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A Novel Long Distance Fiber Bragg Grating Sensor System with Low Threshold Pump Power and High OSNR

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Abstract. We propose a novel fiber Bragg grating (FBG) sensor system with low pump power and high optical signal to noise ratio (OSNR). This sensor system is based on a distributed Raman fiber amplifier and an Erbium doped fiber laser (EDFL). The EDFL cavity is composed by an FBG and a fiber loop mirror which decrease the laser threshold obviously. By recycling the residual Raman pump power as the EDFL pump, the overall system configuration was significantly simplified without any additional light source. The experiment results show that only 140mW of 1470nm Raman pump power can provide a stable output power with an optical signal-to-noise ratio over 50dB even if the FBG is located at a 50km remote sensing position.

Keywords: Long distance FBG sensor system, Raman fiber amplifier, Erbium dope fiber laser, OSNR.

1. Introduction

The Fiber Bragg grating (FBG) technology has attracted much interest in the field of optical sensors since the sensor based on FBG can provide the most simple ways to monitor a variety of external perturbations for example, temperature, strain, and pressure due to its high sensitivity, electro-magnetic immunity, compactness, and ease of fabrication [1-4]. A number of practical FBG based sensor systems have been implemented and demonstrated. In such FBG based sensing systems, one practical issue is to increase the transmission distance because their maximum transmission distance with a broadband light source is limited to 25 km mainly due to Rayleigh scattering induced optical noise as well as background signal loss with the transmission fiber. In order to increase the transmission distance, several novel methods based on Raman amplification have been suggested. For example, Y. Nakajima et al. proposed a novel method of the use of distributed Raman amplification in the signal transmission fiber to increase the sensing signal transmission distance over 50 km in a passive FBG sensor system [5]. However, the requirement of two separate light sources of a broadband light source and a Raman pump could be a limiting factor due to its higher cost. P.-C. Peng et al. proposed an advanced method of the use of the linear cavity Raman laser configuration based on a FBG and fiber loop mirror for a long-distance strain sensing system [6]. Although the use of Raman laser configuration eliminates the requirement of an additional broadband light source and improves the sensing signal quality, but about more than 250 mW threshold pump power is often need this will take higher system cost.

In this paper, we demonstrate a novel and simple, Raman amplifier plus Erbium doped fiber laser (EDFL)-based long-distance sensing system. Our proposed sensing system has only one pump source for distributed Raman amplification and EDFL in the transmission fiber without any additional broadband light source and the residual pump power after the transmission fiber is recycled for the erbium-doped fiber. Using the proposed scheme, we obtain a remote sensing operation of temperature measurement at a location of 50 km and deliver the sensing signals through the transmission fiber with distributed Raman amplification. High quality of sensing signals with a ~50dB OSNR is readily achieved even after the 50 km transmission when the Raman pump power is 140mW.

2. Experimental Setup

Fig.1 shows the experimental setup for the proposed long-distance remote sensing system. A 1470-nm Raman pump with rated power of 250 mW is chosen due to its high absorption. The pump power could be launched into a 50 km long standard single mode fiber (SMF) with ~ 0.2 dB/km attenuation via a 1550/1470 nm WDM coupler. Then, the residual pump power after the SMF was launched into a 7 m long EDF via two 1550/1470 nm WDM couplers. The residual Raman pump was reused as a pump source for pumping the 7 m EDF. The peak absorption coefficient of the EDF at 1530 nm was 6 dB/m. A fiber loop mirror acting as one of the cavity mirror with a wide band reflective spectrum and high reflectivity. The fiber loop mirror is composed by a 3 dB coupler. The other cavity mirror is a FBG. We used the UV beam scanning method with a phase mask to fabricate the FBG in boron (B)-Germanium (Ge) codoped silica based photosensitive fiber. The center wavelength of the FBG with a 0.2 nm spectral width was 1550.2nm and its measured reflectivity was ~85 %.

