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Semiconductor Optical Amplifier-Based Laser with 25 km Long Cavity Length Utilizing Sagnac Fiber Ring Structure[1]

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Abstract—In the investigation, we propose and demonstrate a Sagnac ring based fiber laser structure using a semiconductor optical amplifier (SOA) to act as a gain medium with short to long fiber cavity lengths for wavelength lasing and tuning. Here, ten fiber Bragg gratings (FBGs) with different reflected Bragg wavelengths are used serving as the reflected element in the proposed laser configuration for wavelength lasing and remote sensing simultaneously. Furthermore, the different cavity fiber lengths of a few ten m to 25 km, which are used in the proposed laser scheme, has been analyzed and discussed.

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1. INTRODUCTION

Erbium-doped fiber (EDF) ring lasers with single- and multi-wavelength output simultaneously have considerable interest in the wavelength division multiplexing (WDM) communications and optics sensor applications [1–3]. And so, the long cavity fiber ring laser with ultra high energy pulsed and low repetition rates can be widely applied in micromachining, material processing, remote sensing and light detecting system [4–7]. Furthermore, to achieve the single-longitudinal-mode (SLM) and stable output performances in fiber-based ring lasers, the cavity loss design, double-pass scheme, and mode-locked pulse design have been also investigated and discussed [8–12].

Here, in order to achieve the fiber ring laser with longer cavity, the Raman amplifier (RA)-based, hybrid RA and erbium-doped fiber amplifier (EDFA)-based or hybrid EDFA and semiconductor optical amplifier (SOA)-based fiber lasers have been proposed and investigated [13–15]. However, these proposed amplifier-based fiber lasers have the higher cost and energy consumption in long-cavity laser area.

In this paper, we propose and demonstrate experimentally a Sagnac loop based SOA fiber ring laser configuration, which has a long cavity length for wavelength lasing; together with energy-efficient. Here, ten fiber Bragg gratings (FBGs) are employed serving as reflected element in remote site for wavelength lasing and remote sensing simultaneously, in the operating range of 1530 to 1560 nm. In the experiment, the different cavity lengths of a few ten m to 25 km long are also used in the proposed laser scheme for lasing and tuning due to the Sagnac loop structure. Therefore, this proposed fiber laser scheme not only can use a 25 km long fiber cavity, but also has the energy-efficient via the Saganc design.

2. EXPERIMENT AND RESULTS

Figure 1 presents the experimental setup of proposed Sagnac loop fiber laser configuration with the cavity lengths of a few ten to 25 km for wavelength lasing and sensor detecting simultaneously. This proposed laser constructed by an semiconductor optical amplifier (SOA), a 2 × 2 and 50 : 50 optical coupler (CP), a tunable bandpass filter (TBF), a length of single-mode fiber (SMF), a polarization controller (PC) and ten fiber Bragg gratings (FBGs). As seen in Fig. 1, the 2 × 2 CP could be produced a Sagnac loop laser scheme, and the SOA, TBF, and PC were used inside Sagnac loop. The cavity length of Sagnac loop (L_1) is nearly 8 m long and the external cavity length (L_2) of single-mode fiber (SMF) is among 0 to 25 km long, as illustrated in Fig. 1. Here, the C-band SOA is only operated at 150 mA pumping current. In the measurement, the output wavelength and power are measured by the optical spectrum analyzer (OSA) with a 0.05 nm resolution and power meter (PM), respectively.

