Low noise figure all-optical gain-clamped parallel C+L band Erbium-doped fiber amplifier using an interleaver

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Abstract: A low noise figure (NF), all-optical gain-clamped C+L band erbium-doped fiber amplifier (EDFA) has been demonstrated. A parallel configuration is employed to avoid the crosstalk between the C- and L-band signals. Half of the amplified spontaneous emission from the output signal is filtered by an interleaver and fed back to the parallel EDFA to form lasing cavity. Two lasers in the C- and L-band, respectively, formed in the cavity clamp the C- and L-band signals simultaneously. In the L-band, the double-pass configuration with a fiber Bragg grating is used to improve the gain and NF. Furthermore, co-propagation of the signal and the lasing power leads to a low NF, while the amplified signals are exported separately from the lasing power. Finally, a wide gain-clamping range up to -10dBm and ~5.5dB NF are obtained.

OCIS codes: (140.4480) Optical amplifiers; (060.2320) Fiber optics amplifiers and oscillators

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1. Introduction

Wideband Erbium-doped fiber amplifiers (EDFAs) have become one of the key technologies in optical communications because they are effective to increase the number of WDM channels in 1.5um optical transmission and routing network [1]. In theory, the EDFA can achieve 120nm bandwidth [2]. In dynamic wavelength division multiplexing (WDM) networks that employ reconfigurable optical cross-connection or carry bursty switching in the

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optical domain, power transient induced by the slow response of EDFAs is a challenging issue. The transient effects can be suppressed by using either electric or optical control, or the combination of both methods. Among these schemes, optical gain clamping is a commonly used technique. However, only a very few experiments have been performed on gain clamping of C+L band EDFAs [3-5]. The serial configurations [3,4] inevitably introduce crosstalk between the C- and L-band signals. The parallel configuration [5] can avoid the crosstalk, but the counter-propagation of the signal and the lasing power leads to a high noise figure (NF) [6]. Alternatively, using a fiber Bragg grating (FBG) or a narrow band filter with a centre wavelength in the dead zone of the C/L coupler can realize clamping of both C- and L-band signals [3,5]. However, due to the high loss of the C/L coupler in the gap between the two bands, and the low gain of the dead zone in the C- and L-band EDFA, the lasing power is very low, leading to higher NF and smaller dynamic gain-clamping range [7]. Forming two separate lasers in C- and L-band can avoid such a problem.

In this work, we propose and demonstrate an all-optical gain-clamped parallel C+L band EDFA with a co-propagation configuration, in which a double- pass configuration with a FBG is used to improve the gain and the NF in the L-band [8]. The key component in our design is an interleaver [7], whose even port is used to output the amplified WDM channels and odd port is used to pass the lasing lights in the C- and L-band for gain clamping. Because of inhomogeneous broadening between the C- and L-band, the lasers in the C- and L-band are formed simultaneously in the cavity, and as a result, the C- and L-band signals can be clamped by using a single interleaver. In this scheme the output signal channels do not contain lasing lights as seen in other typical gain clamped amplifiers with co-propagation configuration. Furthermore, the signal co-propagates with the lasers, thus leading to a lower NF [6]. Therefore, the proposed all-optical gain-clamped parallel C+L band EDFA simultaneously achieves low NF and separates lasing lights from the desired signals [7]. In our demonstration, a 100/200-GHz interleaver is employed for a 200-GHz WDM system. The interleaver can be designed to suit specific WDM spacing requirements.

2. Experiment

The experimental setup of the gain-clamped C+L band EDFA is shown in Fig.1. The parallel configuration is formed using a C/L splitter and a C/L combiner. The C/L splitter has a loss of about 15dB from either C- or L-port to the common port at 1568nm. The 90:10 coupler combines 90% of the WDM signal power and 10% of the feedback and sends them into the C+L EDFA. In the L-band EDFA, a double-pass configuration incorporating a FBG with 1553.33nm central wavelength and 0.2nm bandwidth is used. The FBG reflects part of the strong backward ASE power into the EDF to serve as the secondary pump for the L-band signals, leading to a higher gain and a lower NF [8]. The lengths of EDF with ion concentration of 240 ppm used in C- and L-bands are 12 m and 70 m, respectively. The pump power is 90 mW for the C-band EDFA and is tuned at about 80 mW for the L-band EDFA to obtain the similar clamped gains and NFs for both C- and L-band signals. The output of the C/L combiner is connected to the input port of a 100/200GHz interleaver [7]. Since the WDM signals coincide with the even channels of the interleaver, the even port of the interleaver is used to output the amplified signals, and the odd port is used to feedback the wideband ASE spectrum into the C+L EDFA to form lasing cavities. A variable optical attenuator (VOA) is employed to tune the cavity-loss and correspondingly to change the clamped-gain and NF. The isolator ensures that the signals co-propagate with the lasing lights, leading to low NF [6].

