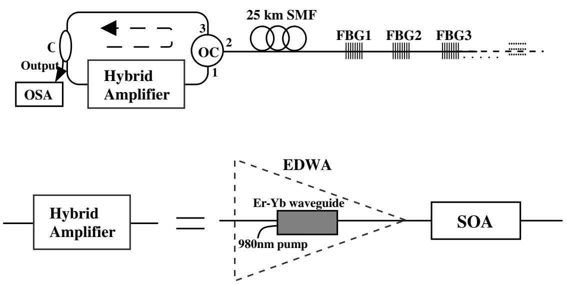

Fig. 1. Schematic diagram of the long-distance FBG sensor system: OSA, optical spectrum analyzer; C, 1×2 coupler with coupling ratio 90:10; OC, optical circulator; SMF, single mode fiber; EDWA, erbium-doped waveguide amplifier; SOA, semiconductor optical amplifier.

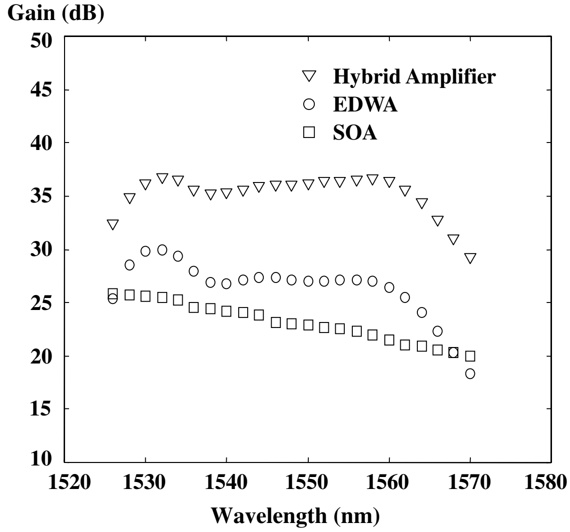

Fig. 2. Optical gain spectra of the EDWA, SOA, and hybrid amplifier with input power set at −25 dBm.

required. The ASE power of amplifiers was measured. Fig. 3 shows the ASE spectra of EDWA and hybrid amplifier. The ASE power from EDWA was only 3 mW. However, the hybrid amplifier increased ASE power from 3 to 23.2 mW.

In this experiment, three sensing FBGs were examined. These three sensing FBGs generated a triple-wavelength fiber laser for the proposed long-distance sensor system. The Bragg wavelengths of FBG1, FBG2, and FBG3 were 1552.52, 1554.47, and 1556.53 nm, respectively. The peak reflectivity for each FBG sensor was ≈99%. The 1×2 optical coupler provided 90% of the recirculating light to the output. The ASE power of hybrid amplifier at the FBG wavelengths was around −10 dBm. Under these conditions, the fiber ring laser with the proposed hybrid amplifier lased a continuous wave with three wavelengths simultaneously. Fig. 4(a) shows the output spectrum of this fiber laser. The optical SNRs provided by FBG1, FBG2, and FBG3 for the sensor system were over 50 dB, even when the three sensing

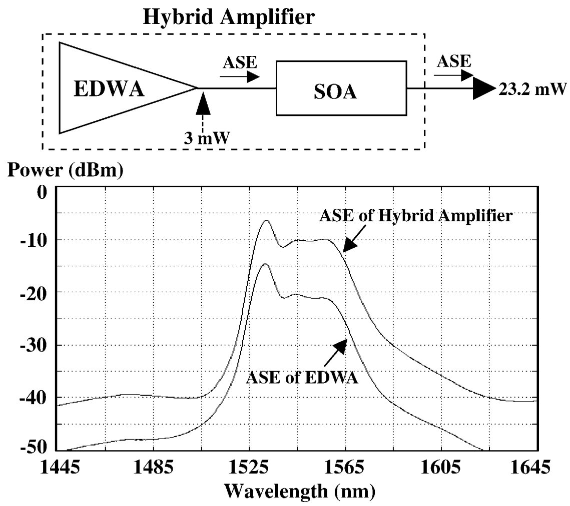

Fig. 3. ASE spectra of the EDWA and hybrid amplifier.

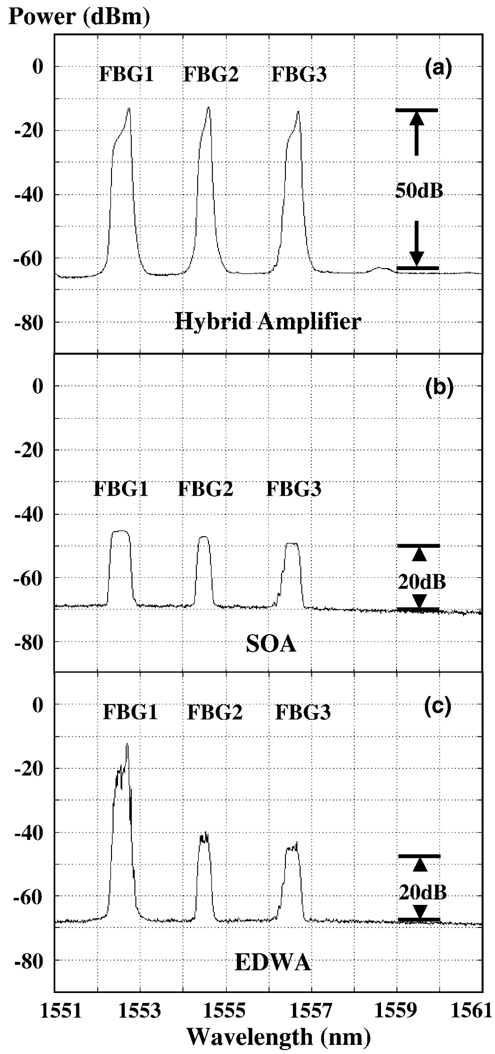

Fig. 4. Output spectra of the fiber ring laser with (a) hybrid amplifier, (b) SOA, and (c) EDWA.

