

Broadband C-plus L-band CW wavelength-tunable fiber laser based on hybrid EDFA and SOA

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ABSTRACT

In this demonstration, we propose and experimentally investigate a widely C + L band wavelength-tunable fiber ring laser in continuous-wave (CW) tuning based on a hybrid semiconductor optical amplifier (SOA) and erbium-doped fiber amplifier (EDFA) in a serial scheme. When a hybrid first-stage SOA and second-stage EDFA is used inside ring cavity, the effectively amplification range can be extended from C-band to L-band. Here, the proposed laser features wide wavelength-tuning range, high output power, and high side-mode suppression ratio (SMSR). In addition, a tunable range over 91.5 nm (from 1518.5 to 1610.0 nm) has been achieved.

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1. Introduction

Recently, broadband wavelength-tunable fiber lasers play the key role in the related applications of optical device testing, wavelength-division-multiplexing (WDM) communication, and fiber sensor system [1,2]. In general, the fiber Fabry–Perot filter (FFPF), tunable bandpass filter (TBF), and fiber Bragg grating (FBG) could be used in the fiber ring cavity for wavelength lasing and tuning, when the erbium-doped fiber amplifier (EDFA), Raman amplifier (RA), semiconductor optical amplifier (SOA) and hybrid optical amplifier were used inside cavity acting as gain medium [3–6]. However, the RA or hybrid RA/EDFA, requiring the higher pumping power lasers, has proposed to achieve broadband gain amplification [7]. And these amplifiers could be utilized inside a fiber cavity for widely wavelength-tuning operation [8]. Besides, using C- plus L-band EDFA module in parallel and cascade structures have also been investigated [9–12]. As mentioned above, these broadband amplifiers could be also employed inside fiber ring cavity to serve as gain medium for widely wavelength tuning [13,14].

In this paper, we investigate a widely CW tuning fiber ring laser in C + L band window based on hybrid fiber amplifier, including the C-band SOA and EDFA with a 3 m EDF, in a serial configuration. Here, a 91.5 nm wavelength range (1518.5–1610.0 nm) can be

achieved by the proposed fiber ring laser when the TBF is utilized inside gain cavity. The output power and side-mode suppression ratio (SMSR) of proposed laser are measured between -14.2 and 5.9 dBm and 44.3 and 62.5 dB/0.01 nm, respectively. Moreover, the flattened power output of -5.0 ± 0.1 dBm also can be obtained for the proposed fiber laser in the wavelengths of 1518.5–1604.1 nm, when the driving currents of 163–209 mA is needed to adaptively adjust.

2. Experiment setup

Fig. 1 presents the experimental setup of CW tuning fiber ring laser scheme covering both C- and L-bands. The proposed fiber ring laser is consisted of a hybrid fiber amplifier, a polarization controller (PC), a TBF including a C- and L-band type, and a 1×2 and $10:90$ optical coupler (CP). The hybrid two-stage amplifier in cascade is constructed by a C-band SOA, a 3 m long erbium-doped fiber (EDF), a 980 nm pumping laser diode (LD), and a 980/1550 nm WDM coupler (WCP) and an optical isolator (ISO), as shown in Fig. 1. Here, the ISO of proposed ring laser is utilized to produce a clockwise propagation. And the lasing wavelength can be observed at the 10% port of CP. The PC is utilized to maintain the polarization state and obtain maximum output power. In the experiment, we employ the intracavity C- and L-band TBFs with tuning ranges of 1520–1560 nm and 1560–1610 nm for lasing and tuning wavelength, respectively. And, their insertion loss and 3 dB bandwidth both are 5.0 dB and 0.4 nm. In the measurement,

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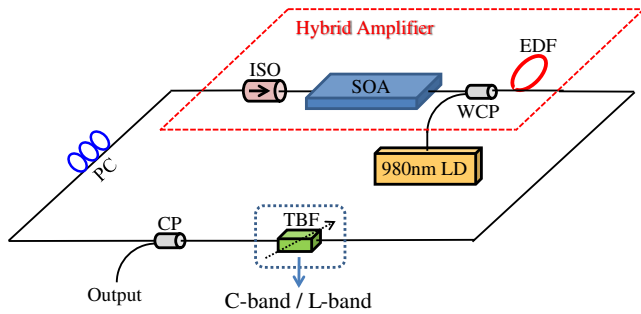


Fig. 1. Experimental setup of CW tuning fiber ring laser scheme covering both C- and L-bands.

the driving current of SOA and pumping power of 980 nm LD are set at 200 mA and 25 mW respectively. And, the output wavelength and power can be measured by an optical spectrum analyzer (OSA) with a 0.01 nm resolution and a power meter (PM) respectively.

