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GAIN ENHANCEMENT IN L-BAND EDFA BY SPLITTING EDF INTO TWO STAGES

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Abstract. An experiment on gain enhancement in the long-wavelength band erbium-doped fiber amplifier (L-band EDFA) is demonstrated using a dual stage configuration. Compared to a conventional single-stage amplifier, the small signal gain for a 1580 nm signal can be improved by 5.5 dB without paying much noise figure penalty. The corresponding noise figure penalty was 0.3 dB due to the insertion loss of the optical isolator. The optimum pump power ratio for the first pump was experimentally determined to be 33%. The maximum gain improvement of 8.3 dB was obtained at a signal wavelength of 1568 nm while signal and total pump powers were fixed at -30 dBm and 92 mW, respectively. These results show that the employment of the dual-stage amplifier system will play an important role in the development of a practical L-band EDFA from the perspective of economical usage of pump power.

Keywords: Erbium-doped fiber, optical amplifier, L-band EDFA, dual-stage EDFA, amplified spontaneous emission

Abstrak. Sebuah esperimen bagi menambah daya pembesaran untuk jalur gelombang panjang (jalur-L) pembesar terdop erbium (PTE) telah didemonstrasi menggunakan reka bentuk yang berbadan dua. Jika dibandingkan dengan pembesar yang berbadan satu, pembesar ini dapat menambah pembesaran untuk isyarat 1580 nm sebanyak 5.5 dB dengan sedikit sahaja penambahan nilai bisingan. Nilai bisingan bertambah sebanyak 0.3 dB kerana kemasukan isolator di dalam reka bentuk. Kadar kuasa pam pertama mestilah 33% daripada jumlah keseluruhan kuasa pam untuk nilai optima. Pembesaran maksimum sebanyak 8.3 dB telah diperolehi oleh isyarat 1568 nm semasa kuasa isyarat dan kuasa pam, masing-masing ditetapkan pada 30 dBm dan 92 mW. Keputusan esperimen menunjukan penggunaan pembesar berbadan dua dapat menjimatkan kos kerana ia menggunakan kuasa pam yang lebih rendah.

Kata kunci: Gentian terdop erbium, pembesar optik, pembesar terdop erbium, jalur L PTE.

1.0 INTRODUCTION

The ever-increasing demand for capacity in WDM transmission systems is mainly driven by Internet traffic. In spite of the impressive progress of WDM technologies to date, advances are still being made. The WDM capacity can be increased by carrying more channels in a broadened optical spectrum. Currently, installed WDM systems utilize the bandwidth from 1530 to 1560 nm (conventional-wavelength band, C-band), which coincides with erbium-doped fiber amplifier (EDFA) gain window. In order to

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cope with the fast pace of capacity demand, new transmission windows are needed. This new gain window is called the long-wavelength band (L-band). A merger between C-band and L-band amplifiers for ultra-dense WDM systems is a pre-requisite that leads to new architectures for broadband amplifiers [1].

The L-band amplifier operation lies at the tail of the erbium gain window where the inversion rate is low. The emission and absorption coefficients in the L-band are also smaller than that in the C-band. These smaller coefficients along with the low average inversion cause the L-band gain coefficient to be significantly smaller than the C-band. Thus, in order to exploit this region for high gain, the length of erbium-doped fiber (EDF) is around 6-8 times longer than that in the conventional amplifier. The longer EDF lengths create several fundamental challenges: power conversion efficiency (PCE) decreases due to the total passive fiber loss increases and performance degradation due to substantial accumulation of backward amplified spontaneous emission (ASE) power. The main challenge therefore in present optical amplifier research is to improve signal gain in the L-band effectively.

Several approaches have been suggested to overcome these problems in the L-band. One of the solutions is the optimization of the fiber parameters that enable high gain in the L-band to be achieved at shorter erbium doped fiber (EDF) lengths [2]. Another effort to improve the gain involves the use of the backward C-band ASE as a secondary pump source to pump an underpumped EDF section [3] and the use of a double pass technique [4]. In this paper, a dual-stage (DS) L-band EDFA is proposed to improve the gain using an optical isolator to split the EDF into two segments.

