Available online at www.sciencedirect.com
SCIENCE DIRECT
Optics Communications 260 (2006) 150–154
OPTICS COMMUNICATIONS
www.elsevier.com/locate/optcom

L-band all-optical gain-clamped EDFA by utilizing C-band backward ASE

Hao Zhang *, Yanli Jin, Qingying Dou, Yange Liu, Shuzhong Yuan, Xiaoyi Dong

Institute of Modern Optics, Nankai University, Tianjin 300071, PR China

Received 14 June 2005; received in revised form 5 October 2005; accepted 5 October 2005

Abstract

By using an optical circulator and C/L-band wavelength division multiplexer to recycle the C-band backward ASE, an L-band gain-clamped erbium-doped fiber amplifier is presented. We have experimentally studied the static gain clamping property of this amplifier. As the ASE feedback attenuation is set to 0, the gain at 1585 nm can be clamped at 18.84 ± 0.26 dB within dynamic range of 25 dB and the critical power reaches about -15.09 dBm. The gain variation and saturated output power at 1585 nm for 0 dB attenuation are 1 dB lower and 2.17 dB higher than those for 30 dB attenuation, which indicates that the L-band EDFA gain can be effectively clamped via the ASE injection technique.

Keywords: Erbium-doped fiber amplifier; Gain clamping; L-band; Amplified spontaneous emission

1. Introduction

Due to their high gain, immunity to crosstalk and insensitivity to polarization, erbium-doped fiber amplifiers (EDFAs) are the key components in wavelength division multiplexing (WDM) systems. Recently, L-band EDFA has become the subject of extensive studies to meet the requirement of increasing communication traffic [1–5]. However, in optical cross-connect (OXC) or optical add-drop multiplexing (OADM) systems, the EDFA gain will change as the input signal power fluctuates. Thus gain clamping is necessary to achieve EDFA with constant gain. Generally, optical automatic gain clamping can be achieved by introducing control light inside the gain medium to share upper energy ions together with the signal light. In various gain-clamping schemes, lasing mechanism is established via optical oscillation cavities by utilizing fiber Bragg gratings or optical filters as wavelength-selective components [6–13]. In 2002 and 2004, Huran et al. [14,15] achieved L-band gain-clamped EDFAs by utilizing broadband FBGs to reflect a portion of C-band backward ASE. However, it is rather difficult and expensive to fabricate such FBGs with wide bandwidth and high reflectivity. In addition, since the signal light propagates along the same path with the control light, it would be inconvenient to adjust the ASE feedback attenuation.

In this letter, we report an L-band gain-clamped EDFA by combining an optical circulator (OC) with a C/L-band wavelength division multiplexer (WDM) to recycle the C-band backward ASE. Experimental results show that gain clamping in this amplifier can be effectively realized by this ASE injection technique. Moreover, the static gain level can be adjusted by changing the ASE feedback.

2. Operation principle

The basic configuration of our L-band gain-clamped EDFA is illustrated in Fig. 1. In this amplifier, two 980 nm laser diodes (LDs) with pump power of 95 and 53 mW are used as the co-pump and counter-pump sources, respectively, and 36 m erbium-doped fiber (EDF) serves as the gain medium. The fiber end reflection at input

* Corresponding author. Tel.: +86 22 23509849; fax: +86 22 23508770.
E-mail address: dr_haozhang@yahoo.com.cn (H. Zhang).

0030-4018/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.optcom.2005.10.017

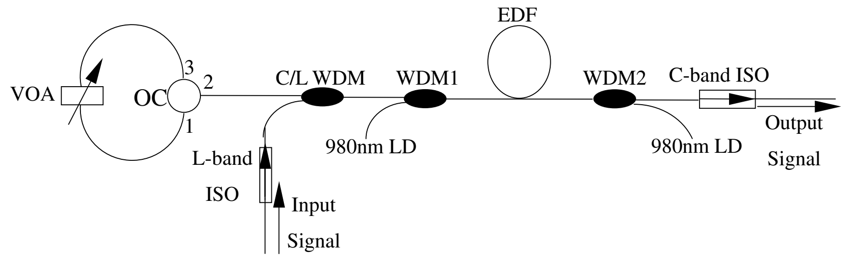

Fig. 1. Schematic diagram of the L-band gain-clamped EDFA by utilizing C-band ASE injection technique.

and output ports may induce laser oscillation inside the amplifier. As a result, the lasing wavelength severely consumes the upper energy erbium ions, which will degrade the gain and noise figure performance of the gain-clamped EDFA. Therefore, to suppress the noise figure and prevent any facet oscillation, two optical isolators (ISOs) are placed at the input and output ports of this amplifier. Confined by the experimental conditions, a C-band isolator is employed at the output port. To separate or combine the C-band ASE and L-band signal light, the C-band, L-band, and C plus L-band ports of a C/L-band WDM are spliced with port 2 of an L-band optical circulator, input isolator, and the signal port of WDM1, respectively. Meanwhile, the L-band optical circulator is placed at the left end of this amplifier to recycle the C-band backward ASE and a variable optical attenuator (VOA) is inserted between port 3 and 1 to adjust the ASE feedback.