To realize the characteristics of proposed hybrid amplifier scheme, first we measure the output amplified spontaneous emission (ASE) spectrum of SOA under different driving currents from 80 to 200 mA. And the threshold and maximum current of SOA is 40 and 230 mA respectively. Thus, Fig. 2 shows the output ASE spectrum of SOA at the driving current of 80, 140, and 200 mA respectively. Here, the maximum power of ASE spectrum is measured at -37.6 , -30.4 and -26.7 dBm/0.01 nm at the wavelength of 1501.4, 1476.6 and 1477.0 nm, respectively, at the three driving currents. And, the measured ASE ranges are 1451.0–1525.8 nm (~ 74.8 nm) and 1435.3 to 1533.3 nm (~ 98.0 nm) at the driving powers of 140 and 200 mA respectively, when the power level is larger than -35 dBm/0.01 nm. Moreover, as the driving current increases gradually, the measured ASE peak also shifts to shorter wavelengths. Then, we can utilize a first-stage SOA to cascade the second-stage EDFA for generating widely ASE source, as illustrated in Fig. 1. Hence, Fig. 2 also shows the output ASE profile (red line) of proposed hybrid fiber amplifier, when the driving current of SOA is 200 mA and the 980 nm pumping power of EDFA is 25 mW. Fig. 2 shows the combined output optical spectrum of the proposed laser. The “light peak” is due to the maximum ASE output of the second-stage EDFA. Moreover, comparing with the original SOA, the observed ASE of hybrid amplifier can extend to longer wavelength, as seen in Fig. 2. And its ASE range of 1446.2–1560.0 nm (~ 113.8 nm) can also be retrieved, while the power intensity is larger than -35.0 dBm. When the 980 nm pumping power of second-stage EDFA is over 25 mW, we observed that the output power of the hybrid amplifier remains the same

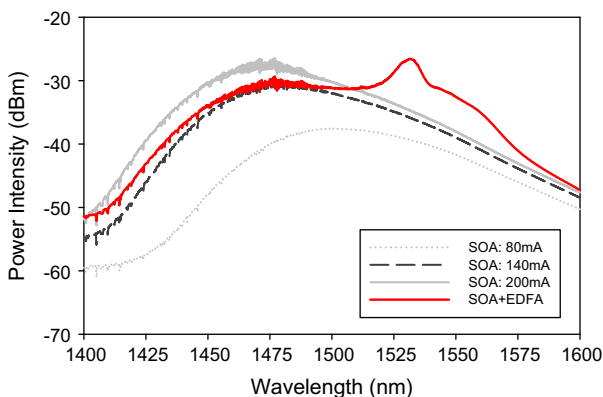


Fig. 2. Output ASE spectrum of SOA at the driving current of 80, 140, and 200 mA respectively. And red line is the ASE profile of proposed hybrid amplifier.

due to the gain saturation effect. Hence 25 mW pumping power is used. When cascading the EDFA with the SOA (biased at 200 mA), the measured ASE profile of hybrid amplifier around 1477 nm is lower than that of using a single SOA (in Fig. 2). This is because the gain of the EDFA is around 1530 nm; the reduction of ASE profile of hybrid amplifier around 1477 nm is due to the power absorption by the EDFA. Here, the measured ASE peak of the SOA shifts to shorter wavelength when the bias current increases. This is because when the carrier density inside the SOA increases, carriers will occupy higher energy states in the conduction band. As a result, the emitted photon will have higher optical frequency, thus shorter wavelength [15].

Then, we execute the proposed broadband fiber ring laser utilizing the hybrid amplifier to serve gain medium. To obtain C + L band wavelength tuning, an intracavity C- and L-band TBF is used for wavelength-selection in the experiment, individually. Due to the unavailability of the C + L band optical filter in the laboratory, we only use C- and L-band optical filter to generate the lasing wavelength respectively. Here, Fig. 3 shows the output wavelength spectra of the proposed fiber ring laser in the wavelengths of 1518.5–1610.0 nm, at the driving current and pumping power of 200 mA and 25 mW, respectively. Furthermore, Fig. 3 also shows that the background ASE noise can be suppressed better in longer wavelength.

Fig. 4 presents the output power and side-mode suppression ratio (SMSR) of the proposed fiber ring laser under different lasing wavelength range of 1518.5–1610.0 nm. Here, the maximum and minimum output powers of 5.9 and -14.2 dBm can be observed at the wavelengths of 1560.5 and 1610.0 nm, respectively. And the measured SMSR are between 44.3 (at 1595.1 nm) and 62.5 dB/0.01 nm (at 1568.1 nm) in the output wavelength range, as illustrated in Fig. 4. Moreover, the higher output power can be retrieved around 1550.0 of 1570.0 nm (~ 20 nm) due to the larger gain distribution. And its power difference of ± 0.6 dB is also measured around the wavelength range, as shown in Fig. 4.