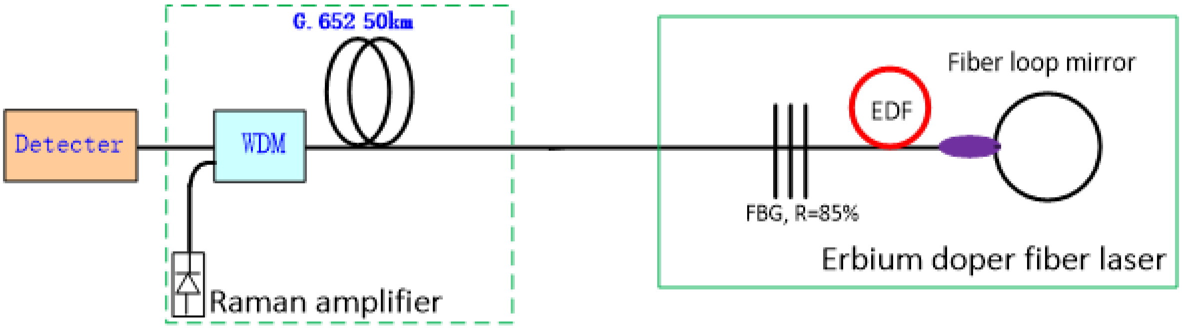


Fig.1 Experimental setup for Raman amplifier plus EDFL-based long-distance remote sensor system

3. Experiment Results and Discussion

The FBG was placed into a temperature heating oven for temperature sensitivity measurement. The temperature-heating oven used in this experiment has a temperature tuning range between -40 ℃ and 100 ℃ and good temperature stability. Resolution of the sensor system was detected by the OSA with resolution of 0.01 nm. Fig.2 shows the spectrum of the OSA detected. Curve (a) is the detected signal when the Raman pump power is 75mW and the residual pump power after the transmission fiber (EDFL pump power) is 5.25mW. We can see there is only ASE source. When the Raman pump power is increased the residual pump power is increased. When the residual Raman pump power is equal to the EDFL threshold (about 5.42mW), the EDFL begin to lase which showed in curve (b). Curve (c) show the laser signal when the pump power is 85mW and the residual power is 5.7mW. But we can see the OSNR is still very small. When the Raman pump power is reached 140mW and the residual EDFL pump power is 10.9 mW, the detected signal OSNR is nearly 50dB, which was shown in Fig.3.

Fig.4 shows the detected laser signal spectrum stability at room temperature. The spectrum is swept every one minute. We can see that the signal is very stable. The signal peak is kept at 1550.178nm. The fluctuation of the output signal peak power less than 0.2dB can be obtained during 16 minutes sweeping time.

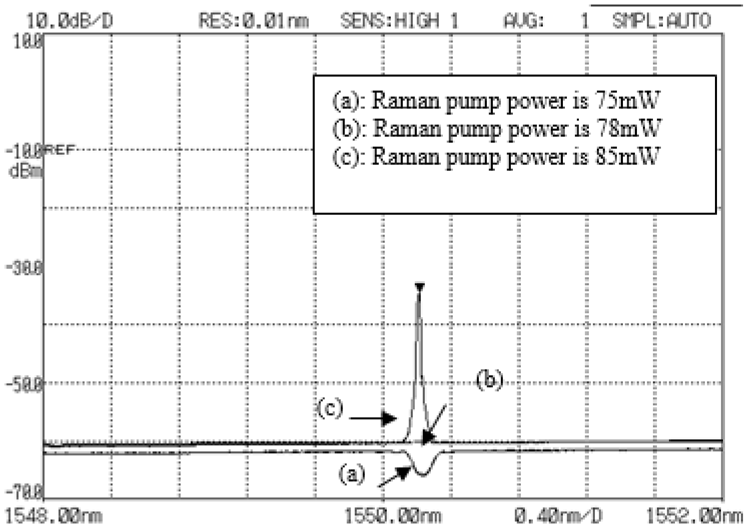


Fig.2 Detected signal power around threshold.

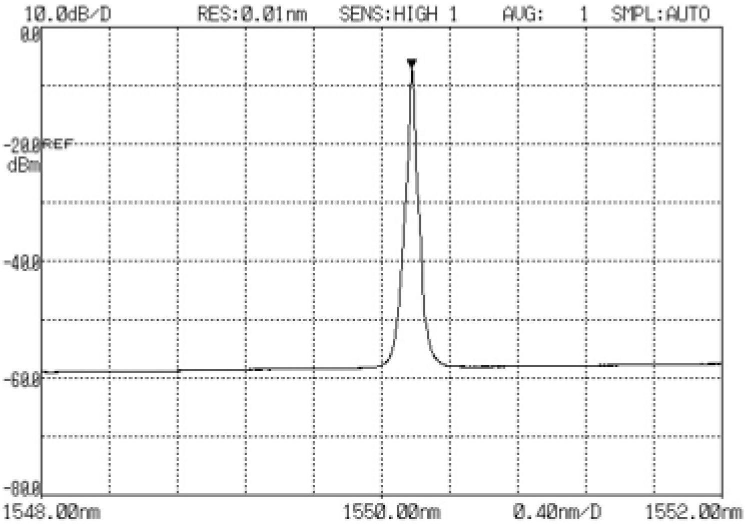


Fig.3 Laser spectrum when the Raman pump power is 140mW at room temperature (OSNR=50dB)

