Long-distance strain-induced-grating-based fiber sensors with erbium-based amplifiers

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Abstract. We investigate and demonstrate experimentally a two-stage erbium-based amplifier with a larger amplified-spontaneous-emission light source for a long-distance fiber sensor by using strain-induced fiber Bragg gratings in the fiber systems. In a 20-km-long fiber sensor system, the sensor has a maximal ≈2.28-nm wavelength shift under a 1500-μm/m strain.
[DOI: 10.1117/1.2746913]

Subject terms: fiber sensor; EDWA; EDFA.

Paper 060650R received Sep. 6, 2006; revised manuscript received Nov. 24, 2006; accepted for publication Dec. 3, 2006; published online Jun. 25, 2007.

1 Introduction

The fiber Bragg grating (FBG) sensor is an important passive component due to its use in multipoint sensing and high signal-to-noise ratio (SNR).[1] Spectrally broadband light sources of a light-emitting diode (LED) and erbium-doped fiber amplifier (EDFA) have been used in a passive FBG sensor system. Such FBG sensor systems based on fiber laser structures have been reported to be efficient due to their high output power and high SNR.[2,3] When a strain or a temperature variation is imposed on the FBG, the Bragg wavelength drifts and the lasing wavelength shifts.

Another simple type of fiber laser is the fiber ring laser, and its lasing wavelength also can be determined by an FBG. By inserting a fiber Fabry-Perot tunable filter (FFP TF) into the gain cavity, we can simply implement a tunable fiber laser for application to an FBG sensor system.[4,5] However, the scanning rate of the tunable filter always limits the dynamic range of a fiber laser sensor. The lasing power also determines the transmission distance of reflected light.

In this paper, we report investigating and demonstrating experimentally a two-stage erbium-based amplifier with a larger amplified spontaneous emission (ASE) light source for long-distance strain-induced-grating sensors using FBGs.

0091-3286/2007/$25.00

2 Fiber Sensor Experiment

Figure 1 shows the experimental setup of the proposed 20-km-long multiplexed FBG-based sensor system and erbium-based fiber ring laser configuration. The proposed architecture is composed of a two-stage erbium-based amplifier, an FFP TF, a 2×2 optical coupler (OCP), and seven FBGs with different central wavelengths. The proposed fiber sensor monitoring system (MS) is shown in the outer dashed box in Fig. 1. The central wavelengths of FGB_1 to FBG_7 are 1534.6, 1539.6, 1548.3, 1552.6, 1556.1, 1557.9, and 1562.2 nm at room temperature, respectively. The reflectivity and 3-dB bandwidth of those FBGs are nearly 90% and 0.4 nm.

The FFP TF is an all-fiber device having a widely tunable range, low insertion loss (<0.5 dB), and low polarization-dependent loss (PDL) of ≈0.1 dB. This filter, having a free spectral range (FSR) of 44 nm and a 3-dB bandwidth of 0.4 nm, can provide wavelength selection in the ring laser cavity on applying external voltage (<12 V) to the piezoelectric transducer (PZT) of the FFP filter. The optical outputs are observed by an optical spectrum analyzer (OSA) with 0.05-nm resolution.

The proposed two-stage erbium-based fiber amplifier, which consists of an erbium-doped waveguide amplifier (EDWA) and a cascaded (EDFA), is also shown in Fig. 1. The first stage is the EDWA and the second is the EDFA. The EDWA, which is manufactured via a two-step ion-exchange process, has the advantage of inheriting the known properties of the EDFA, such as low noise figure, slight polarization dependence, and no crosstalk between