2.0 CONFIGURATION

Figure 1 shows a configuration of the dual stage L-band EDFA. It consists of two sections of EDF (EDF1 and EDF2), two 980 nm laser diodes (P1 and P2) and an optical isolator. EDF1 and EDF2 are fixed at 20 m and 30 m, respectively. Both EDF have an Er^{3+} peak absorption of 5.6 dB/m at 1531 nm. The optical isolator is inserted between the first and second stages to eliminate any backward amplified spontaneous emission (ASE). Wavelength selective couplers (WSC1 and WSC2) are used to combine the test signal and the 980nm pump into the EDF. The pump powers of P1 and P2 are optimized at 35 and 57 mW, respectively. A tunable laser sourse (TLS) is used for the evaluation of the amplifier performances in conjunction with an optical spectrum

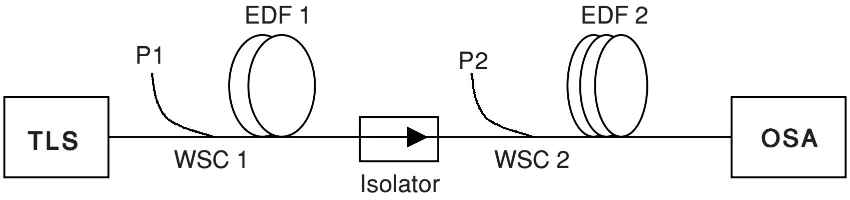

Figure 1 Configuration of the dual stage L-band EDFA

analyzer (OSA). The gain and noise figure were compared with those of single-stage amplifier. The single stage (SS) amplifier used a 50 m EDF, which was forward pumped by a 92 mW of pump power.

3.0 RESULTS AND DISCUSSION

Figure 2 depicts the ASE spectra of both SS and DS amplifiers with a total pump power of 92 mW where the thin line represents the ASE spectrum of the proposed DS amplifier. As is apparent in the figure, the spectrum of the proposed amplifier is much higher than that of the SS amplifier, represented by the thick line. By splitting the pumping into two positions along the length of the EDF as a DS amplifier, the ASE level is increased due to a large forward ASE from the first-stage whereby the first-stage population has not been depleted by a backward-propagating ASE of the second stage. The pump power of the first stage is fixed at 35 mW that is 33% of the total pump power because this is the optimum value as shown in Figure 3. Figure 3 also shows the gain and noise figures as functions of the power ratio of pump 1. The maximum gain is obtained at 33% before decreasing slowly until the ratio reached 85%. On the other hand, the noise figure shows a constant value of 3.2 dB at pump 1 ratios of 28% to 85%.

The gain and noise figure characteristics against the input signal power were measured by varying the input signal power from –40 to 0 dBm as shown in Fig. 4. The input signal power and wavelength were fixed at –30 dBm and 1580 nm, respectively. The

