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IEEE/OSA Optical Fiber Communications Conference (OFC 2020)

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Abstract: We investigate an extended L-band EDFA pumped by C-band wavelengths. A two-stage scheme with 1480 nm/1545.5 nm pumping is demonstrated with 20-dB gain over 1570-1620 nm and NF lower than 5.7 dB.

1. Introduction

Long wavelength-band (L-band) erbium-doped fiber amplifiers (EDFAs) usually amplify optical signals over the wavelength range from 1565 nm to 1605 nm. With improvements of erbium-doped fiber (EDF) technology, extended L-band EDFAs covering the 1565 nm-1620 nm bandwidth have been developed [1–3] to further increase the transmission capacity of wavelength division multiplexing (WDM) optical communication networks. However, the power conversion efficiency (PCE) of L-band EDFA is usually lower than that of C-band EDFA. L-band EDFA exploit the tail of the Er^{3+} gain band (away from the 1530 nm peak) where the emission cross sections are very small. As a result, a longer fiber length is required to achieve sufficient gain, which consequently leads to higher background loss. High Er^{3+}doping concentration is a common technique to enhance the gain performance of L-band EDFAs but, in this case, the clustering effect may become one of the main limitations of the PCE. Due to the low PCE of L-band EDFA, multiple high-power single-mode laser diodes at 980 nm or 1480 nm are usually required in conventional core-pumped scheme, which means that the gain performance of the amplifier becomes limited by the number and output power of these laser diodes. Fiber lasers operating in the C-band could be an alternative to 980 nm and 1480 nm laser diodes to pump L-band EDFAs [4,5]. These lasers could provide not only a lower quantum defect, but also much higher output power. In this work, we investigate the performance of extended L-band EDFA with C-band pumping. We first experimentally investigate the influence of pumping wavelength (in the C-band) on the gain and noise figure performance of the extended L-band EDFA. With a one-stage EDFA, we use different C-band pump wavelengths: 1530.7 nm, 1537.8 nm, 1545.5 nm and 1553.3 nm. Then, we examine a two-stage scheme that combines 1480 nm laser diode pumping for the first stage and 1545.5 nm pumping for the second stage. A 20-dB gain over the wavelength range of 1570 nm-1620 nm is shown with the noise figure (NF) lower than 5.7 dB.

2. Experimental setup and results

2.1 One-stage L-band EDFA with C-band pumping

We designed a silica-based EDF that was fabricated in-house at the COPL. The experimental setup, with forward pumping, is shown in Fig. 1(a). The C-band pump light is generated by a tunable light source and amplified by a high power EDFA (gain of 30 dB) followed by a circulator and a fiber Bragg grating (FBG), with 50 GHz bandwidth, to remove the amplified spontaneous emission (ASE) noise. Pump wavelength is determined by tuning the C-band laser and changing the FBG; the four available wavelengths are 1530.7nm, 1537.8 nm, 1545.5 nm and 1553.3 nm (shown in Fig. 1(b)). The measured EDF absorption at these four pump wavelengths are 22 dB/m, 23 dB/m, 19dB/m and 9 dB/m, respectively. A wideband coupler combines the signal and pump light before launching into the EDF with a coupling ratio of 98/2. Input and output signals are measured on an optical spectrum analyzer (OSA) to determine the gain and NF. The input signal power for the calculation is measured after the wideband coupler and before the EDF with the pump light source running, so that the influence of the components before the EDF is removed (i.e. we present measurements of internal gain and NF). Fig. 2(a)-(b) show the small signal gain and NF for different C-band pump wavelengths when the input signal is -22 dBm. The pump power launched into the EDF is 530 mW, the EDF length is 30 m. A wideband 20 dB gain covering the whole extended L-band is obtained with only one pump source at either 1530.7 nm, 1537.8 nm or 1545.5 nm. The gain is however much lower when using 1553.3 nm pumping, which can be explained by the lower absorption coefficient at 1553.3 nm at this wavelength. As for the NF, as the pump wavelength increases the NF, which is degraded to unacceptable level for system application of L-band EDFA, especially when the pump wavelength is longer than 1540 nm. This is related to the lower inversion level of the EDF at the amplifier input [6], which is critical to obtain good noise figure performance. The gain and NF with input power of -3 dBm are shown in Fig. 2(c) and Fig 2(d). Higher gain saturation is observed for 1530.7 nm pump compared to 1537.8 nm or 1545.5 nm.