In this experiment, the reflected Bragg wavelengths and peak reflectivities of ten FBGs used are 1531.80, 1535.93, 1537.33, 1538.33, 1542.35, 1543.40, 1544.38, 1547.98, 1554.48, and 1559.55 nm, and 81.7, 86.8, 87.3, 87.3, 88.1, 88.5, 87.4, 86.73, 88.4, and 87.8%, respectively. The ten FBGs are cascaded in remote site to connect to Sagnac loop as seen in Fig. 1. And the interval of each FBG is nearly 2 m long. Furthermore, the tuning range and 3 dB bandwidth of

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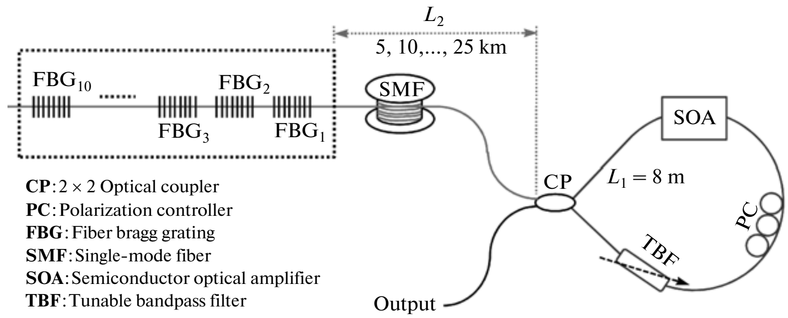

Fig. 1. Experimental setup of proposed Sagnac loop fiber laser configuration with the cavity lengths of a few ten to 25 km for wavelength lasing and sensor detecting simultaneously.

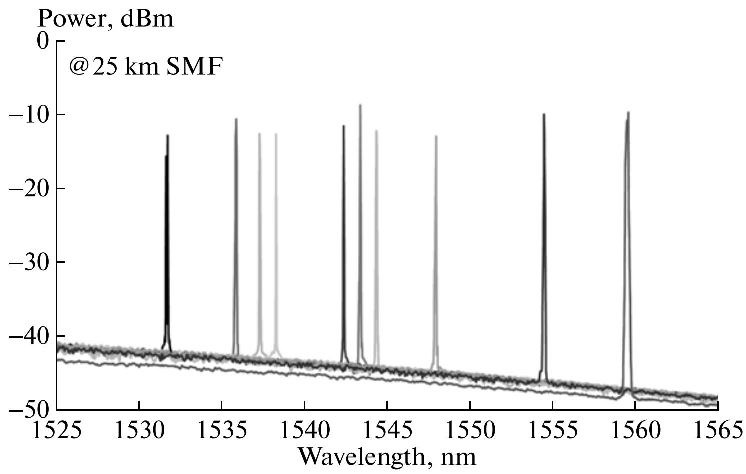

Fig. 2. Output spectra of ten lasing wavelengths via the FBGs in the proposed Sagnac loop fiber laser structure.

TBF are 30 nm (1530–1560 nm) and 0.4 nm respectively. And the TBF is tuned to align and match the corresponding reflected Bragg wavelength of each FBG used for wavelength lasing. Here, the PC is used to adjust the polarization status and maintain the maximum output power for this Sagnac loop laser.

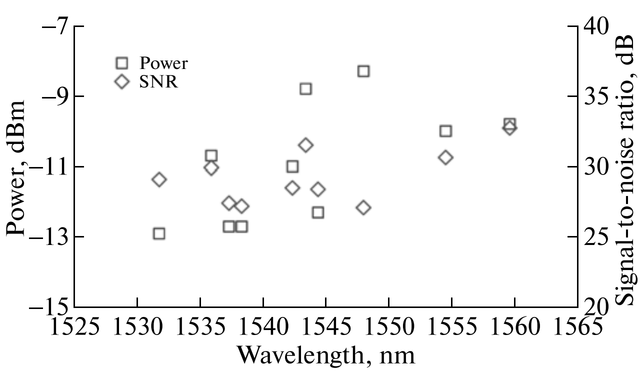

Fig. 3. Output powers and signal-to noise ratios (SNRs) of the ten lasing wavelengths in the proposed laser scheme.

In the measurement, first we set the SMF length L_2 is 25 km long in the proposed fiber laser configuration. Figure 2 shows the output spectra of ten lasing wavelengths via the FBGs in the proposed Sagnac loop fiber laser structure. And, we can observe the higher amplified spontaneous emission (ASE) spectrum of the proposed laser is around in the shorter wavelength range. Besides, the ASE noise can be suppressed are better, when the lasing wavelength is tuned in the higher wavelength gradually, as also shown in Fig. 2. The different peak power can be observed in Fig. 2 due to the various reflected Bragg wavelength of each FBG and gain distribution of SOA.