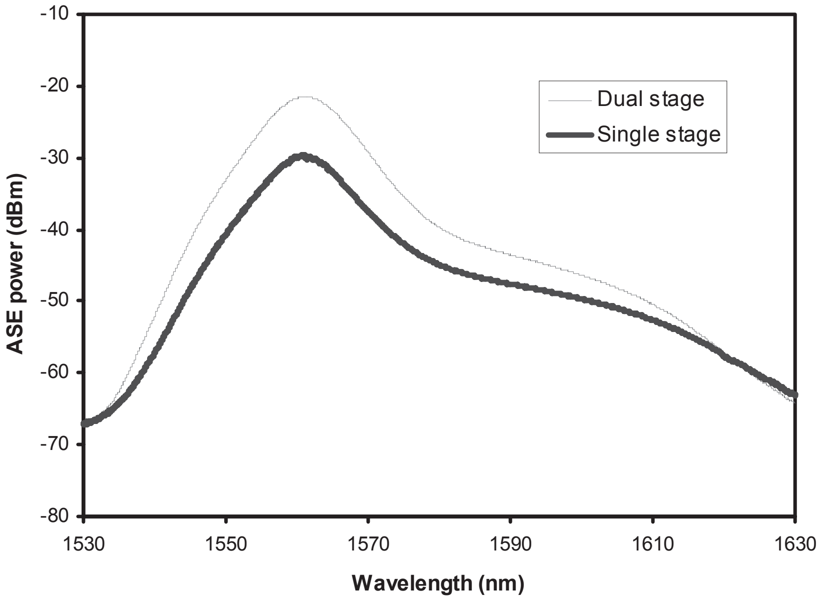

Figure 2 ASE spectra of the L-band EDFA with the total pump power of 92 mW. For DS amplifier, pump 1 and pump 2 are fixed at 35 mW and 57 mW, respectively

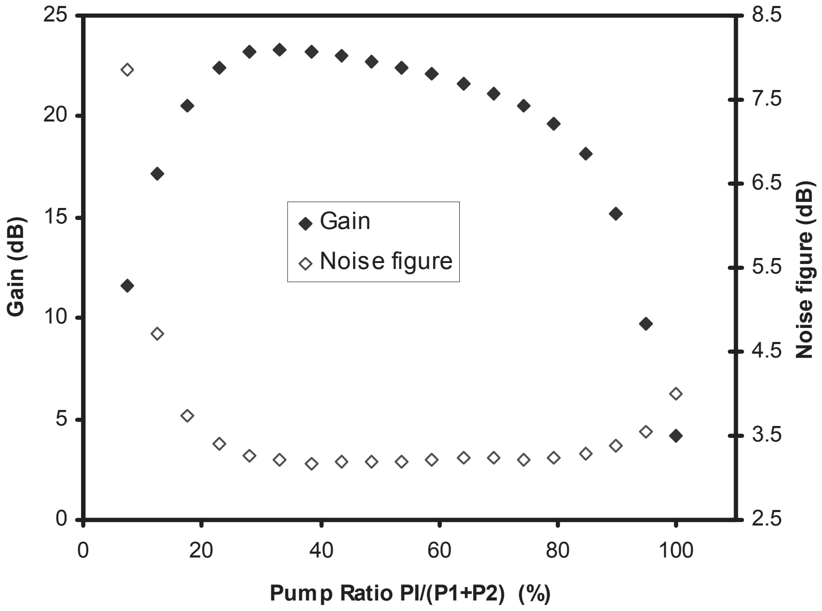

Figure 3 Gain (closed) and noise figures (clear) as functions of power ratio of pump 1

gain and noise figure also were compared to those of DS system without an optical isolator. A gain enhancement of about 5.5dB is obtained at small signal levels for the DS amplifier with the isolator compared to those of the SS amplifier. This is attributed to the dual forward pumping scheme as well as the optical isolator that blocks the backward-propagating ASE and increases the forward ASE level and thus the amount of energy available for transfer from short to long wavelength also increases. The first-stage amplifier works as a preamplifier with a relatively high inversion rate, while the second stage acts as a power amplifier with high pump efficiency.

For the DS system without the isolator, the backward ASE of the second-stage depletes the population of the first-stage. Therefore, the L-band gain is lower than that of the configuration with the isolator due to the insufficient forward ASE as shown in Fig. 4. The saturation powers of the SS and DS amplifiers without the isolator and that of the DS amplifier with the isolator are –12 dBm, –12 dBm and –14 dBm, respectively. On the other hand, the noise figure of the proposed dual-stage amplifier is higher by 0.3 dB than that of the SS amplifier for all input signal powers. This noise figure degradation is caused by the inserted component loss. The optical isolator is used to separate the EDF into two sections to prevent the backward ASE from entering the first-stage section and the severe degradation of the noise figure. For the DS system without the isolator, a noise figure as high as 6.2dB is obtained at a small signal wavelength as shown in Fig. 4. The measured excess powers of the 980 nm pump at the EDF ends of 20 m and 30 m were less than 0.1 mW. This shows that almost all of the 980nm pump power is absorbed by the EDFs.

