Two-Stage L-Band EDFA Applying C/L-Band Wavelength-Division Multiplexer With the Counterpropagating Partial Gain-Clamping

Yung-Hsin Lu and Sien Chi

***Abstract*—A simple ring laser technique of two-stage gain-clamped long-wavelength band erbium-doped fiber amplifier is investigated. The ring laser light is excluded at the output end and noise-figure degradation can be reduced due to the counterpropagating partial gain-clamping in the second stage. The laser mechanism is achieved by the C/L-band wavelength-division multiplexer instead of a tunable bandpass filter and an optical circulator at the output end, which were often used in the previous counterpropagating ring laser architectures, and thus, this design is cost-effective. The gain-clamping of long-wavelength band (1569–1606.2 nm) in our configuration is demonstrated experimentally for the saturating tone (1587.6 nm) power up to -2 dBm.**

***Index Terms*—C/L-band wavelength-division multiplexer (WDM), erbium-doped fiber amplifier (EDFA), gain clamped, long wavelength, partial gain-clamping.**

I. INTRODUCTION

THE long-wavelength band (L-band) erbium-doped fiber amplifier (EDFA) is one of the key components for fiber transmission with the wavelength-division-multiplexing (WDM) technology. In a WDM system, the gain of EDFA fluctuates when the channels are added or dropped. To stabilize the gain, two main optical techniques applying the ring laser with tunable bandpass filter (TBPF) or laser cavity with fiber Bragg gratings (FBGs) have been investigated [1], [2]. The laser fixes the population inversion of active ions at different desired levels against input power variations so the gain-clamping can be achieved.

For the gain-clamped fiber amplifier with ring laser cavity, the noise-figure degradation is more unobvious because the laser light at the input end of the erbium-doped fiber (EDF) with the copropagting gain-clamping has lower intensity than that with the counterpropagating gain-clamping [3], [4]. However, the laser light with the copropagating gain-clamping will exist at the output end as well as the amplifying signals. In order to satisfy the gain-clamping and low noise-figure degradation, the partial counterpropagating gain-clamped technique has been demonstrated [5], [6].

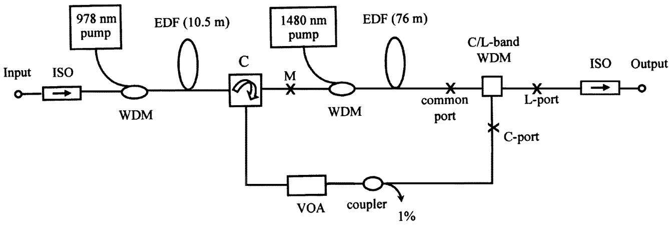

Fig. 1. Schematic diagram of the proposed two-stage gain-clamped L-band EDFA.

In this letter, we propose a novel and simple configuration of two-stage gain-clamped L-band EDFA. The middle isolator in the conventional two-stage EDFA is replaced by the circulator. Without TBPF and FBG, the counterpropagating laser is formed by applying an optical circulator and a C/L-band wavelength-division multiplexer (C/L-band WDM), which are located at the input and output ends in the second stage, respectively. Through the measurements of the gains and noise figures of 1569–1606.2-nm input probe by adjusting the 1587.6-nm saturating tone from turned OFF to -2 dBm, the gain-clamped effects and good noise figure have been successfully demonstrated.

II. EXPERIMENT

The schematic diagram of two-stage gain-clamped L-band EDFA we propose is shown in Fig. 1. The typical insertion loss of the isolator, pump WDM, and circulator are 0.9, 1, and 0.5 dB, respectively. The EDF with a peak absorption 6.7 dB/m at 1530 nm is used as the active medium. For low noise figure, we use a 978-nm pump laser diode to achieve the high population inversion in the first-stage EDFA. The pump power of 30 mW was used for an EDF of 10.5-m length. In the short EDF length, the gain of L-band signal almost keep constant against input power variations. For the second stage, the long EDF with 76-m length was prepared for L-band EDFA. In order to maximize the power conversion efficiency, the 1480-nm pump laser diode with 70 mW was used. For the C/L-band WDM, the function is to separate conventional band (C-band) and L-band lights and the minimum isolations coressponding to the C-port and L-port are 13 and 36 dB respectively, except for the transitional region of 1562–1570 nm. The counterpropagating laser is formed with the circulator and C/L-band WDM, and can be monitored through 1% port of the 99/1 coupler in the ring cavity.

