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Gain clamping in double-pass L-band EDFA using a broadband FBG

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Abstract. A highly efficient gain-clamped L-band EDFA with improved noise figure characteristic is demonstrated by simply adding a broadband C-band FBG in double-pass system. The combination of the FBG and optical circulator has created laser in the cavity for gain clamping. By adjusting the power combination of pumps 1 and 2, the clamped gain level can be controlled. The amplifier gain is clamped at 28.1 dB from −40 to −25 dBm with a gain variation of less than 0.5 dB by setting the pumps 1 and 2 at 59.5 and 50.6 mW, respectively. The gain is also flat from 1574 nm to 1604 nm with a gain variation of less than 3 dB. The corresponding noise figure varies from 5.6 to 7.6 dB, which is 0.8 to 2.6 dB less than those of unclamped amplifier.

Keywords. Gain clamping; optical amplifier; L-band EDFA; two-stage EDFA; double-pass EDFA.

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1. Introduction

Dense wavelength division multiplexing (DWDM) transmission systems are being deployed by service providers to meet the rapidly growing data traffic demands. Wide band fiber amplifiers are important subsystems for the next generation terabit DWDM transmission networks operating in the third window at 1550 nm. An earlier work by Yamada *et al* [1] shows the wide-band operation of an EDFA using two parallel optical amplifiers operating in the region of 1530–1560 nm (C-band) and 1570–1600 nm (L-band) with the output combined using a directional coupler. A major potential problem associated with the amplifier is a need to control the gain of EDFAs due to circumstances such as faults, adding and dropping of wavelength and rerouting. In these cases, the total input signal power to the amplifier varies abruptly causing the dynamics of the population inversion to change accordingly. Therefore, the amplifier gain increases or reduces with the potential to cause receiver saturation or bit error rate increment. Therefore, a gain-clamping mechanism is desired.

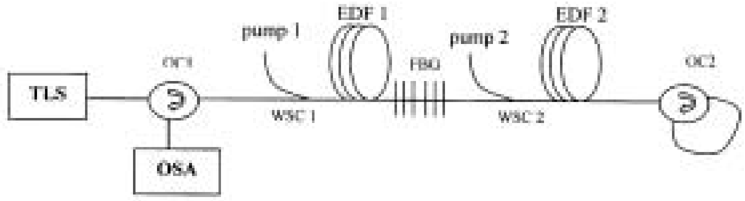

Figure 1. Configuration of the gain-clamped L-band EDFA.

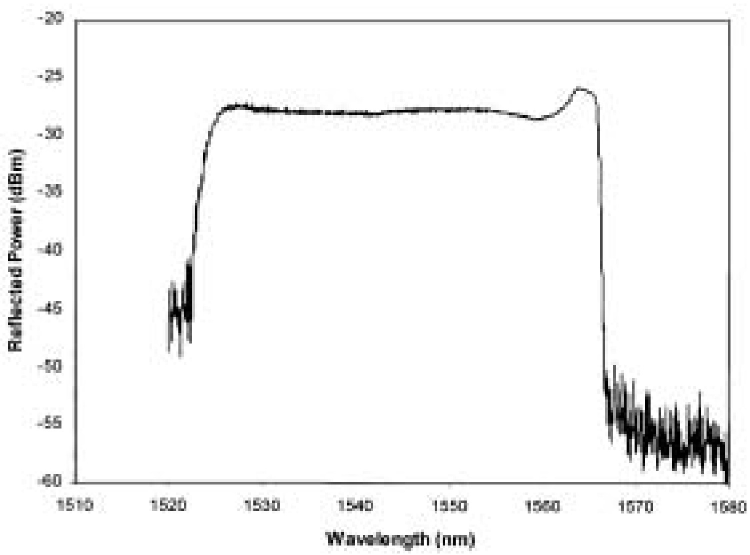

Figure 2. Reflection characteristics of the broadband FBG.

To date, several techniques have been suggested and experimentally verified for C- and L-band EDFA to control the dynamic gain variation, including the use of optoelectronic feedback circuits [2] and gain clamping by an all-optical feedback loop [3–5]. In this paper, a gain-clamped L-band EDFA with high gain is demonstrated by the incorporation of a broadband fiber Bragg grating (FBG) in the double-pass amplifier system.