The principle of this amplifier can be described as follows: After the L-band signal light propagates through the input isolator and L-band port of the C/L-band WDM, it will enter the bi-pumped amplifier from the C plus L-band port. Meanwhile, after the C-band backward ASE travels through the C/L-band WDM and optical circulator, it will be re-injected into the amplifier and shares the erbium ions together with L-band signal light. Thus, the C-band ASE works as control light and gain clamping in this amplifier is achieved. Furthermore, by tuning the attenuation of ASE feedback, the clamped gain level can be conveniently adjusted.

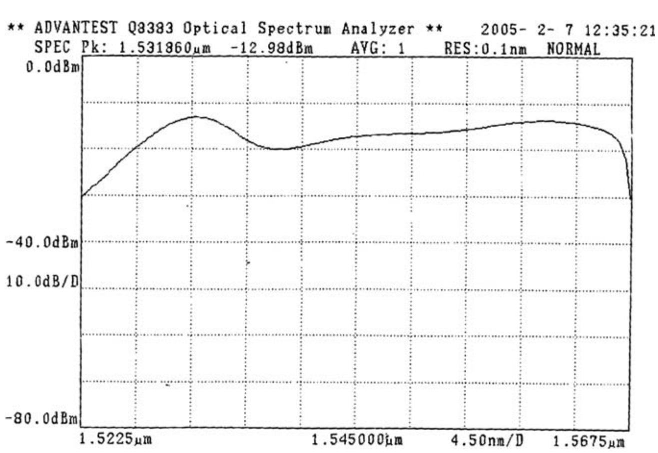

Fig. 2. C-band backward ASE measured at port 3 of the OC.

Fig. 2 shows the output spectrum at port 3 of the optical circulator. From this figure, it is clear that the backward ASE is mainly located in the conventional band and its power is sufficiently high. After the C-band ASE is attenuated and propagates through C/L-band WDM, it will enter the amplifier together with L-band signal and work as the control light.

3. Experimental results and discussion

As the input signal power is fixed at about −40 dBm, we have studied gain spectrum evolution of this EDFA when feedback attenuation is adjusted from 0 to 30 dB, as shown in Fig. 3. It is apparent that the EDFA gain generally becomes higher with the increase of feedback attenuation. The average gains of this amplifier are 17.72 and 25.53 dB for attenuation of 0 and 30 dB, respectively. The increase of feedback attenuation induces the decrease of C-band feedback control light, which will inevitably lead to the gain promotion. From this figure, it can be also found that the change of feedback attenuation does not have an explicit influence on the noise figure. Within attenuation range of 0–30 dB, the corresponding average noise figures are 6.33, 6.43, 6.13, 6.35, 6.81, 6.95, and 6.91 dB, respectively.

To evaluate the static gain clamping property of this EDFA, we have measured the gain and noise figure characteristics at 1585 nm with respect to the input signal power when feedback attenuation changes within 0–30 dB, as shown in Fig. 4. The static gain level increases with the decrease of feedback ASE, which is in agreement with the results in Fig. 3. For feedback attenuation of 0–30 dB and input signal power of −40 to −15 dBm, the EDFA gains are clamped at 18.84 ± 0.26, 19.50 ± 0.29, 20.45 ± 0.19, 21.47 ± 0.37, 22.33 ± 0.45, 22.91 ± 0.70, and 23.23 ± 0.76 dB, respectively. From Fig. 4, it can be also found that the saturated input and output power decreases with the increase of feedback attenuation. As the feedback attenuation increases from 0 to 30 dB, the saturated input powers are −5.51, −5.90, −7.15, −8.47, −9.85, −11.78, and −12.57 dBm, respectively. The corresponding saturated output powers reach 10.58, 10.81, 10.48, 10.06, 9.67, 8.82, and 8.41 dBm, respectively. Except the output saturated power for feedback attenuation of 5 dB, all experimental data conform to the above regularity. In our opinion, the deviation of the saturated output power for 5 dB