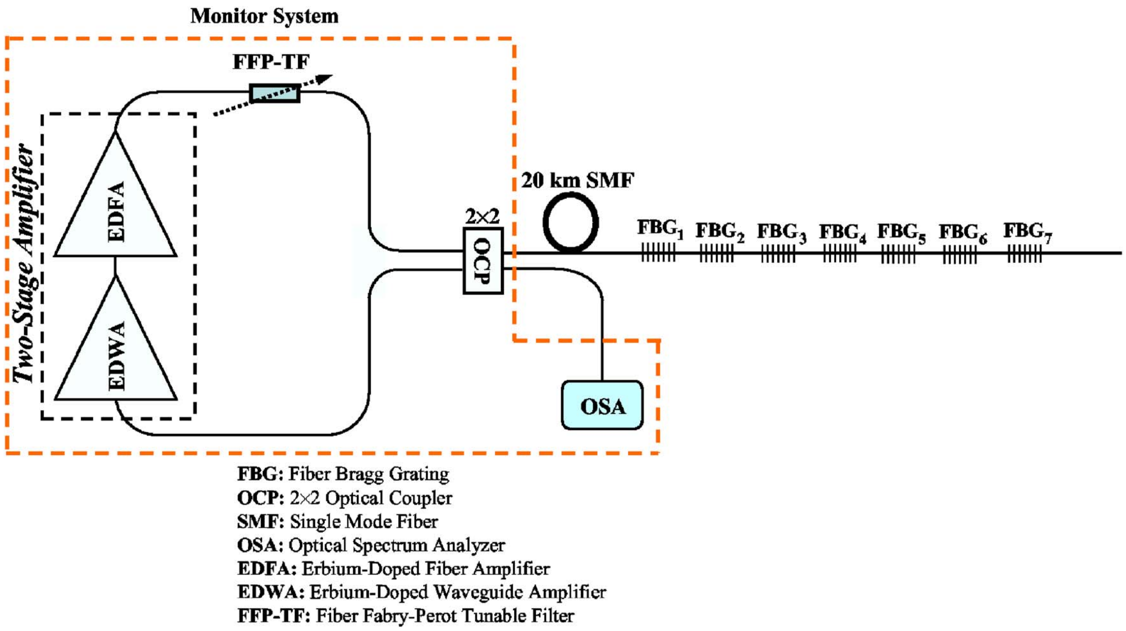

Fig. 1 Experimental setup of the proposed 20-km-long multiplexed FBG-based sensor system and erbium-based fiber ring laser configuration.

wavelength-division multiplexing (WDM) channels. All optical performance is measured when the laser pump diode current equals 440 mA at ambient temperature. The second EDFA stage consists of a 10-m-long EDF length, a 980-nm pump laser, a 980 to 1550-nm WDM coupler, and an optical isolator (OIS). The pump power of the 980-nm laser is 10 mW. Figure 2 shows the ASE spectra of the EDWA, EDFA, and two-stage amplifier, respectively. The retrieved ASE of the two-stage amplifier has a higher and flatter power level than the EDWA and EDFA used. The flatter ASE is due to the gain saturation effect. Based on the proposed ASE source and fiber laser scheme, the lasing lightwave can be transmitted in a long-distance single-mode fiber (SMF) for a fiber sensor.

The proposed fiber laser configuration containing the two-stage erbium-doped gain section is a loop reflector which operates in a unidirectional manner due to the inclusion of an isolator. The other cavity reflection point is provided by one of a series of FBG elements at different nominal wavelengths. The FBG elements serve as the sensors and can be connected as part of the cavity via a single-mode fiber link 20 km long. Because of the inclusion of the wavelength filter within the loop reflector, lasing of the system occurs only when the filter transmission passband is aligned in wavelength with one of the Bragg elements. The scanning speed of FFP TF is about 200 ms, and the scanning wavelength range is 44 nm over C band in this experiment. That is to say, the wavelength ranges of FBGs are required to be within the operating range. Furthermore, to obtain a larger scanning sensor range, one needs a broadband light source and a larger FSR of the FFP TF in the sensor system.