locations were 25 km from the optical spectrum analyzer. The peak power of lased output at triple-wavelength was approximately −13.3 dBm.

To compare the characteristics of different gain media, experiments with only the SOA and the EDWA incorporated into the laser cavity were performed. The ASE power of SOA and EDWA at the FBG wavelengths were around −26.3 and −21.1 dBm, respectively. Fig. 4(b) shows the output spectrum of this fiber laser with only the SOA. The optical SNRs and peak power were only around 22 dB and −47.1 dBm, respectively, because the SOA did not have sufficient gain and power to generate multiwavelength oscillations. Fig. 4(c) shows the output spectrum of this fiber laser with only the EDWA. Due to the homogeneous broadening property of the EDWA, this fiber laser was only lasing one wavelength. Therefore, we employ the hybrid amplifier (EDWA + SOA) for the FBG sensor system.

Fig. 5 shows the wavelength shifts of FBG3 when different strains were imposed on it. There was no influence on the lasing wavelengths for FBG1 and FBG2 when the wavelength of FBG3 drifted. Fig. 6 shows the peak power variations of the fiber laser as a function of time. The fluctuations of the lasing peaks were less than 0.58 dB. Such a lasing output is stable and sufficiently intense for the long-distant fiber sensor system.

The wavelength operation range and maximum number of sensors for this FBG sensor system depend on the gain of hybrid amplifier and the cavity loss at different wavelengths. In the previous study [7], the hybrid amplifier can support 24 lasing wavelengths with wavelength spacing of 0.5 nm and SNR better than 42 dB. Furthermore, the maximum peak intensity fluctuation between the 24 wavelength lines was less than 1.5 dB. Therefore, the hybrid amplifier for FBG sensor systems could support 6 sensors with wavelength spacing 2 nm. The lasing wavelengths would be stable enough for sensor systems.

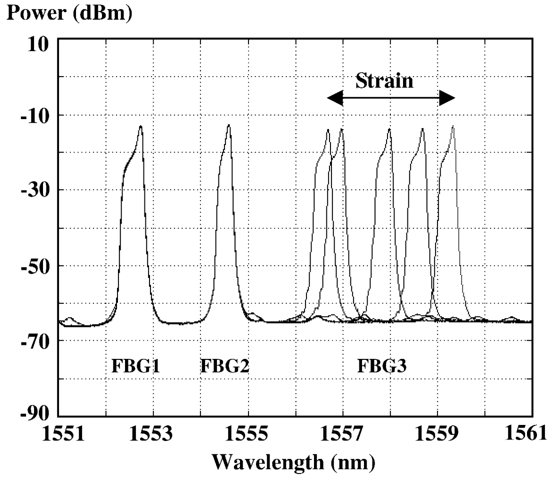

Fig. 5. Wavelength shifts of FBG3 when different strains were imposed.

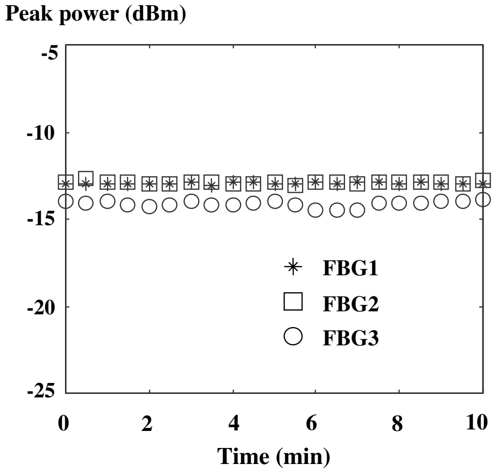

Fig. 6. Variation of peak power as a function time for each lasing wavelength.

3. Conclusion

This investigation proposed a long-distance FBG sensor system using a fiber ring laser with an EDWA and an SOA. Owing to the higher ASE power and gain spectrum, the proposed fiber laser generated multiwavelength output for multipoint sensing at a long distance. Experimental results demonstrated that the multiwavelength fiber laser generated stable and intense peak power, even when the FBGs were at a location of 25 km. Furthermore, employing EDWA made the system more compact and has potential for integrating the system into planar waveguides. The proposed fiber sensor system could be used for long-distance or large-scale smart structures.

Acknowledgments

This work was supported in part by the MediaTek Fellowship and in part by the National Science Council of ROC under Contract NSC 93-2752-E-009-009-PAE, Contract NSC 93-2219-E-007-001, and Contract NSC 93-2215-E-155-005.

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