Furthermore, to obtain the flattened output power spectrum of proposed fiber laser structure, the driving current of SOA with properly adjustment is required in the measurement. According to the measured results of Fig. 4, we can set the output power around -5.0 dBm to achieve the flattened characteristic. Hence, Fig. 5 presents the flattened output spectrum of proposed ring laser at the -5.0 dBm fixed output power in the wavelength range of 1518.5–1604.1 nm, when the driving current range is between 163 and 209 mA. And, the measured output power difference of ± 0.1 dB can be completed under the properly operating currents. In addition, the entire measured SMSRs in the wavelength range are larger than 44.2 dB/0.01 nm in this measurement. Here, we also measured the stabilities of wavelength and output power of the

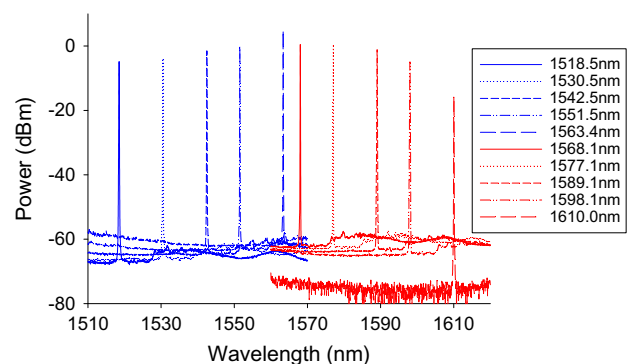


Fig. 3. Output wavelength spectra of the proposed fiber ring laser in the wavelengths of 1518.5–1610.0 nm, at the driving current and pumping power of 200 mA and 25 mW, respectively.

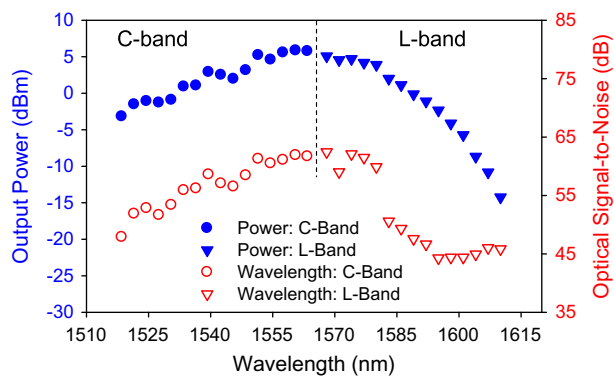


Fig. 4. Output power and SMSR of the proposed fiber ring laser under different lasing wavelength range of 1518.5–1610.0 nm.

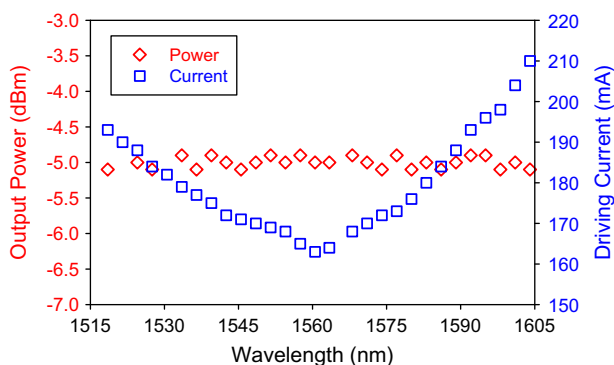


Fig. 5. Flattened power spectrum of proposed fiber laser under different driving current when output power is set at -5 dBm.

proposed fiber laser. We selected the lasing wavelength of 1545.5 nm, and the initial output power is 1.9 dBm during the stability measurement. The maximum output power fluctuation and wavelength variation are within 0.9 dB and 0.2 nm in the observing time of 30 min.

Compared with the C + L band EDFA for fiber ring laser structures [9–12], the proposed fiber laser has the benefits of higher energy-efficiency, low-cost, simple architecture and broad tuning range.

3. Conclusion

We have proposed and demonstrated a CW tuning fiber ring laser structure using a proposed hybrid fiber amplifier serving as a

gain medium covering both C-band and L-band. Here, the hybrid amplifier included a C-band SOA and C-band EDFA with a 3 m EDF in a serial configuration. Hence, a 91.5 nm wavelength range (from 1518.5 to 1610.0 nm) could be achieved by the proposed fiber ring laser, while the TBF was utilized inside gain cavity. In the measurement, the output power and SMSR of ring laser were measured between -14.2 and 5.9 dBm and 44.3 and 62.5 dB/0.01 nm, respectively. In addition, to retrieve the flattened output power spectrum around -5.0 ± 0.1 dB, the driving current of proposed laser with properly adjustment was required in the wavelength range of 1518.5–1604.1 nm (85.6 nm bandwidth). And its corresponding SMSRs were larger than 44.2 dB.

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