A flat L-band Er-doped fiber amplifer clamping gain by backward C-band amplified spontaneous emission

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A flat high gain L-band gain-clamped erbium-doped fiber amplifier (GC-EDFA) by using backward C-band amplified spontaneous emission (ASE) is proposed. It uses two stages of EDFs pumped forward as gain media, and a broadband chirp fiber Bragg grating (CFBG) to reflect the backward C-band ASE back into the loop to control the gain, which avoids spectral-hole and relaxation oscillation due to no controlling laser exists. Compared with other similar GC-EDFAs, the proposed structure has higher and flatter clamped gain in L-band because of its optimal structure — the length of EDFs and pump power, pump scheme, etc.. The gain is above 23 dB, the bandwidth of 3 dB is more than 36 nm, and the input signal saturation power arrives −15 dBm.

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The L-band embium-doped fiber amplifier (EDFA) is one of the key devices for dense wavelength division multiplexing (DWDM) transmission systems, because it significantly increases the amplification wavelength range by combining with a conventional band (C-band) EDFA in a parallel configuration. The EDFAs have a gain spectrum varying greatly when the input signal power varies. While DWDM networks require optical amplifiers maintain constant gain in the presence of a changing number of wavelength channels. Optical gain clamping is a promising method for stabilizing the gain of fiber amplifiers in the presence of input power variations.

The gain can be clamped at the desired level by clamping the average inversion of the active ions in the amplifier. In this paper, we demonstrate an all-optical gain-clamped EDFA (GC-EDFA) scheme based on reflecting amplified spontaneous emission (ASE) back into the EDFA by a chirp fiber Bragg grating (CFBG). Backward C-band ASE is used as a reference level to monitor and control the gain of the EDFA in the L-band. Compared with other gain clamping schemes based on lasing mechanism, the laser burning hole and relaxation oscillation are avoided[1−5] due to non-optical cavity structure. The backward ASE reflected back into the EDF by the CFBG provides efficient ASE suppression along the EDF[6].

Other similar GC-EDFAs based on reflected ASE, most of which have flat gain spectra while not broad dynamic range or have broad dynamic range while not high flat gain spectra[1,2,6−9], such as the gain flatness for 1570-1600 nm is more than 6 dB[2], our structure has high and flat gain as well as broader dynamic range in its bandwidth range (L-band) because of optimal matching between pump power and EDF length[10].

The configuration of the proposed gain-clamped L-band EDFA is shown as Fig. 1. It consists of two sections of high concentration EDFs, a 980 nm/1550 nm WDM and a 1480 nm/1550 nm WDM2, a 980-nm laser diode (LD) and a 1480-nm LD, two L-band isolators (ISO1, ISO2), a C/L WDM, and a CFBG with reflectivity more than 98% in C-band, as shown in Fig. 2. The CFBG is connected to the C port of the C/L WDM to reflect the backward C-band ASE back into EDFs. Both EDFs are highly-doped and pumped forwardly. The length of EDF1 pumped by a 96-mW 980-nm LD through WDM1 is about 25 m. The length of EDF2 is about 20 m, pumped by a 90-mW 1480-nm LD. The ISO1 at the input can avoid reflection of signal disturbing the tunable laser source (TLS). The ISO2 at the output can avoid laser because of reflection of fiber end. Based on the above design, the input L-band signal enters the loop through the L port of the C/L WDM after the ISO1, and the amplified signal comes out from ISO2. In this configuration, the TLS provides L-band input signal. The pump, the signal, and the fed back ASE travel in the same direction in the EDFs. The gain and noise figure (NF) of the amplifier are detected at the output by an optical spectrum analyzer (OSA).

To facilitate our description, the propagating direction of the signal is defined as the forward direction; the opposite is backward. The backward ASE spectrum detected at the C port of the C/L WDM is shown in Fig. 3, from which we can find that the power of the backward C-band ASE is high. The backward C-band ASE generated near the input end will deplete much of the population inversion, resulting in a waste of pump power. In the structure, the whole backward C-band ASE generated near the input end is reused using a CFBG to feed back it into the EDF as an ASE seed, instead of being wasted. As well as the backward ASE from EDF2 can be a secondary pump for EDF1, and the forward ASE from EDF1 can be absorbed by EDF2 too, which improves the pump efficiency.

Figure 4 shows gain and NF of the amplifier versus the wavelength of the input signal at −30 dBm. In the range of 1572 − 1604 nm, the gain flatness is ±0.92 dB. The 3-dB bandwidth is more than 36 nm

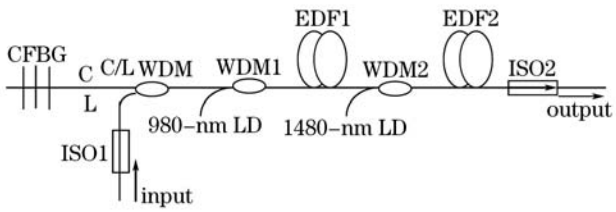

Fig. 1. Configuration of proposed L-band EDFA gain clamped by backward C-band ASE.

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(1570 − 1606 nm). The gain and NF can be read on OSA as shown in Fig. 5.

Figure 6 shows the gain and NF against input signal power at 1585 nm. When the CFBG is used, almost all the backward C-band ASE is reflected back into the loop, competing the up-level population with the L-band signals which decreases the amount of available population inversions for L-band signal, so the signal gains less up-level erbium ions population, its gain is clamped at a certain level. At small input signal power, the gain is flat, while increasing the power of input signal, the gain saturates, and begin to decrease with the input signal power increasing. The saturated input signal power reaches −15 dBm in the research.