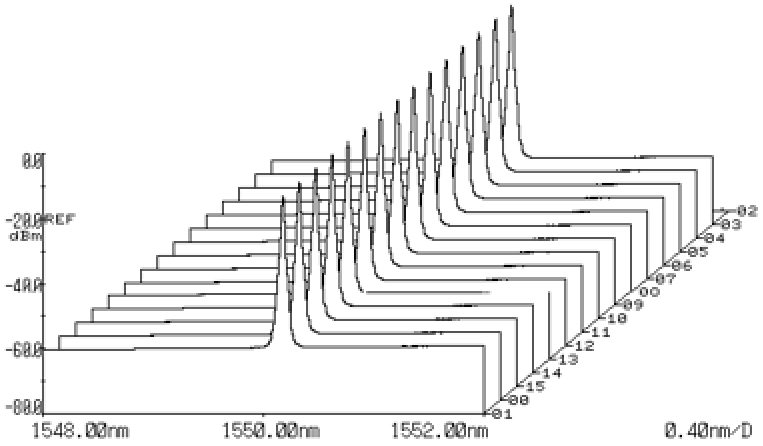
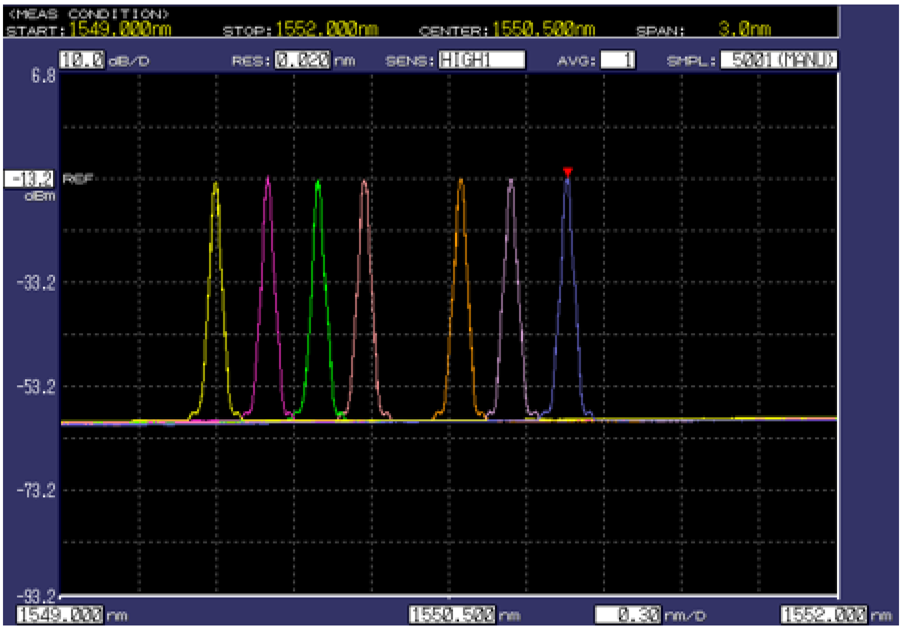


Fig.4 The output laser signal spectrum stability (16minutes)



<MEAS CONDITION>
START:1549.000nm STOP:1552.000nm CENTER:1550.500nm SPAN: 3.0nm
10.0 dB/D RES:0.020 nm SENS:HIGH1 AVG: 1 SMPL: 5001(MANU)

