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Ultra-Broadband Amplified Spontaneous Emission Source by Using Heterogeneous Optical Amplifier[1]

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Abstract—In this work, we propose and experimentally investigate an ultra-broadband amplified spontaneous emission (ASE) light source with 113.8 nm bandwidth (1446.2 to 1560.0 nm) by using a cascaded two-stage optical amplifier, which is consisted of semiconductor optical amplifier (SOA, 1st stage) and erbium-doped fiber amplifier (EDFA, 2nd stage), when the output intensity is above –35 dBm/0.01 nm. And, the EDFA only uses a 3 m long erbium-doped fiber (EDF) with a 27 mW pumping power and SOA is driven at 200 mA bias current. Moreover, the proposed amplifier also can provide a broadband gain amplification of 114 nm in the wavelengths of 1464.0 and 1578.0 nm with the noise figure distribution of 6.8 to 8.1 dB.

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1. INTRODUCTION

Broadband optical amplifier-based amplified spontaneous emission (ASE) source has been not only intensively investigated as an important light source for passive optical networks (PONs) and density wavelength division multiplexing (DWDM) communications [1–4], but also employed to as a testing instrument for optical components [5, 6]. Besides, the ASE source requires the performance, such as a widely wavelength range, high power stability and moderate linewidth of effectiveness, etc., for fiber gyroscopes and spectral slicing WDM system [7–9]. Besides, to achieve a broadband ASE source of erbium-doped fiber amplifier (EDFA)-based, using the fiber grating-based and mirror architectures [10] and employing the stimulated Raman scattering (SRS) and four-wave mixing (FWM) effects in a fiber ring cavity [11]. And, these proposed methods can extend the wavelength range from C-band to L-band.

In this paper, we propose and experimentally investigate an widely broadband ASE source with 113.8 nm bandwidth of 1446.2 to 1560.0 nm by using a cascaded two-stage optical amplifier, which is constructed by a semiconductor optical amplifier (SOA, 1st stage) and an erbium-doped fiber amplifier (EDFA, 2nd stage), when the output intensity is above –35 dBm/0.01 nm. Hence, when the first-stage SOA is used to pump the second-stage EDFA, the observed ASE source will be broader and flatter by the proposed amplifier architecture. Moreover, the measured power difference (ΔP) of 4.9 dB is also obtained in the proposed ASE light source. Here, the proposed hybrid amplifier also can provide a broadband gain amplification of 114 nm in the wavelengths of 1464.0 and 1578.0 nm with the noise figure distribution of 6.8 to 8.1 dB.

2. EXPERIMENT SETUP

Figure 1 shows the experimental setup of ultra-broadband ASE source architecture by using hybrid two-stage fiber amplifier. The proposed two-stage amplifier was consisted of a C-band SOA (produced by *Kamelian*), two optical isolators (ISOs), a length of erbium-doped fiber (EDF) with 3 m long, a 980 nm pumping laser diode (LD), and a 980/1550 nm WDM coupler (WCP), as illustrated in Fig. 1. Here, the forward ASE source first-stage SOA ($\mathrm{ASE}_\mathrm{F}^\mathrm{SOA}$) was used to cascade and pump the second-stage EDFA. Hence, there were two pumping sources, which were the 980 nm LD and $\mathrm{ASE}_\mathrm{F}^\mathrm{SOA}$, for the second-stage EDFA to generate a broadband ASE source. Besides, there was no ISO among the two-stage hybrid amplifier. Then, we could measure and obtain the broadband ASE spectrum in the output of hybrid amplifier by using an optical spectrum analyzer (OSA) with a 0.01 nm resolution.