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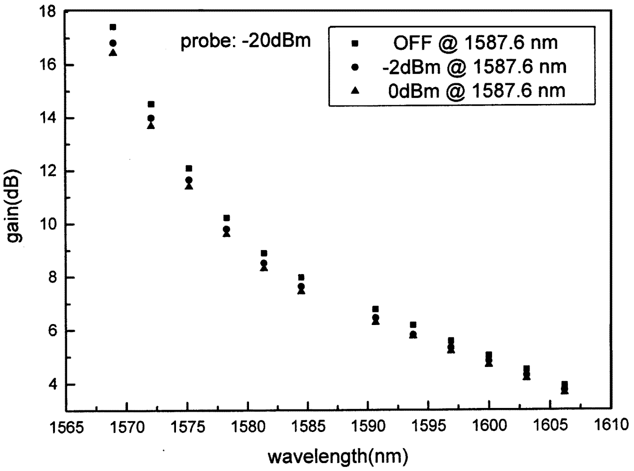

Fig. 2. Gain spectrum of L-band signals between input port and M in Fig. 1.

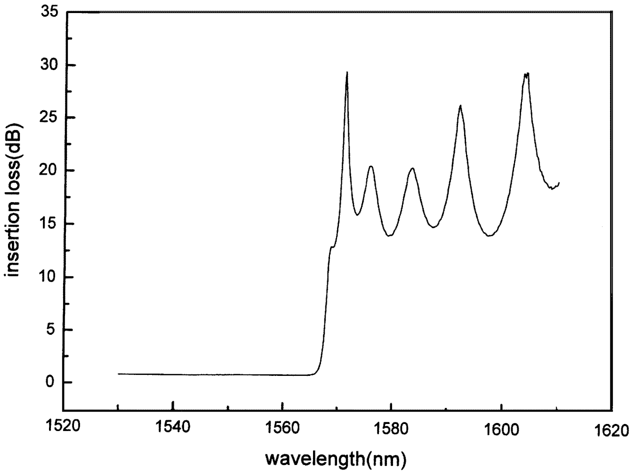

Fig. 3. Spectrum of insertion loss measured from C-port to common port of C/L-band WDM.

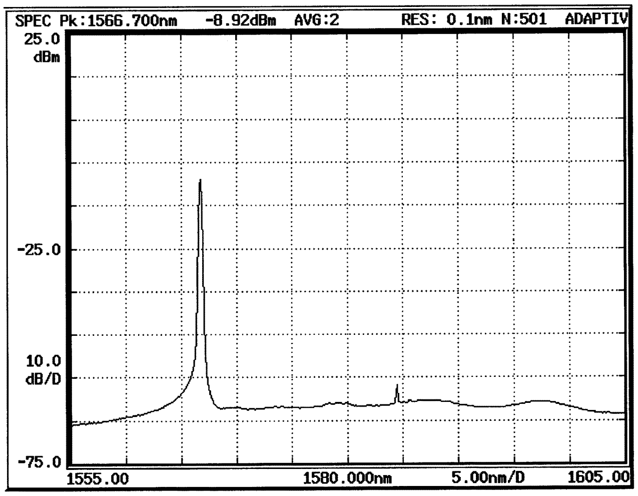

Fig. 4. Spectrum of counterpropagating ring laser when −20-dBm input signal at 1584.5 nm and the 1.5-dB attenuation are applied.

It is worthy noting that the lower the attenuation of the variable optical attenuator (VOA) becomes, the higher the laser intensity becomes.

