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All-optical gain-clamped wideband serial EDFA with ring-shaped laser

Yung-Hsin Lu *, Sien Chi

Institute of Electro-Optical Engineering, National Chiao-Tung University, Hsinchu 30050, Taiwan, ROC

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Abstract

We experimentally investigate the static and dynamic properties of all-optical gain-clamped wideband (1530–1600 nm) serial erbium-doped fiber amplifier with a single ring-shaped laser, which consists of a circulator and a fiber Bragg grating at the output end. The lasing light passing through the second stage is intentionally blocked at the output end by a C/L-band wavelength division multiplexer owning the huge insertion loss, and thus, the copropagating ring-laser light is formed by the first stage. This design can simultaneously clamp the gains of 1547 and 1584 nm probes near 14 dB and shows the same dynamic range of input power up to −4 dBm for conventional band and long-wavelength band. Furthermore, the transient responses of 1551 and 1596 nm surviving channels exhibit small power excursions (<0.54 dB) as the total saturating tone with −2 dBm is modulated on and off at 270 Hz.

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Keywords: Gain-clamped; Wideband; Serial; Erbium-doped fiber amplifier; Fiber Bragg grating; Transient response

1. Introduction

Erbium-doped fiber amplifiers (EDFAs) are widely used in the wavelength division multiplexing (WDM) networks, due to the high gain, wide gain bandwidth and the insensitivity to polarization. However, adding/dropping randomly WDM channels causes the harmful power transients and gain variations due to the cross-gain saturation effect. To stabilize the EDFA behavior, the optical gain-clamped (GC) technique, using an optical feedback loop, or a fiber Bragg grating (FBG) cavity has successfully demonstrated [1,2]. The gain-controlled principle is that the laser light at a certain wavelength fixes the population inversion at a low level and clamps the gain at all wavelengths in a homogeneous broadening medium [3].

Many conventional band (C-band: 1530–1560 nm) and long-wavelength band (L-band: 1570–1600 nm) EDFAs with optical gain-clamped

* Corresponding author. Tel.: +886-3-571-2121x56335; fax: +886-3-571-6631.

E-mail addresses: yhlu.eo85g@nctu.edu.tw (Y.-H. Lu), schi@mail.nctu.edu.tw (S. Chi).

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architectures have been extensively reported [4–9]. Recently, an optical gain-clamped wideband (C + L-band: 1530–1600 nm) EDFA is proposed by Hsu et al. [10]. The novelty is that they attempt to solely apply an optical feedback loop in the parallel EDFA configuration. Unfortunately, the simple design does not exhibit the acceptable gain-clamping due to the correlation between the lasing power, C-band and L-band input powers. In this paper, we propose a novel and simple gain-clamped wideband serial EDFA employing the single ring-shaped laser, which comprises a circulator and a FBG at the output. The optical gain and noise figure characteristics in terms of FBG wavelengths are examined. It is demonstrated experimentally that the dynamic ranges of input power for C-band and L-band signals are identical by using a FBG at a certain wavelength. Furthermore, the study on the transient effect confirms the small power excursion even though the total input power with −2 dBm is modulated on and off at 270 Hz.

2. Experimental setup

The schematic diagram of the proposed all-optical gain-clamped wideband EDFA was shown in Fig. 1. The configuration contained a conventional serial EDFA comprising two amplification stages and a copropagating ring-shaped laser loop. Although the first stage behaved as a C-band EDFA, the L-band signals were still amplified. A 978-nm laser diode with 85 mW was used as a pump for the EDF of 10.5 m length to obtain a high population inversion, and thus, reduced the noise figure. As for the second stage, L-band signals were amplified only. We used a 1480-nm laser diodes with 75 mW to pump a section of EDF with 76 m in order to raise the conversion efficiency. Between the two stages, the first C/L-band WDM was used to separate the C-band and L-band signals. The separated signals were combined with the second C/L-band WDM, placed at the output of the second stage.