2. Experimental set-up

The proposed configuration of gain-clamped EDFA is shown in figure 1. It consists of two sections of EDF, two laser diodes, a fiber Bragg grating and two circulators. Both EDFs have a length and nominal Er^{3+}-concentration of 50 m and 400 ppm, respectively. 980 nm laser diodes are used to pump both EDFs using forward pumping scheme. Two wavelength selective couplers (WSCs) were used to combine 980 nm pump from each laser diode with the tested signal. A broadband C-band FBG with a peak reflectivity at 1567 nm is employed in between the two EDF sections to create a laser in the amplifier system. The reflection spectrum of the FBG is shown in figure 2. It has a reflectivity of about 99% and a bandwidth of 40 nm centered at 1545 nm. At the amplifier output end, an optical circulator is employed which acts as a broadband reflector. It retro-passes the tested and laser signals back into the system. A tunable laser source (TLS) was used for the evaluation of the amplifier performances in conjunction with an optical spectrum analyzer (OSA), which is located at port 3 of the optical circulator OC1. The amplifier performances are also measured for unclamped amplifier, which is modified from the gain-clamped case by removing the FBG, for comparison purpose.

3. Result and discussion

Figure 3 shows the gain and noise figure of 1580 nm signal with respect to a variation of input signal power for the gain-clamped and unclamped amplifiers. Pump 2 is fixed at 50.6 mW for both gain-clamped amplifiers. Pump 1 for GC 1 and GC 2 are fixed at 48.6 mW and 59.5 mW, respectively. For the unclamped amplifier pumps 1 and 2 are fixed at 28.3 and 56.5 mW, respectively. Both gain-clamped (GC) amplifiers show a constant gain at small signal power compared to unclamped amplifier. The gain is clamped at 24.9 dB and 28.1 dB for GC1 and GC2 respectively, with a gain variation of less than 0.5 dB. The dynamic range of GC 1 and GC 2 is −20 and −25 dBm, respectively. This clamping effect is due to the laser light at 1567 nm, which is formed by the existence of the FBG and OC2 in the amplifier system. In a homogeneously broadened medium, laser light at certain wavelength fixes the total population inversion [6]; therefore the gain for all the wavelengths is dependent only on their absorption and emission cross-sections. Any variations

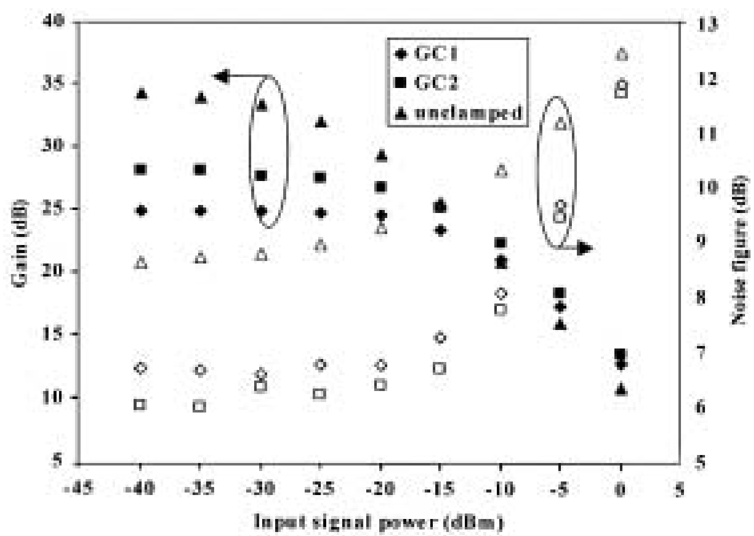

Figure 3. Gain (closed) and noise figure (clear) as functions of input signal power.