The input signal power consists of probe and saturating tone, which provided with two tunable light source. The input probe is fixed at −20 dBm and the saturating tone is at the wavelength of 1587.6 nm, respectively. In our experiment, the probe signal was swept from 1569 to 1606.2 nm with 3.1-nm spacing. To protect the optical spectrum analyzer (OSA), an attentuator of near 2.8 dB was applied in front of the OSA. Finally, we use time domain extinction method with Anritsu optical modulator and ADVANTEST OSA to measure the gain and noise figure between input port and M or between input port and output port in Fig. 1.

III. RESULT AND DISCUSSION

The proposed two-stage gain-clamped L-band EDFA has gain-constant effect and low noise-figure degradation. In the first stage, gain-constant performance is obtained due to weak L-band gain saturation for the short EDF length. Therefore, the laser light for gain-clamping is unnecessary to pass through the input end of EDF, so the low noise-figure degradation can be expected. An EDF with a length of 10.5 m was forwardly pumped by 978-nm laser diode of 30 mW. The gain spectrum of L-band signals between input port and M in the Fig. 1 is shown in Fig. 2. For the probe of 1584.5 nm, the gain fluctuations were 0.34 and 0.58 dB when the 1587.6-nm saturating tone was from switched OFF to −2 and to 0 dBm, respectively.

As for the second stage, a ring laser architecture is attached with a 76-m-long EDF which was pumped with the 1480-nm laser diode of 70 mW. The counterpropagating ring laser cavity is mainly constructed with the circulator and C/L-band WDM. It is more cost-effective as compared with the previous laser construction, comprising a TBPF and two circulators. Fig. 3 shows the insertion loss spectrum of C-port to common port of the C/L-band WDM. The measurements show the insertion loss has an abrupt increase near the critical wavelength of 1566 nm; hence, there is high isolation for the wavelength longer than the critical value. Due to this restriction, the ring laser will oscillate near 1566 nm started by the backword amplified spontaneous emission (ASE). Fig. 4 shows the experimental results that the laser oscillated at 1566.7 nm, which was monitored at 1% port of the 99/1 coupler via OSA. Furthermore, Fig. 5 shows that the ring laser light at the output is extremely small due to the counterpropagating ring cavity and the larger insertion loss (around 9 dB) between the common port and L-port of C/L-band WDM.

Fig. 6 shows the gains and noise figures against input power variations for −20-dBm input probe at 1584.5 nm. When optical feedback was applied, the probe signal gain against the input power variations almost keep constant as compared with no optical feeback EDFA. The dynamic input power ranges and the noise figures depend on the ring laser intensity, which can be operated by adjusting the attenuations of VOA. The dynamic input power ranges and the noise figures increase as the attenuation decreases. By applying the attenuation of 1.5 dB, the dynamic range was up to −2 dBm, the worst noise figure was 6.29 dB and the gain fluctuation was 0.58 dB. For the two-stage EDFA without optical feedback, the minimum noise figure was observed for critical input power near −8 dBm. The dip effect results from the interplay between self-saturation by backward ASE and signal-induced saturation [7]. Similar noise

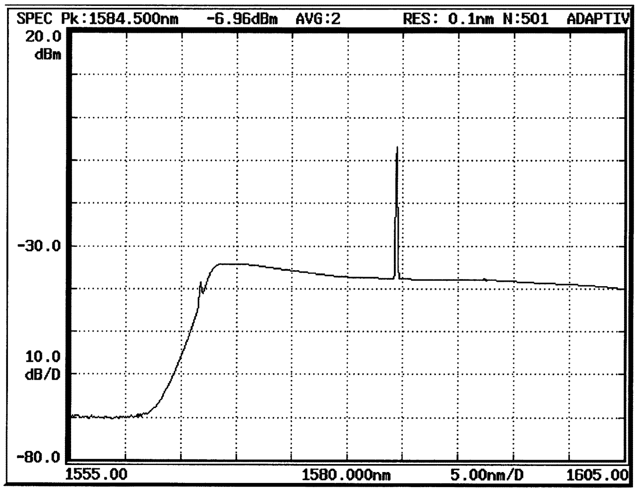

Fig. 5. Output spectrum of proposed two-stage gain-clamped EDFA when −20-dBm input signal at 1584.5 nm and the 1.5-dB attenuation are applied.