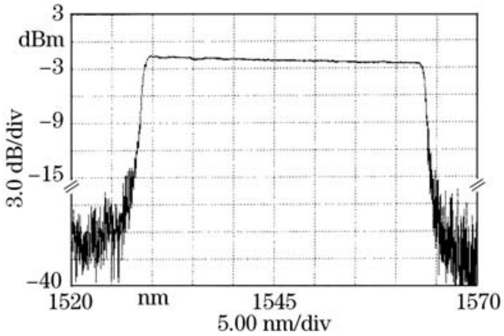

Fig. 2. Reflective spectrum of the CFBG.

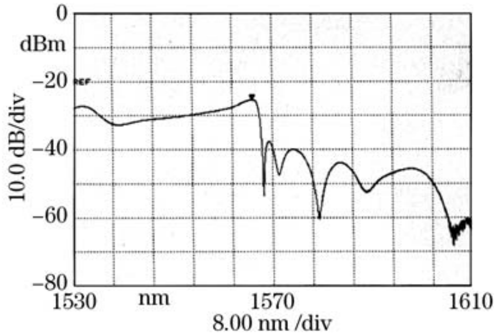

Fig. 3. Backward ASE from C port of C/L WDM.

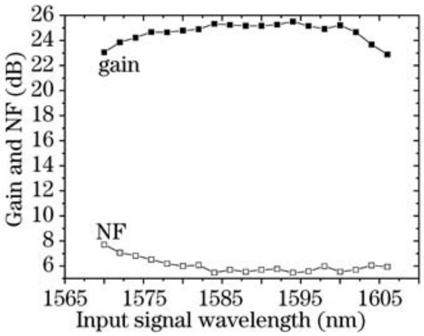

Fig. 4. Gain and NF versus input signal wavelength at −30 dBm.

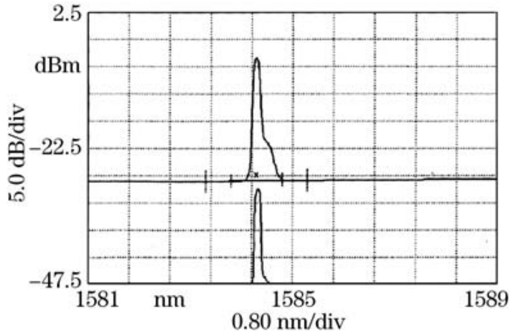

Fig. 5. Gain measurement spectrum with input signal power of −30 dBm.

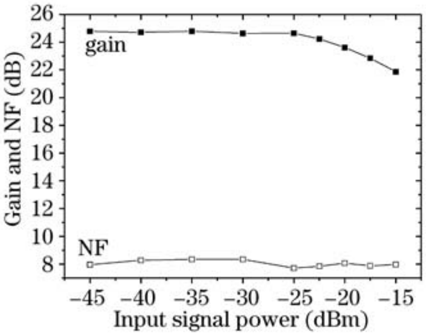

Fig. 6. Gain and NF against input signal power at 1585 nm.

In conclusion, we proposed a gain-clamped L-band EDFA using backward ASE reflected by a CFBG. It uses two stages of EDFs pumped forward as gain media, and uses a broadband CFBG to reflect the backward C-band ASE back into the loop to control the gain, which avoids spectral-hole and relaxation oscillation due to no controlling laser exists. The structure has high and flat clamped gain in L-band because of its optimal structure-the length of EDFs and pumps power, pump scheme, etc.. The gain is above 23 dB, and the flatness from 1572 to 1604 nm is ±0.92 dB. The 3-dB bandwidth is more than 36 nm (1570 − 1606 nm), and the saturated input signal power reaches −15 dBm.

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References

1. Y. H. Lu and S. Chi, IEEE Photon. Technol. Lett. **15,** 1710 (2003).
2. S. W. Harun, S. K. Low, P. Poopalan, and H. Ahmad, IEEE Photon. Technol. Lett. **14,** 293 (2002).
3. J. T. Ahn and K. H. Kim, IEEE Photon. Technol. Lett. **16,** 84 (2004).
4. J. T. Ahn, H. S. Seo, W. J. Chung, B. J. Park, and K. H. Kim, IEEE Photon. Technol. Lett. **17,** 555 (2005).
5. A. R. Pratt, K. Fujii, and Y. Ozeki, IEEE Photon. Technol. Lett. **12,** 983 (2000).
6. H. Meng, Y. Liu, W. Gao, H. Zhang, S. Yuan, and X. Dong, Opt. Technol. Lett. **36,** 501 (2003).
7. S. W. Harun and H. Ahmad, Electron. Lett. **39,** 1238 (2003).
8. A. Buxens, H. N. Poulsen, A. T. Clausen, and P. Jeppesen, Electron. Lett. **36,** 821 (2000).
9. B. Xia, L. R. Chen, and P. Chan, in *Proceedings of OFC'2002* 643 (2002).
10. Y. Jin, Q. Dou, Y. Liu, J. Liu, L. Xu, S. Yuan, and X. Dong, Opt. Commun. **266,** 390 (2006).
11. Y. Xiao, X. Liu, and D. Liu, IEEE Photon. Technol. Lett. **12,** 789 (2000).