The ring-shaped laser loop to control the gain variations was built via a 90/10 coupler, a circulator and a FBG, which are sited at the input and output ends of the whole system, respectively. FBG-1 at 1565.8 nm and FRG-2 at 1566.5 nm were used in turn. The reflectivity of FBGs is above 99.9%. Fig. 2 depicted the characteristics of the first C/L-band WDM. In the experiment, the laser wavelength was located at the dead zone (about 1565–1569 nm) of first C/L-band WDM, i.e., one part of laser light immediately transmitted

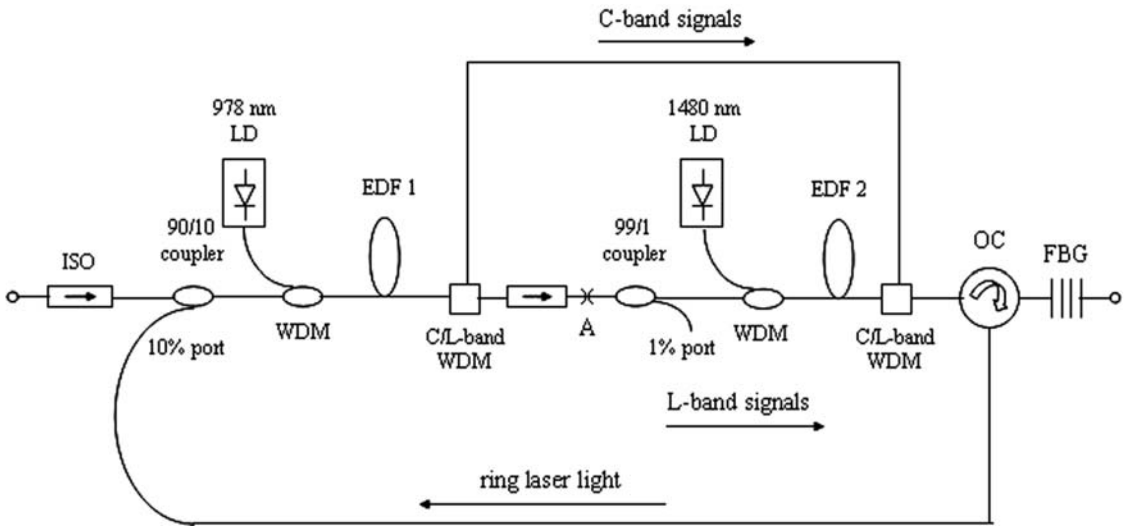

Fig. 1. Configurations of the proposed gain-clamped wideband EDFA with the ring-shaped laser.

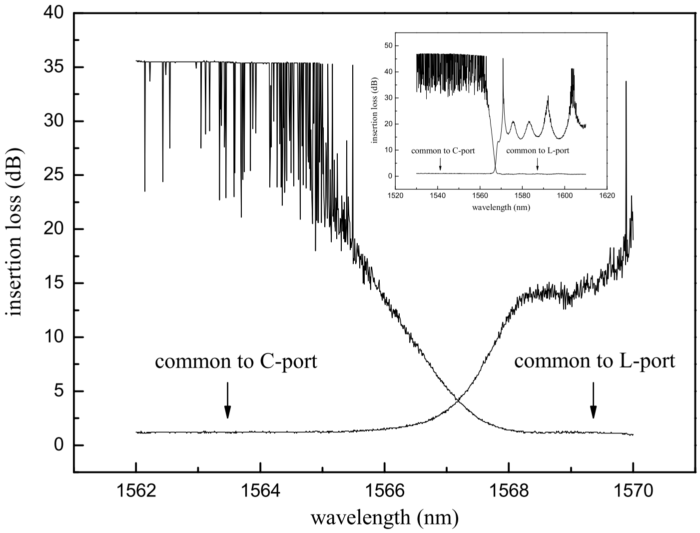

Fig. 2. Characteristics of the first C/L-band WDM.

forward to the output end and the other met the second stage. It is worth mentioning that the ring-shaped laser light was achieved solely by the first stage because the laser light at the output end of the second stage was blocked due to the serious insertion loss (>30 dB) between L-port and common port of the second C/L-band WDM. The purpose of this design was to reduce the correlation between the lasing power and the L-band input power.