Figure 3 shows the optical output spectra of the sensor system for the case where the FFP TF is tuned to sequentially address each FBG. As can be seen, the fiber ring laser is forced to lase at a series of wavelengths, as determined by each central wavelength of the FBG. The SNRs of the seven lasing wavelengths are larger than 40 dB. From Fig. 3, the output powers of the seven lasing wavelengths are larger than 7.4 dBm, and their power variation of is below 0.5 dB. Thus, the proposed grating sensor system can obtain larger reflected power and smaller power variation.

When external strain is applied to one FBG, the lasing central wavelength will shift. In the strain measurement, the tuning voltage of the FFP TF was manually adjusted to optimize the output power, and it tracked the FBG wavelength shift. In the experiment, we use applied strains from 0 to 1500 μm/m. Therefore, Fig. 3 also shows the lasing wavelength spectra observed at the output port when the maximal strain (1500 μm/m) was applied to the FBG_2

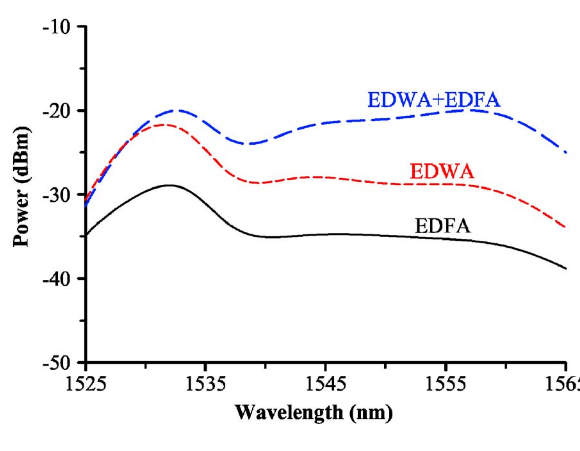

Fig. 2 ASE spectra of the EDWA, the EDFA, and the proposed two-stage amplifier. (The pumping current of the EDWA is 440 mA, and the EDFA operates at 10-mW pumping power with a 10-m-long EDF.)

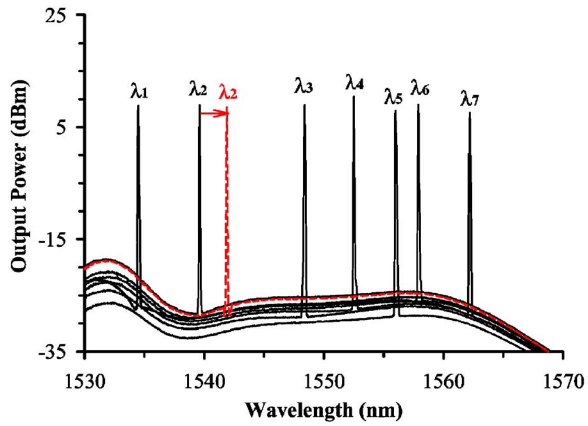

Fig. 3 Optical output spectra of the sensor system for the case where the FFP TF is tuned to sequentially address each FBG. The dashed line shows the wavelength shift of FGB_2 when the external strain is applied. (FBG_1 to FBG_7 are at 1534.6, 1539.6, 1548.3, 1552.6, 1556.1, 1557.9, and 1562.2 nm, respectively, at room temperature.)

(dashed line in Fig. 3). The shift of the reflected wavelength is nearly 2.28 nm when the maximum strain is applied to the FBG.

3 Conclusion

In summary, we have investigated and demonstrated experimentally a two-stage erbium-based amplifier with a larger amplified spontaneous emission light source for a long-distance fiber sensor by using strain-induced fiber Bragg gratings in the proposed fiber systems. In a 20-km-long fiber sensor system, the strain-induced fiber sensor has a maximal ≈2.28-nm wavelength shift under a 1500-μm/m strain.

Acknowledgment

This work was supported in part by the National Science Council (NSC) of Taiwan (ROC) under grants NSC 95-2221-E-155-059 and NSC 95-2221-E-155-072.

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