First of all, we would measure the ASE spectra of SOA under different pumping currents of 60 to 200 mA to realize its output characteristic. Besides, the threshold and maximum current of SOA was 40 and 230 mA, respectively. Figure 2 presents the forward ASE spectra of SOA when the pumping current is set at 80, 140, and 200 mA, respectively. As shown in

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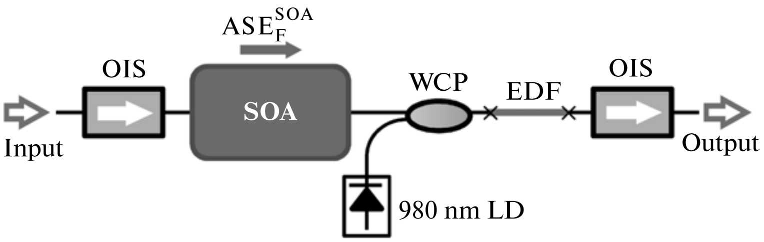

Fig. 1. Experimental setup of ultra-broadband ASE source architecture by using hybrid two-stage fiber amplifier.

Fig. 2, the maximum peak powers of –37.6, –30.4, and –26.7 dBm/0.01 nm are measured at the wavelengths of 1501.4, 1476.6, and 1477.0 nm, respectively, under the three pumping currents. When the output power level is larger than –35 dBm/0.01 nm, the measured ASE ranges are 74.8 nm (1451.0 to 1525.8 nm) and 98.0 nm (1435.3 to 1533.3 nm) at the pumping powers of 140 and 200 mA respectively. However, the obtained power differences (ΔP) are 4.6 and 8.3 dB in their corresponding output ASE ranges.

As mentioned above, we could use the first-stage SOA to cascade and pump the second-stage EDFA for ASE output. In the next experiment, we will realize and discuss the absorption spectrum of the 3 m EDF without pumping power, when the SOA was used to cascade EDFA. Thus, Fig. 3 shows the output ASE spectra of the proposed hybrid amplifier, when the driven current of SOA is 40, 120, and 200 mA respectively, and the pumping power of EDFA is zero. As seen in Fig. 3, we can observe a drop point of absorption spectrum around 1530.2 nm while the SOA is 40 mA. This is because the original absorption distribution of unpumped EDF. And, as the driven current of SOA increases gradually, the obtained output ASE spectra (undergoing the unpumped EDF of 3 m) also become wider and higher, as shown in Fig. 3. Besides, Fig. 3 also presents the absorption spectrum (red line) of proposed amplifier undergoing a 3 m unpumped EDF, when the SOA is set at 200 mA. The unpumped EDF will also result in the power absorption ranges of 1400.0 to 1541.0 nm and 1541.0 to 1600.0 nm, as illustrated in Fig. 3. Between the two ranges, the introduced losses are measured at <4.4 dB. As mentioned above, the ASE_F^{SOA} source was also a pumping light for the second-stage EDFA. Therefore, we observe that the ASE_F^{SOA} source under 200 mA driven current also can induce some gain between 1541.0 and 1578.6 nm after passing through the unpumped EDF, as shown in the absorption spectrum of Fig. 3.

Then, we set the 980 nm pumping power of second-stage EDFA at 14 and 27 mW under the different driven currents of 40, 120, and 200 mA for first-stage SOA, respectively, in this measurement. Here, Fig. 4a shows the ASE spectra of proposed hybrid amplifier with 14 mW pumping power of 980 nm LD under the driven current of 40, 120, and 200 mA in second-stage SOA, respectively. As the driven current of SOA adds

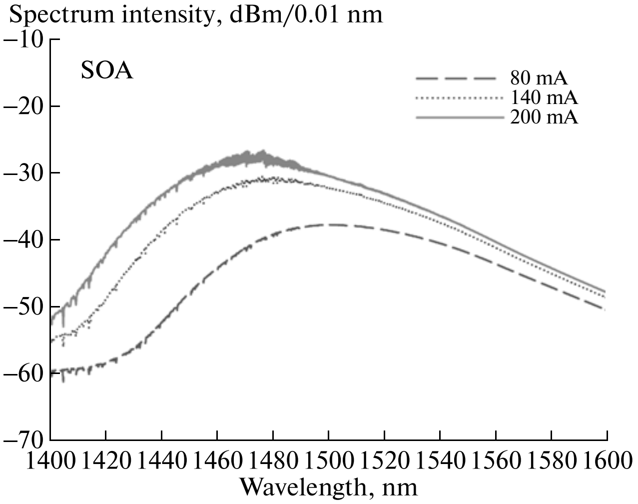

Fig. 2. Forward ASE spectra of SOA when the pumping current is set at 80, 140, and 200 mA, respectively.