Fig.5 Laser wavelength shifts from -40 °C to 100 °C

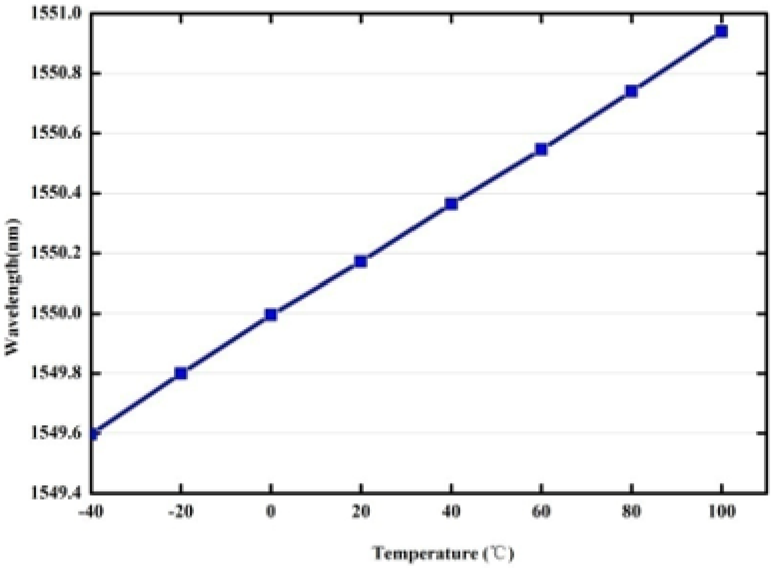


Fig.6 Laser centre wavelength as a function of Temperature

Fig.5 shows the wavelength shifts of FBG when the oven temperature is changed from -40 °C to 100 °C. We can see that the signal wavelength shift from 1549.6nm to 1550.94nm. And the signal has high OSNR over 45 dB. And the output power is very stable.

Fig.6 illustrates the wavelength as a function of the temperature. The FBG temperature is from -40°C to 100°C, the wavelength is changed from 1549.6nm to 1550.94nm. The laser wavelength and FBG temperature shows a good linear relationship. And the temperature sensitivity is 9.571pm /°C.Our experiment has shown that our system has good repeatability.

We also investigate the relationship between signal peak power and Raman pump power. The result is shown in Fig.7. We can see that the signal peak power is increased with Raman pump power. When the Raman pump power is increased from 80mW to 250 mW, the signal power is increased from very small power to 0.15mW. At the same time, the signal SNR value increased rapidly with Raman pump power when the pump power increased from 80 to 100mW. When pump is 100mW, the SNR is already nearly 40dB high. But after 100mW, SNR increased very slowly.

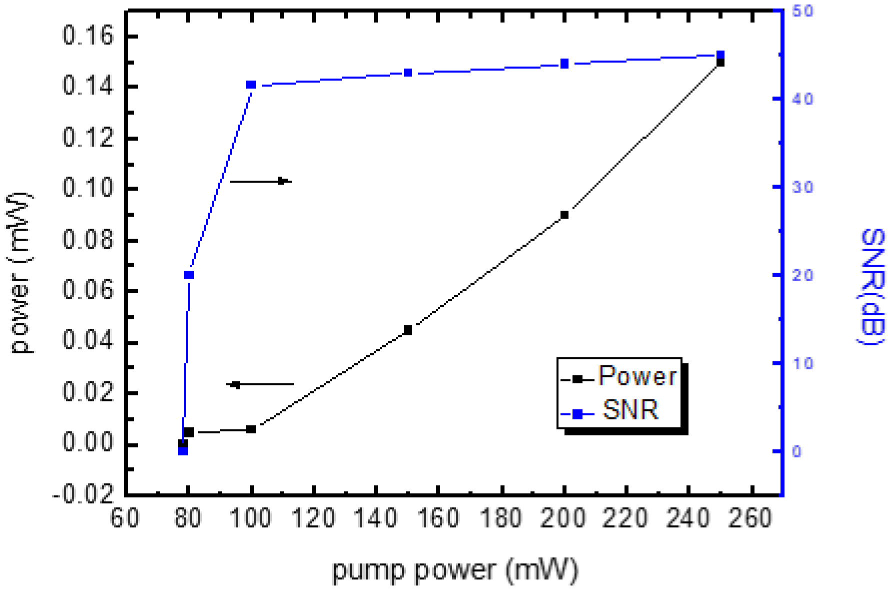


Fig.7 Detected signal peak power/SNR VS.Raman pump power

4. Summary

A long distance FBG sensor system using Raman amplifier and a linear-cavity Erbium doped fiber laser scheme has been proposed. Our proposed sensing system has only one pump source for distributed Raman amplification and EDFL in the transmission fiber without any additional broadband light source and the residual pump power after the transmission fiber is recycled for the erbium-doped fiber. Experiment results show a detected signal with stable and intense peak power even if the FBG was located at a 50-km far sensing position. With the help of fiber loop mirror, the EDFL laser has very small threshold 5.42mW corresponding to 78mW Raman pump power. Also high optical SNR of 50 dB is obtained with only 140mW Raman pump power and corresponding 10.9 mW residual power for EDFL. The proposed FBG sensor system can be used for long-haul structure.

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