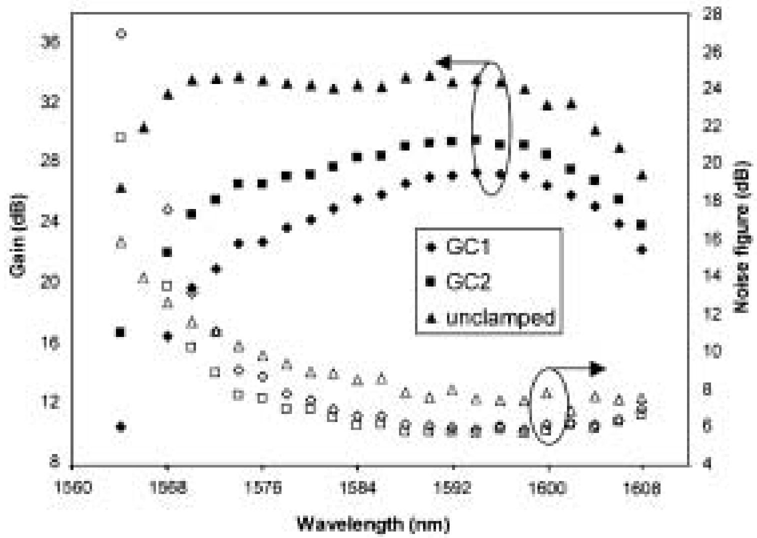

Figure 4. Gain (closed) and noise figure (clear) as functions of input signal wavelength.

in other conditions such as pump power and input signal power are compensated for by the adjustment of the laser light power. The consequence of this is that each signal wavelength experiences a constant gain, independent of pump and input signal power variations. In gain-clamped amplifier system, the laser light will reduce the clamped-gain value due to saturation effect. However, the clamped-gain is higher in this double-pass gain-clamped system compared to those of conventional gain-clamped EDFA [5]. This is attributed to the tested signal amplified twice in different directions in the double-pass system, and the total gain is almost doubled due to the increase of the effective EDF length.

At larger input signals, both gain-clamped amplifiers show a higher gain compared to those of unclamped amplifier as shown in figure 3. This is attributed to the incorporation of broadband C-band fiber Bragg grating that blocks the backward C-band ASE from EDF2 and increases the forward ASE level and thus the amount of energy available for transfer from short to long wavelength also increased. Noise figure on the other hand, shows a small reduction in gain-clamped amplifier. The noise figure is improved due to the increased population inversion in the first stage. This is attributed to the broadband FBG that blocks the backward propagating ASE of the second stage. Figure 4 shows a small signal gain and noise figure spectra for gain-clamped and unclamped amplifiers. The small signal gain is reduced for both the gain-clamped EDFA compared to those of unclamped amplifier due to the limited total population inversion. Compared to the unclamped amplifier, the flat-gain region of the gain-clamped amplifier is shifted to the longer wavelength. For the GC2 amplifier the flat-gain is obtained at about 28 dB with gain variation of less than 3 dB from 1574 nm to 1604 nm. The noise figure varies from 5.6 to 7.6 dB at this flat-gain region. The noise figure values are improved from 0.8 to 2.6 dB compared to those of unclamped amplifier due to the reason as explained above.

This gain-clamped system has a lower dynamic range than that of the ring laser configuration as demonstrated in our earlier work [5], which is dependent on the gain-clamped level and also on the design. The gain variation in this amplifier is quite high (0.5 dB) compared to 0.1 dB obtained in the ring laser configuration. This is attributed to the multiple splices which give rise to back reflection at the signal wavelength. This causes interference and increases the gain variation. This design has the advantage of higher gain as compared to the ring configuration.

4. Conclusion

A gain-clamped L-band EDFA with high gain and improved noise figure characteristics has been proposed and demonstrated. It uses a broadband C-band FBG in conjunction with an optical circulator to create laser in the cavity for gain clamping. The clamped gain level can be controlled by adjusting the power combination of pumps 1 and 2. The amplifier gain is clamped at 28.1 dB from -40 to -25 dBm with gain variation of less than 0.5 dB by setting the pumps 1 and 2 at 59.5 and 50.6 mW, respectively. The gain is also flat from 1574 nm to 1604 nm with a gain variation of less than 3 dB. The corresponding noise figure varies from 5.6 to 7.6 dB, which is 0.8 to 2.6 dB less than those of unclamped amplifier.

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