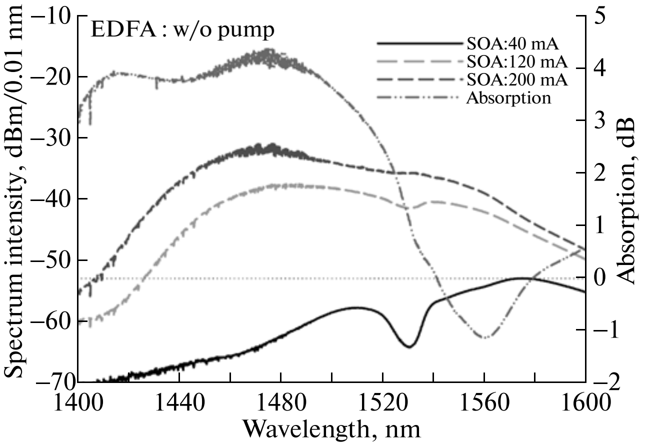

Fig. 3. Output ASE spectra of the proposed hybrid amplifier, when the driven current of SOA is 40, 120, and 200 mA respectively, and the pumping power of EDFA is zero. And absorption spectrum (red line) of proposed amplifier undergoing a 3 m unpumped EDF, when the SOA is set at 200 mA.

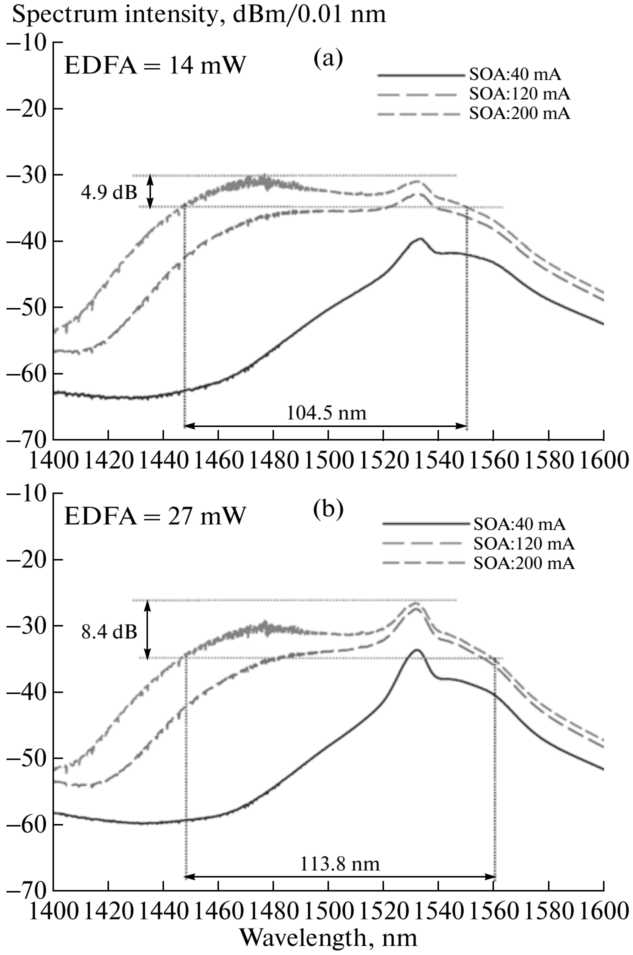

Fig. 4. ASE spectra of proposed hybrid amplifier with (a) 14 and (b) 27 mW pumping powers of 980 nm LD under the driven current of 40, 120, and 200 mA in second-stage SOA, respectively.

increasingly, the observed output range and power of ASE spectra are also increase. When the 200 mA driven current is used, the two peak powers of −30.1 and −31.0 dBm/0.01 nm are obtained at the wavelengths of 1476.3 and 1532.0 nm respectively. Besides, Fig. 4a presents the maximum ASE range of 104.5 nm (1446.4–1550.9 nm) while the intensity level is >–35.0 dBm. And the measured maximum power difference (ΔP) is 4.9 dB among this ASE range.