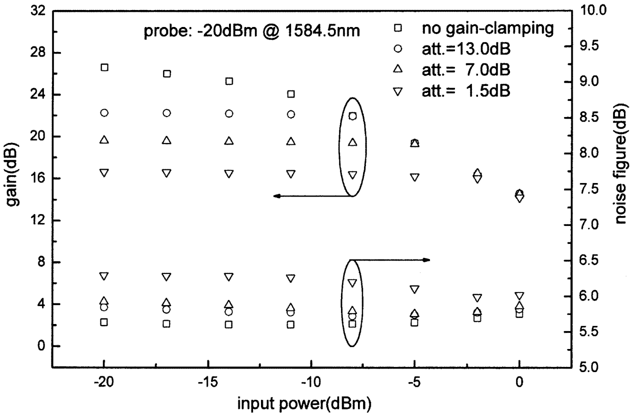

Fig. 6. Dependence of gain and noise figure on input power for −20-dBm input probe at 1584.5 nm between input port and output port in the Fig. 1.

figures were measured for optical feedback EDFA system but now the self-saturation for the second stage mostly arises from the counterpropagating ring lasing oscillation. For the input powers within the dynamic range, the significant noise-figure penalties are induced by the intense ring laser light passing through the second EDF. However, for input powers above the dynamic range, the noise figures are primarily dominated by the signal-induced saturation. The slight noise-figure degradation was caused by the regenerative backward ASE. The results show that the critical input power coressponding to minimum noise figure increases with the decreasing of the attenuation of VOA. For the attenuations of 7 and 1.5 dB, the critical powers were raised from −8 dBm to nearly −5 and −2 dBm, respectively, compared with no gain-clamped EDFA.

In order to evaluate the suitability of the proposed gain-clamped EDFA for all L-band channels, the gain and noise-figure measurements in the L-band ranging from 1569 to 1606.2 nm with 3.1-nm spacing were observed, as shown in Fig. 7. We studied the gain characteristics of L-band signals for two extreme situations, which are −20-dBm input probe and −2-dBm saturating tone, respectively. The gain variations of each L-band probe signal were no more than 0.7 dB and the differences mostly came from the first-stage EDFA. These results demonstrated the effectiveness of our amplifier configuration.

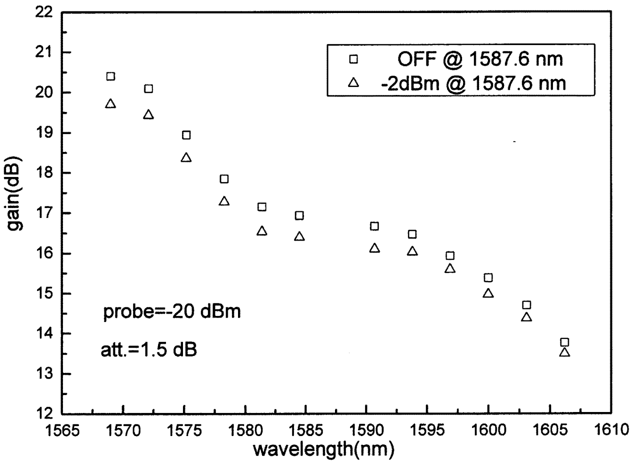

Fig. 7. Gain-clamped effects for all L-band channels in our configuration.

IV. CONCLUSION

A two-stage L-band EDFA using a ring laser with the C/L-band WDM has been presented. To satisfy the requirement of low noise-figure penalty, the partially gain-clamped technique was applied in our configuration. The first-stage EDFA owned the gain-constant property, which arises from L-band weak gain saturation in the short EDF length. A counterpropagating optical feedback was attached on the second-stage EDFA in order to prevent the ring laser light from existing at the output. Stabilizing gain characteristics with the lasing oscillation was also confirmed in this experiment. The optical amplifier possessed the ability of gain constant for the dynamic range up to −2 dBm. According to the analysis of noise figures, the critical input power for smaller attenuation of VOA shifts to higher level. Finally, the experimental results showed that the proposed system is applicable for the gain-clamping of L-band probe between 1569 and 1606.2 nm.

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