The performances of the proposed gain-clamped amplifier were evaluated by the probe and saturating tone (sat. tone) technique. The C-probe and L-probe with −25 dBm and the C- and L-sat. tones were set at 1547, 1584, 1543 and 1588 nm, respectively. The optical gain and noise figure

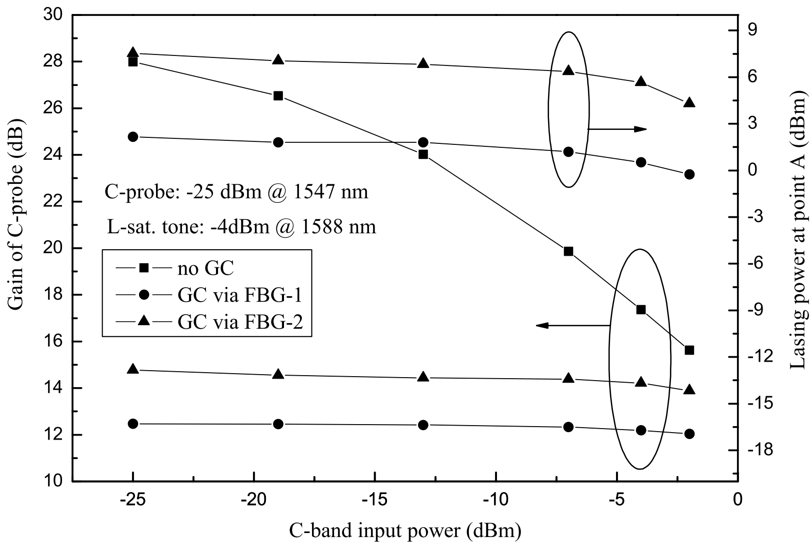

Fig. 3. C-probe gains and lasing powers at point A against C-band input powers for FBG-1 and FBG-2 as L-sat. tone is fixed at −4 dBm.

characteristics were measured by using time domain extinction method with Anritsu optical modulator and OSA. The transient behaviors were examined through a high-speed photo-detector with 1 GHz bandwidth.

3. Experimental results and discussion

Fig. 3 shows the C-probe gains and lasing powers at point A with C-band input powers for FBG-1 and FBG-2, respectively. Three useful messages are obtained: (1) No matter FBG-1 or FBG-2 is used, the C-probe gains are well controlled and the lasing powers almost keep constant. In fact, the L-probe gains in the first stage are also clamped at 3.5 dB (not shown in Fig. 3). (2) The clamped C-probe gains and lasing powers at point A increase as FBG-1 is replaced by FBG-2. This is because the insertion loss between common port and C-port in first C/L-band WDM increase with the longer wavelength, whereas the insertion loss between common port and L-port decrease. (3) The second stage is operated in the saturation region due to the high lasing power at point A. It is easily understood that the gain-clamping in the second stage is achieved as the amplified L-band signal power is significantly smaller than the lasing power at point A. Consequently, we predict that the amplifier with FBG-2 owns larger L-band power dynamic range, as compared with the FBG-1 case. The detailed results will be described in the following.

The gain characteristics at 1547 and 1584 nm for various C-band and L-band input powers of the un-clamped amplifier (with an open feedback loop) are shown in Figs. 4(a) and (b), respectively. Due to the short EDF length in first stage, the C-probe gain spectra show relatively irrelevance to L-band input powers as compared with L-probe gain spectra against C-band input powers. Figs. 5(a) and (b) illustrate the optical gains of C-probe and L-probe, respectively, for the proposed amplifier with FBG-1 at 1565.8 nm. The amplifier exhibits good C-probe gain-clamped performance within 0.64 dB variation for the measured input power range, i.e., the C-band and L-band input powers are up to −2 dBm. However, the gain-