When we increase the pumping power of 980 nm LD to 27 mW, the ASE spectra of proposed hybrid amplifier are measured, as shown in Fig. 4b, under the driven current of 40, 120, and 200 mA in second-stage SOA, respectively. As the same as Fig. 4a, as the driven current of SOA increase gradually, the observed output range and power of ASE spectra are also increase. When the 200 mA driven current is fixed, the two peak powers of −29.3 and −26.6 dBm/0.01 nm are obtained at the wavelengths of 1477.0 and 1531.6 nm, respectively. Furthermore, Fig. 4a also shows the maximum ASE range of 113.8 nm (1446.2–1560.0 nm) when the power intensity level is >–35.0 dBm. And the measured maximum ΔP is 8.4 dB among this ASE range.

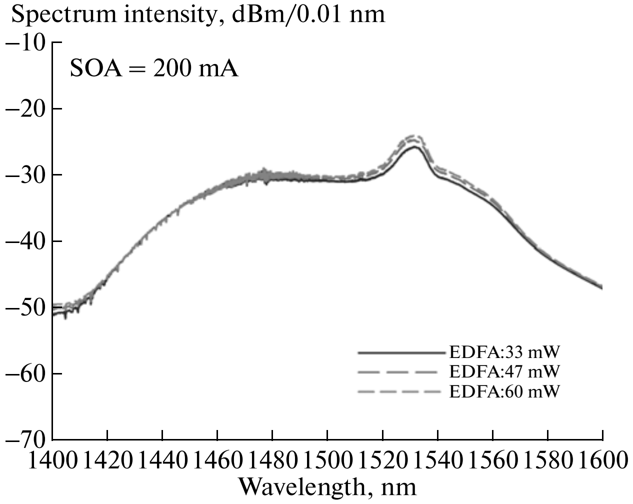

Fig. 5. Measured ASE spectra of the proposed hybrid amplifier at the pumping powers of 33, 47, and 60 mW, respectively, while the driven current of SOA is fixed at 200 mA.

Finally, we fixed the driven current of SOA at 200 mA for the proposed amplifier under the different pumping powers in the next experiment. Hence, Fig. 5 shows the measured ASE spectra of the proposed hybrid amplifier at the pumping powers of 33, 47, and 60 mW, respectively, while the driven current of SOA is fixed at 200 mA. As shown in Fig. 5, as the pumping power increases gradually, the obtained whole ASE spectra only increase 1.8 dB maximally due to the gain saturation of second-stage EDFA. And, their corresponding ASE output ranges are 118.0, 119.3, and 119.9 nm, when the output level is >–35.0 dBm. However, the maximum AP is also measured at 9.3, 10.3, and 11.1 dB, respectively, as seen in Fig. 5. As a result, according to the obtained results, if we want to get a broader and flatter ASE source by using the proposed optical amplifier, the pumping power and driven current can be set at 14 mW and 200 mA for the operating conditions.