3. Results and discussions

At first, we use the 10% output port of the 90:10 coupler to observe the generated lasers in the ring cavity. The laser spectrum without input signals is shown in Fig. 2, where the lasing wavelengths in the 1530-nm and the 1570-nm bands originate from the self-lasing of the wideband ASE filtered by the interleaver. Two lasers are formed through the C/L splitter and combiner, and they do not affect each other. Therefore, the C- and L-band signals can be gain-

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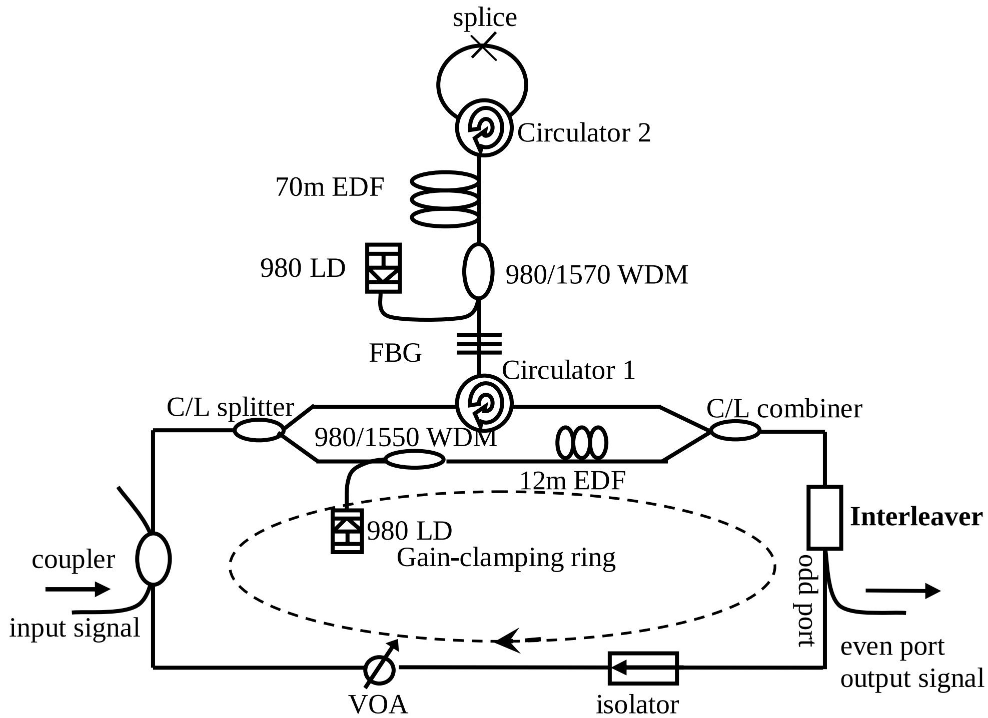

Fig. 1. The experimental setup

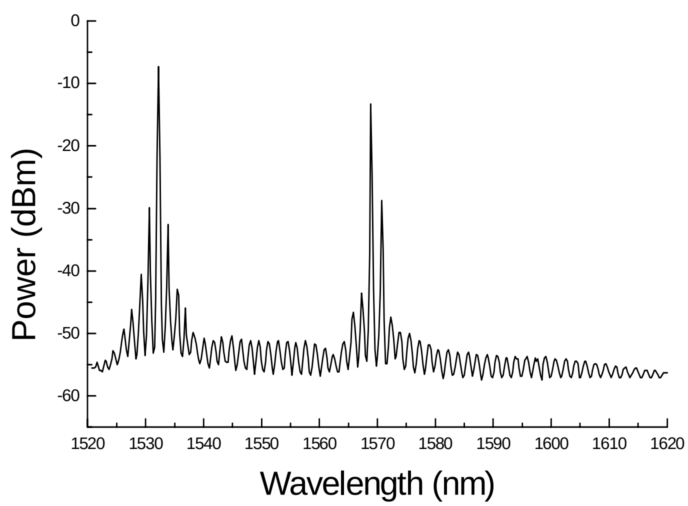

Fig. 2. The laser spectrum

clamped simultaneously by using a single interleaver. In the lasing ring, with increasing pump power, the wavelengths of the lasers would shift to about 1555 nm and 1580 nm due to the high gain at such wavelengths. If the pump power is kept at a given level, the wavelengths of the lasers do not change with increasing input signal power. However, the lasing power

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decreases, thus eventually the lasing cannot be maintained and the gain-clamping effect disappears. In practical applications, the pump power would not be changed, so the performance of gain-clamping is only determined by the cavity-loss [7].