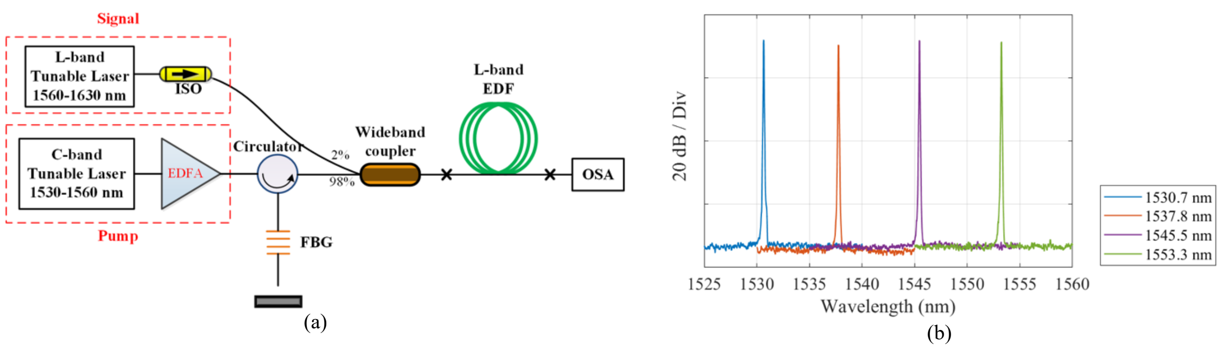

Fig. 1. (a) The schematic of one-stage EDFA. (b) Output spectra of pump lights with different wavelengths.

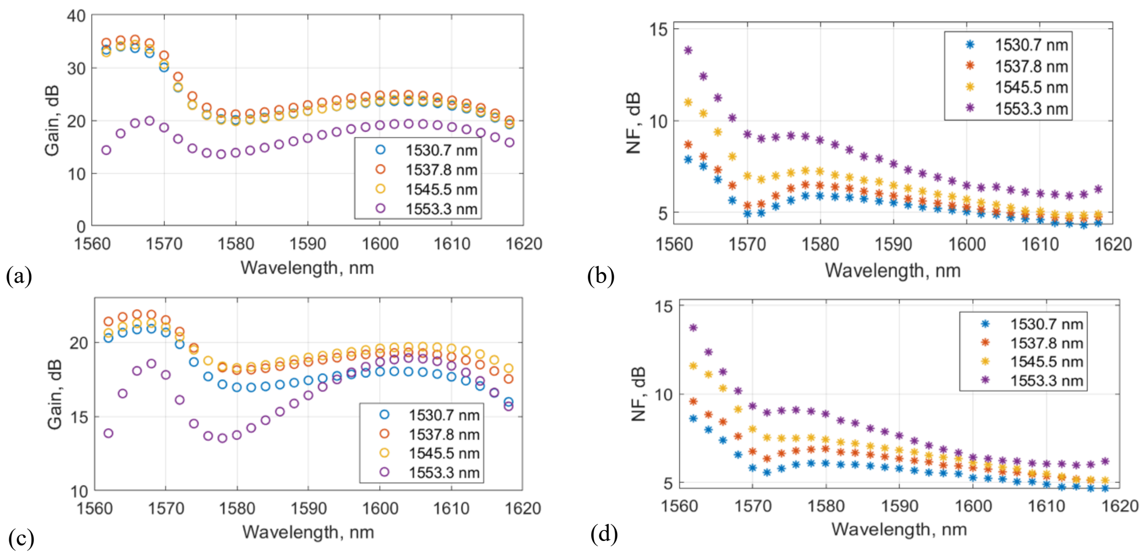

Fig. 2. Performance of extended L-band EDFA with different pump wavelengths: (a) -22 dBm input: gain. (b) -22 dBm input: NF. (c) -3 dBm input: gain. (d) -3 dBm input: NF.