Hence, Fig. 3 presents the output powers and signal-to noise ratios (SNRs) of the ten lasing wavelengths in the proposed laser scheme. The measured powers and SNRs of ten lasing wavelengths are –12.9, –10.7, –12.7, –12.7, –11.0, –8.8, –12.3, –8.3, –10.0, and –9.8 dBm and 29.10, 29.90, 27.42, 27.20, 28.50, 31.50, 28.40, 27.10, 30.62, and 32.72 dB,

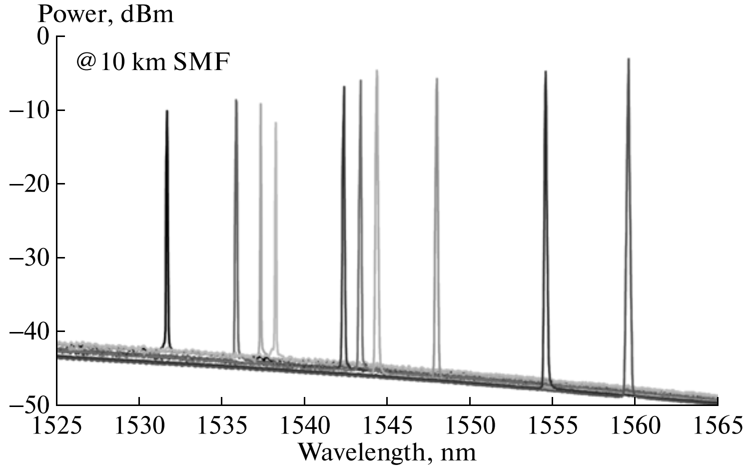

Fig. 4. Output spectra of ten lasing wavelengths via the corresponding reflected wavelength of FBGs in the proposed fiber laser structure.

respectively, at the wavelengths of 1531.80, 1535.91, 1537.31, 1538.30, 1542.32, 1543.38, 1544.35, 1547.95, 1554.46, and 1559.52 nm. Moreover, the maximum output power difference and SNR variation of 4.6 and 5.6 dB are observed in this measurement.

Then, we set the SMF length L_2 to 10 km long in the proposed laser scheme as seen in Fig. 1. So, Fig. 4 shows the output spectra of ten lasing wavelengths via the corresponding reflected wavelength of FBGs in the proposed fiber laser structure. The ASE background noise of the proposed laser, which can be more suppressed, is better when the lasing wavelength is tuned at the higher wavelength, as also shown in Fig. 4. Moreover, the different output power is also observed in Fig. 4 because of the various reflected Bragg wavelength of each FBG and gain distribution. Hence, the measured powers and SNRs of ten lasing wavelengths are −10.2, −8.7, −9.2, −11.8, −6.9, −6.1, −4.7, −5.9, −4.9, and −3.2 dBm and 32.32, 35.71, 34.21, 31.74, 38.64, 39.53, 40.92, 40.54, 42.6, and 45.43, respectively, at the wavelengths of 1531.80, 1535.91, 1537.31, 1538.30, 1542.32, 1543.38, 1544.35, 1547.95, 1554.46, and 1559.52 nm. Moreover, the maximum output power difference and SNR variation of 8.6 and 13.1 dB are observed in this measurement. As a result, the measured output powers and SNRs of Fig. 4 are larger and better than that of Fig. 2, due to the smaller cavity loss in the proposed fiber laser scheme.