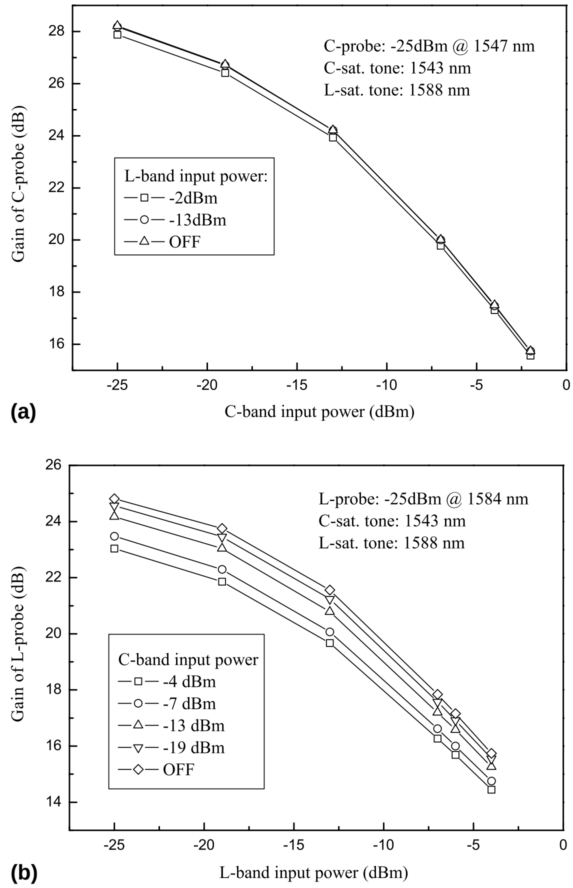

Fig. 4. Optical gain spectra of (a) 1547 nm and (b) 1584 nm as a function of the C-band and L-band input powers for the un-clamped amplifier.

clamped variation of L-probe will exceed in 1 dB as the C-band and L-band input powers are larger than −7 dBm. This is because the lasing power at point A is not enough high (around 1.5 dBm). Apparently, there are different power dynamic ranges for C-band and L-band signals. In order to overcome this problem, FBG-2 at 1566.5 nm is used to obtain higher lasing power at point A instead of FBG-1 (see Fig. 3). In our experiment, the insertion losses for common port to C-port and L-port of first C/L-band WDM are 1.3, 16.1 dB and 2, 9.1 dB corresponding to FBG-1 and FBG-2, respectively. Therefore, although the ring-shaped lasing power becomes smaller for the FBG-2 case, the lasing power at point A increases instead. The C-band power dynamic range is suppressed to −4 dBm, as

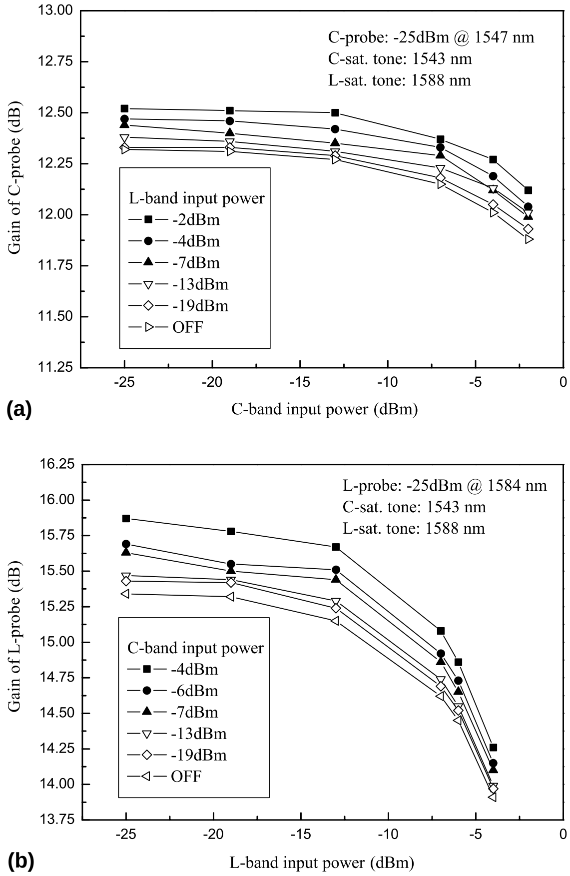

Fig. 5. Optical gain spectra of (a) 1547 nm and (b) 1584 nm as a function of the C-band and L-band input powers for the proposed amplifier with FBG-1.