We characterize two EDFAs in different configurations. The first configuration is a conventional parallel C+L band EDFA without dynamic gain clamping. The second one is the proposed C+L band EDFA with co-propagation configuration at an appropriate cavity-loss setting. The overall NF of the EDFA is primarily determined by the noise performance of gain-fiber section that is close to the signal input. In the counter-propagation configuration, the lasing power reaches its maximum at the signal input port, saturating the gain of the amplifier and resulting in a high NF for the input signal. While in the co-propagation configuration, the lasing light experiences the gain along the EDF and reaches its maximum power at the output of the fiber. Obviously the co-propagation configuration outperforms the counter-propagation one in noise performance. Furthermore, by carefully adjusting the cavity-loss, we can obtain an optimal lasing power level at the input of the EDF to achieve the best noise performance. The choice of the cavity loss also depends on other factors such as the clamped gain and the dynamic gain-clamping range. In the experiment, we set the cavity-loss at 24 dB based on the previous study [6,7] and our experience, which includes the 10-dB loss of the input coupler.

We study the gain-clamping effects of the C-band channel at 1550.063 nm and the L-band channel at 1580.576 nm. We tune the pump laser diode in L-band EDFA, which is about 80mW in this experiment, to keep the gains and the NFs of C- and L-band signals at the same level. Figure 3 shows that C- and L-band signals have similar gain-clamping characteristics. When the cavity-loss is set at 24 dB, both signals at 1550.063 nm and 1580.576 nm show clamping characteristics, with clamped gains of 15.96 dB and 17.96 dB, respectively. The input-signal power within the gain-clamping range is as high as –10dBm, with a gain variation of below 0.2 dB. At 24-dB cavity-loss condition, the saturated powers are ~10 dBm and 12 dBm at 1550.063 nm and 1580.576 nm, respectively. For low input powers, the NFs for the 1550.063-nm and 1580.576-nm signals are about 5.5 dB. The low NFs can be attributed to the co-propagation configuration and the optimal cavity-loss. For input powers higher than -10 dBm, the gain-clamping effect disappears, and as a result, the NFs of the gain-clamped EDFA are equal to or even higher than those of the conventional ones because of larger insertion loss. Such a gain-clamped EDFA simultaneously achieves low NF and separation of the lasing lights from the signals [7]. Reducing the overall insertion loss of the optical components in the cavity can achieve even lower NF.

Finally, we measured the gain spectra and NFs of the all-optical gain-clamped C+L-band EDFA with 24 dB cavity-loss from 1526.464 nm to 1608.506 nm, as shown in Fig.4. It can be seen from the figure that the signal can be effectively amplified from 1525 nm to 1610 nm and the gain-clamping effect is obvious. The gain spectra with –30-dBm and –15-dBm input-signal powers are almost identical across the C- and L-bands except for the 1530-nm band and 1565-nm band. Because of the strong spectral hole-burning in the 1530nm band, the gain for –15 dBm input power decreases slightly compared with the one for –30dBm input power. The "dead zone" of the C/L splitter is from 1565 nm to 1569 nm, where the gain is lower, leading to a high NF. The gain and the NF at 1567.929 nm for –15-dBm input power are 14.87 dB and 7.26 dB, respectively. When the input signal power decreases to –30 dBm, the gain and NF at 1567.929 nm are 14.29 dB and 7.65 dB, respectively. The NFs of all the C- and L-band signals are ~5.5 dB except for the one at 1568 nm in the "dead zone" of the C/L splitter. If a gain-equalization filter is used, the proposed EDFA can achieve a flat and clamped gain in both the C- and L-band.