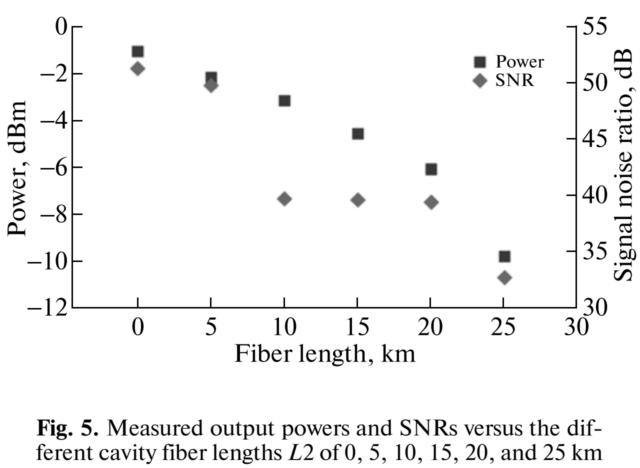

Fig. 5. Measured output powers and SNRs versus the different cavity fiber lengths $L2$ of 0, 5, 10, 15, 20, and 25 km long using in the proposed laser structure, respectively, at the lasing wavelength of 1559.52 nm.

Next, Fig. 5 shows the measured output powers and SNRs versus the different cavity fiber lengths L_2 of 0, 5, 10, 15, 20, and 25 km long using in the proposed laser structure, respectively, at the lasing wavelength of 1559.52 nm. While the L_2 is 0 and 25 km long, the obtained output powers and SNRs are −1.1 dBm and 51.2 dB, and −9.8 dBm and 32.72 dB, respectively. As illustrated in Fig. 5, with the fiber length L_2 is increase gradually, the obtained output power and SNR are also increase. However, when the lengths of L_2 are 10, 15, and 20 km long, respectively, the observed SNRs are almost the same.

As we know, the FBG can be used to act as a sensor for the temperature and strain sensing due to its high sensitivity [16–19]. In our proposed laser scheme, each FBG would be also employed to serve as remote sensor in the remote site. To verify and ensure the FBG sensor in the proposed laser, a strain is applied on the FBG_{10}, which reflected wavelength is 1559.52 initially. When we apply the strain of 2000 με in FBG_{10}, the corresponding wavelength shift is measured around 2.8 nm, as shown in Fig. 6. As a result, the ten FBGs also can be employed to sense the temperature and strain changes in remote site for the proposed fiber laser.

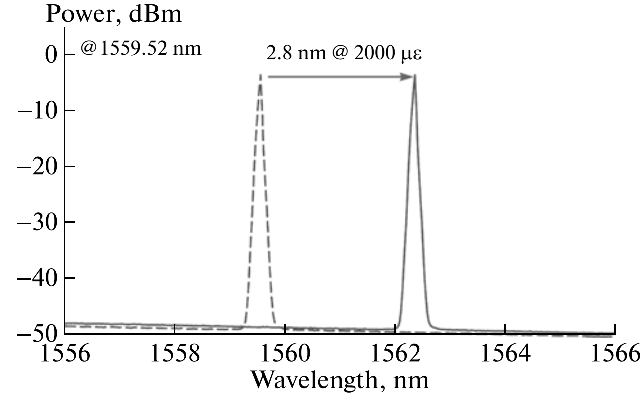

Fig. 6. Output spectrum of the proposed laser scheme, when the strain of 2000 με is applied on FBG_{10}.

3. CONCLUSIONS

In summary, we have proposed and demonstrated a Saganc ring based fiber laser structure using a SOA to act as a gain medium with short to long fiber cavity lengths for wavelength lasing and tuning. Here, ten FBGs with different reflected Bragg wavelengths are used serving as the reflected element in the proposed laser configuration for wavelength lasing and remote sensing simultaneously. Besides, the different cavity fiber lengths of a few ten m to 25 km, which are used in the proposed laser scheme, has been analyzed and discussed. Here, we don't require the nonlinear effect and high power consumption to achieve the long cavity length of fiber ring laser scheme. We just use the simple Sagnac architecture design to accomplish the 25 km cavity length. Therefore, this proposed fiber laser scheme not only can use a 25 km long fiber cavity, but also has the energy-efficient via the Sagnac design.

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