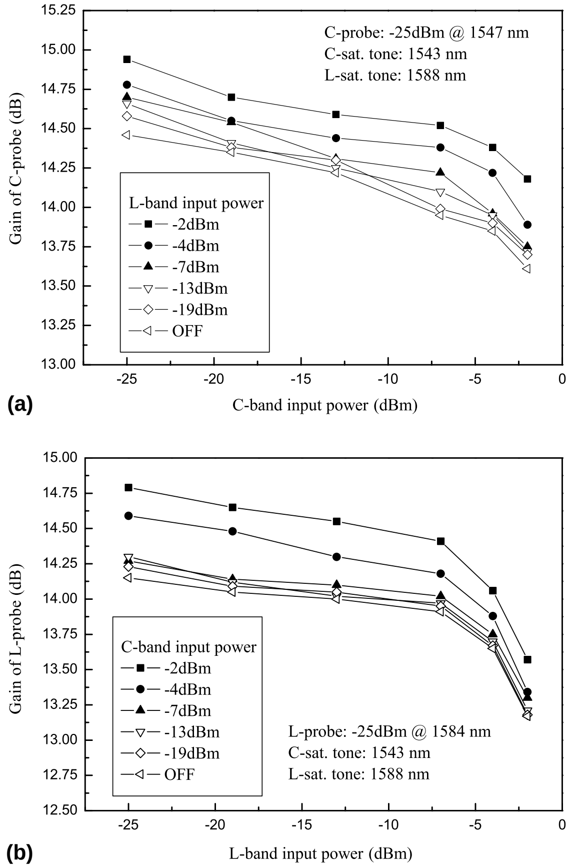

Fig. 6. Optical gain spectra of (a) 1547 nm and (b) 1584 nm as a function of the C-band and L-band input powers for the proposed amplifier with FBG-2.

shown in Fig. 6(a). The gain spectra at 1547 nm are within 14.3 ± 0.5 dB. For L-band operation, as expected, this design raises the power dynamic range to -4 dBm and offers the L-probe gain within 14.1 ± 0.5 dB, as shown in Fig. 6(b). To sum up, the C-band and L-band power dynamic ranges are adjusted to the same and the C-band and L-band output powers are approximately the same, which result from the use of FBG-2 in the proposed amplifier. Figs. 7(a) and (b) show the noise figure characteristics corresponding to Figs. 6(a) and (b), respectively. The noise performances of C-probe and L-probe are less than 5.4 and 6.7 dB, respectively.

Besides measuring the static properties of the proposed amplifier, dynamic gain (power) excursions of surviving channels are also investigated. A tunable bandpass filter (TBF), a high-speed photodetector and a oscilloscope are connected with the FBG output. Here, the probes (surviving channels) are changed to 1551 and 1596 nm at -20 dBm for increasing the ratio of the probe to the sat. tone at the output end. The C- and L-sat. tones with -5, -8 and -11 dBm, are modulated on and off at 270 Hz to simulate the adding/dropping channels. The transient behaviors of 1551 and 1596 nm are shown in Figs. 8(a) and (b). Because the laser wavelength at 1566.5 nm is not close to the spectral band occupied by signal wavelengths, the static power excursions are dominant which result from the spectral hole burning (SHB), i.e., inhomogeneity of the erbium gain medium [11–13]. Moreover, the effect can be reduced by decreasing