2.2 Two-stage L-band EDFA with 1480 nm and 1545.5 nm pumps

It is well-known that the NF of a multi-stage amplifier is dominated by NF of the first stage. To lower the noise figure but still benefit from the good PCE of C-band pumping, we assembled a two-stage amplifier as shown in Fig. 3(a). The first stage has an EDF length of 10 m (EDF1) and is pumped by a commercial single-mode 1480 nm laser diode with a power of 100 mW. The EDF length of the second stage (EDF2) is 20 m and the C-band pump source is the same as the one in Fig. 1(a). A 1480 nm/L-band WDM multiplexer and a C/L-band WDM multiplexer are used to combine the signal and pump light in the first and the second stages respectively. A saturating tone with the wavelength of 1595 nm and the input power of -1 dBm is added to the input signal of -20 dBm. The input signal used to calculate gain and NF is measured and calibrated at the output of WDM1, and Fig. 3(b) show the results.

Due to the limited L-band range of the C/L-band WDM multiplexer, the measurements could only be performed for signal wavelengths of 1570 nm-1620 nm. In Fig.3(b), we compare the EDFA performance when the second stage is pumped with 1545.5 nm (red) or 1480 nm (yellow) with the same pump power (250 mW, the highest output power of 1480 nm laser diode). A gain enhancement between 1.6 dB to 2.5 dB is obtained with 1545.5 nm pumping in the second stage, with negligible impact on the NF that remains below 6.5 dB in both cases. For the 1595 nm signal with an input power of -1 dBm, the gain is 17 dB with 1545 nm pump and 15.17 dB with 1480 nm pump as the second pump source. The PCE is therefore 53% higher when using 1545 nm pumping compared to 1480 nm pump. When further increasing the power of the 1545.5 nm pump to 550 mW, a 20-dB gain covering the extended L-band is obtained with an average NF of 4.5 dB, which is very close to the NF of the first stage.

(a)

(b)

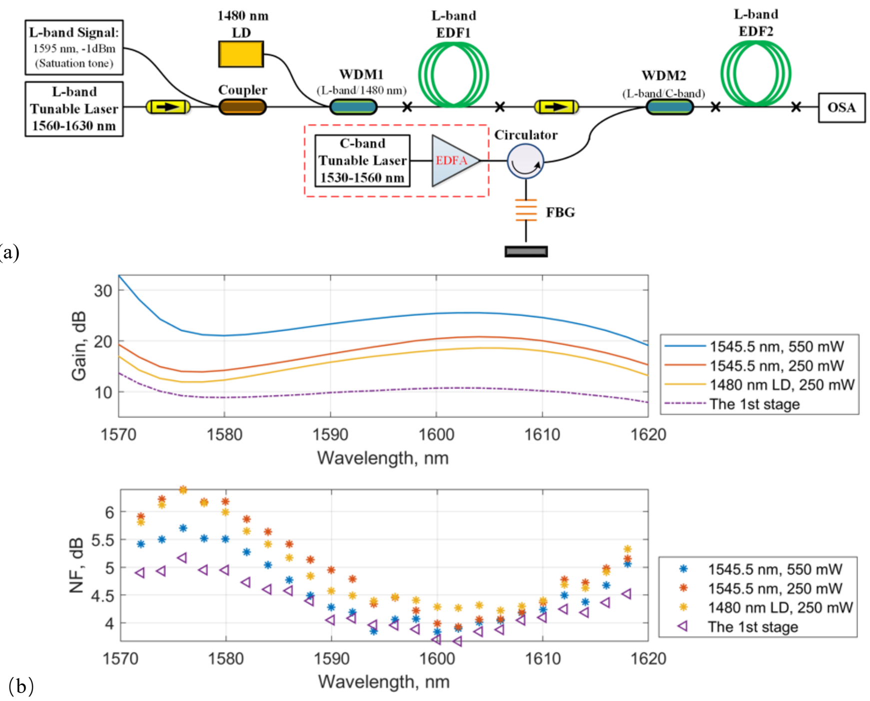

Fig. 3 (a) The schematic of the wo-stage EDFA. (b) The results of gain and NF of the two-stage EDFA.

3. Conclusion

We investigated an extended L-band EDFA pumped by C-band wavelengths. With a single stage, C-band pumping leads to efficient amplification over the extended L-band but at the expense of higher noise figure. However, the benefit of C-band pumping in terms of power conversion efficiency can be exploited when using a two-stage EDFA with a first stage pumped by 1480 nm to maintain good noise figure performance. A 20-dB gain covering 1570-1620 nm with a maximum noise figure of 5.7 dB is thus demonstrated.

4. Acknowledgement

This work was funded by NSERC and Huawei Canada. The author Chengmin Lei acknowledges China Scholarship Council (CSC) for its financial support.

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