Though the proposed amplifier could achieve a wider ASE spectrum, but it could also provide gain amplification. Hence, we will also experiment the gain measurement by using the hybrid amplifier. First, we measured the gain and noise figure (NF) spectra of original SOA driving at 200 mA, when the input power of testing signal was set at −10 dBm in the wavelength range of 1464 to 1596 nm. Figure 6a shows the gain and NF spectra of SOA, operating at 200 mA, in the wavelengths of 1464 to 1596 nm for −10 dBm input power of testing signal. The effective gain range of 1485 to 1557 nm can be obtained when its corresponding NF is below 9.0 dB, as seen in Fig. 6a. Here, the

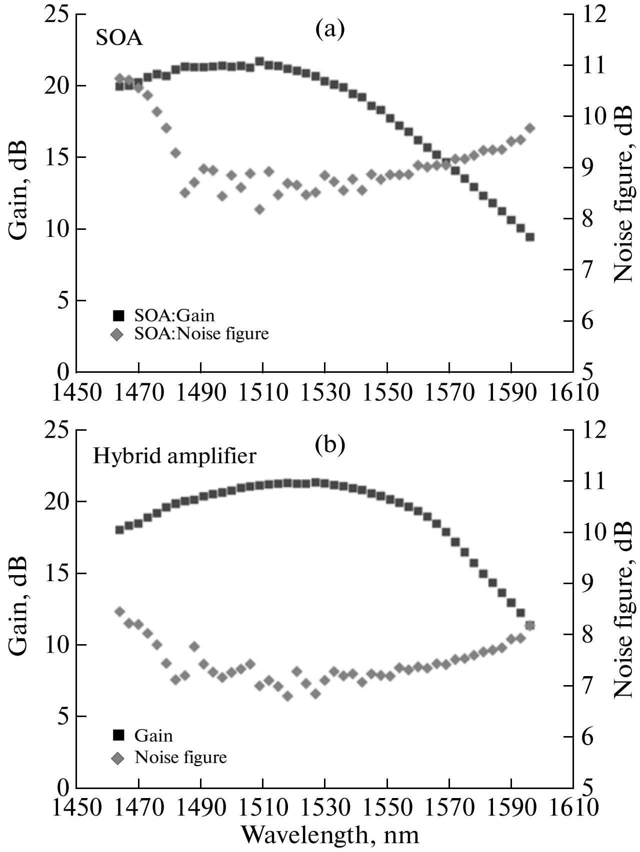

Fig. 6. The Gain and NF spectra of (a) SOA and (b) proposed hybrid amplifier, respectively, in the wavelengths of 1464 to 1596 nm for −10 dBm input power of testing signal.

maximum and minimum gains of 21.8 and 16.9 dB are observed at the wavelengths of 1509 and 1557 nm, respectively. Besides, the measured NF profile is between 8.1 and 8.9 dB in the wavelengths of 1485 to 1557 nm (72 nm).

Then, we experimented and measured the gain and NF spectra of proposed hybrid fiber amplifier. So, Fig. 6b presents the gain and NF spectra of proposed amplifier, operating at 200 mA current and 27 mW pumping power, in the wavelengths of 1464 to 1596 nm for −10 dBm input power of testing signal. As shown in Fig. 6(b), the gain profile can be measured between 21.40 and 11.37 dB in the wavelengths of 1464 to 1596 nm, and the corresponding NF spectrum is also observed between 6.8 and 8.4 dB. Thus, if the gain and NF are >15 and <9 dB, respectively, the effective amplification range can be achieved in the wavelengths of 1464 and 1578 nm (114 nm bandwidth), as illustrated in Fig. 6b. As a result, comparisons of Figs. 6a and 6b, the proposed amplifier not only can extend the amplification range to 114 nm, but also can reduce the NF from 8.1 to 6.8 dB (with ~1.3 dB improvement).

3. CONCLUSIONS

In summary, we have proposed and experimentally investigated an ultra-broadband ASE light source with 113.8 nm bandwidth from 1446.2 to 1560.0 nm by using a cascaded two-stage optical amplifier, which was consisted of SOA (1st-stage) and EDFA (2nd-stage), when the output intensity is above −35 dBm/0.01 nm. And, the EDFA only used a 3 m long erbium-doped fiber (EDF) with a 27 mW pumping power and SOA was driven at 200 mA bias current. Moreover, the proposed amplifier also could provide a broadband gain amplification of 114 nm in the wavelengths of 1464 and 1578 nm with the noise figure distribution of 6.8 to 8.1 dB.

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