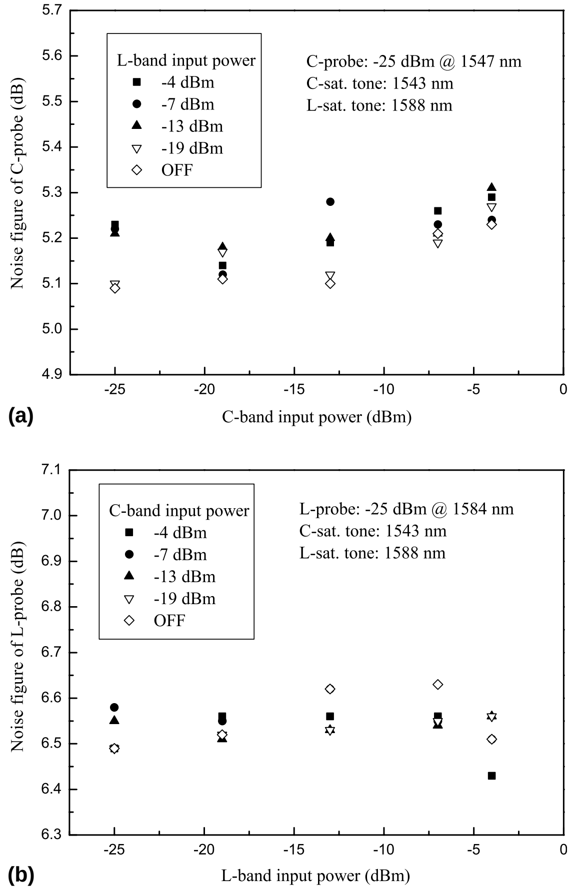

Fig. 7. Noise figure spectra of (a) 1547 nm and (b) 1584 nm as a function of the C-band and L-band input powers for the proposed amplifier with FBG-2.

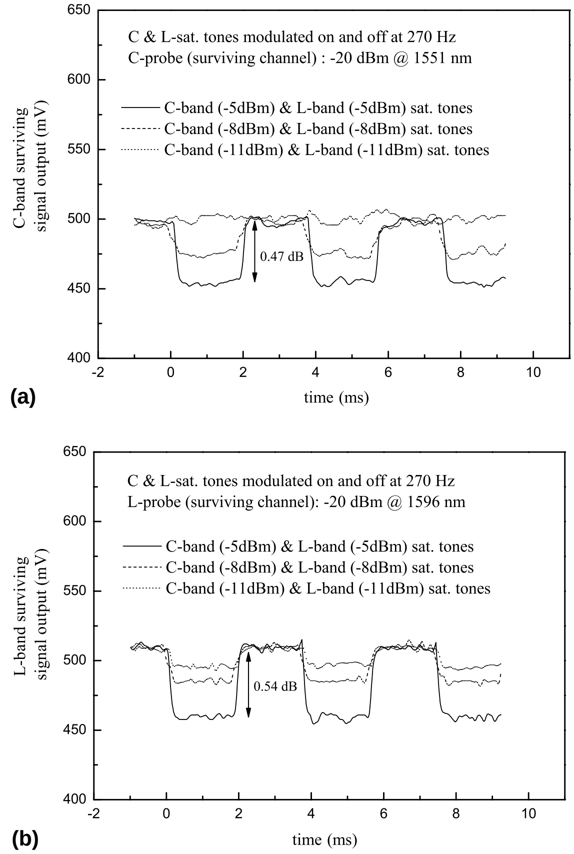

Fig. 8. Transient responses of (a) C- and (b) L-surviving channel output powers to adding/dropping C- and L-sat. tones with −5, −8 and −11 dBm.

total input powers, which causes the increase of lasing power. The drawback of this way is to sacrifice the available power dynamic range [14].

4. Conclusion

We have presented the static and dynamic performances of all-optical gain-clamped wideband serial EDFA with a ring-shaped laser, consisting of a circulator and a FBG at the output. The ring-shaped laser purposely designed is generated from the first stage to reduce the correlation between lasing power and L-band input power. The originality of this technique is that a sole optical feedback loop is applied to clamp the C-band and L-band gain characteristics simultaneously. The C-band and L-band power dynamic ranges are dependent upon the laser wavelength determined by FBG. It is experimentally demonstrated that choosing an appropriate FBG results in the same C-band and L-band power dynamic range. According to the static gain measurements, the dynamic range is up to −4 dBm within ±0.5 dB gain fluctuation as FBG-2 at 1566.5 nm is used. The transient behavior observations show that the power excursions of surviving channels are within 0.54 dB as total sat. tone (C-sat. tone plus L-sat. tone) with −2 dBm is modulated on and off at 270 Hz. Also, the power excursions can be suppressed at the expenses of the available dynamic ranges.

Acknowledgements

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