Using one interleaver can simultaneously realize co-propagation of the signal and the lasing light, which leads to low NF, separation of the lasing light from the desired signals, and formation two separate lasers in the C- and L-band to obtain better gain-clamping effects. If we use the odd port of the interleaver as the output port, the EDFA can amplify the odd WDM channels. This scheme could be extended to other channel spacings (e.g., 50-or 25-GHz) by

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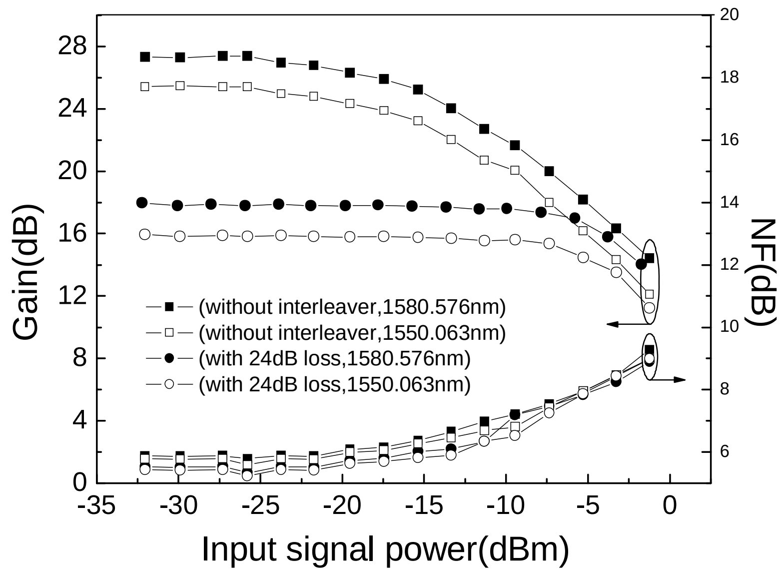

Fig. 3. The gain and the NF versus input signal powers at1550.063 nm and 1580.576 nm, respectively.

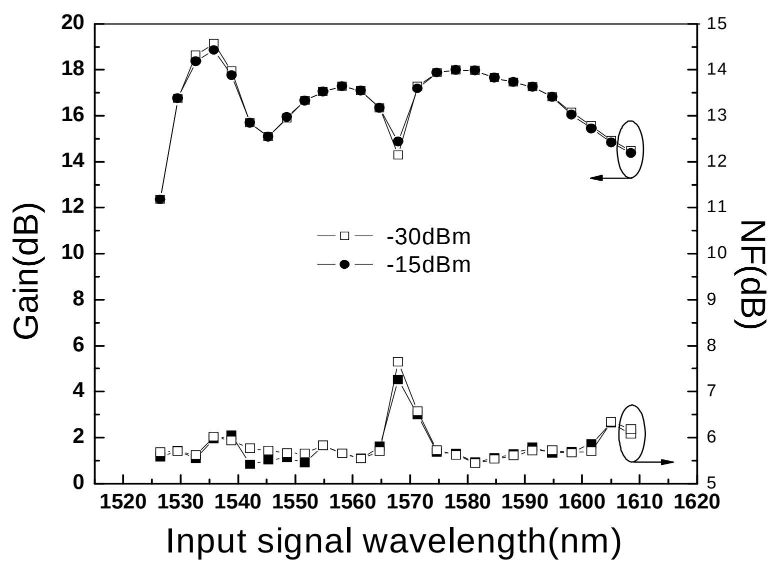

Fig. 4. The gain and NF variations with the input signal wavelength

choosing the appropriate interleaver. In addition, to reduce the bandwidth wasted by the interleaver for gain clamping, a better design of the filtering component could be devised to support more signal channels.

4. Conclusion

We have demonstrated, for the first time to the best of our knowledge, an all-optical gain-clamped parallel C+L band EDFA using a co-propagation configuration. In the L-band, we used a double-pass configuration incorporating a FBG to improve the gain and the NF of the L-band signal. The clamped-gains at 1550.063nm and 1580.576nm are respectively 15.96 and 17.96 dB at 24-dB cavity loss. The gain can be clamped for an input signal power level as high as –10 dBm, with a gain variation of less than 0.2 dB. Because of co-propagation of the lasing lights and the signals and the optimal cavity-loss, the NF is kept at about 5.5 dB in the C- and L-band except for the dead zone of the C/L splitter, where the NF is about 7.65dB. The interleaver separates the lasing lights from the amplified signals. Such an EDFA is suitable for 200 GHz or coarser DWDM systems. The proposed scheme could be extended to other channel spacing by choosing an appropriate interleaver.

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