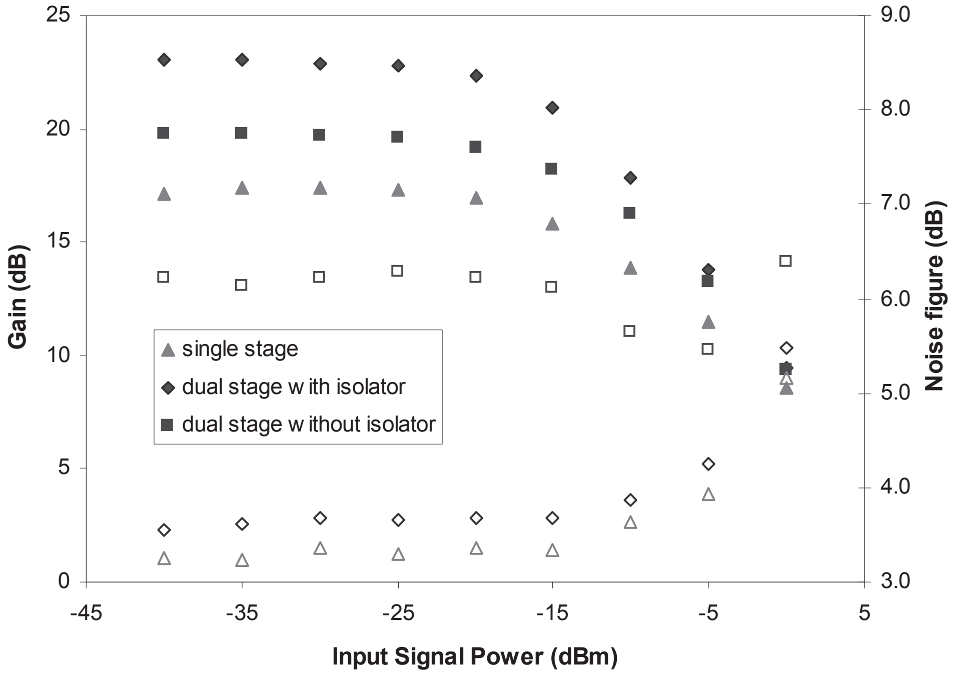

Figure 4 Gain (closed) and noise figures (clear) as functions of input signal power for SS, DS amplifiers without the isolator and DS amplifier with the isolator

Figure 5 shows the gain and noise figure spectra for an input signal power of –30 dBm and a total pump power of 92 mW. As is apparent in the figure, the gain of the DS amplifier is higher than that of the single stage amplifier particularly at shorter wavelengths. This improvement is obtained by amplifying and employing the forward ASE from the first stage to the second stage. The first 10~15 m of the forward-pumped EDF experiences a very high pump power with correspondingly high population inversion rates in the C-band in both the forward and backward directions. However, insertion of the isolator blocks the backward ASE from the second stage, which has a higher pump power allocation. Suppression of this high-power backward ASE enables built-up of the forward ASE in the first stage since there is no other mechanism that can deplete the inversion. This results in a very high power forward ASE which can be used to transfer energy from the higher energy C-bands to the lower energy L-band wavelengths. It also can be seen in Figure 5 that the maximum gain enhancement value of 8.3 dB is obtained in the DS amplifier compared with the conventional SS amplifier at a wavelength of 1568 nm. The corresponding noise figure penalty is 0.5 dB. The noise figure penalties were obtained particularly at longer wavelengths for the same reason as that explained above. These results show that the employment of the DS amplifier system will play an important role in the development of a practical L-band EDFA from the perspective of economical usage of pump power.

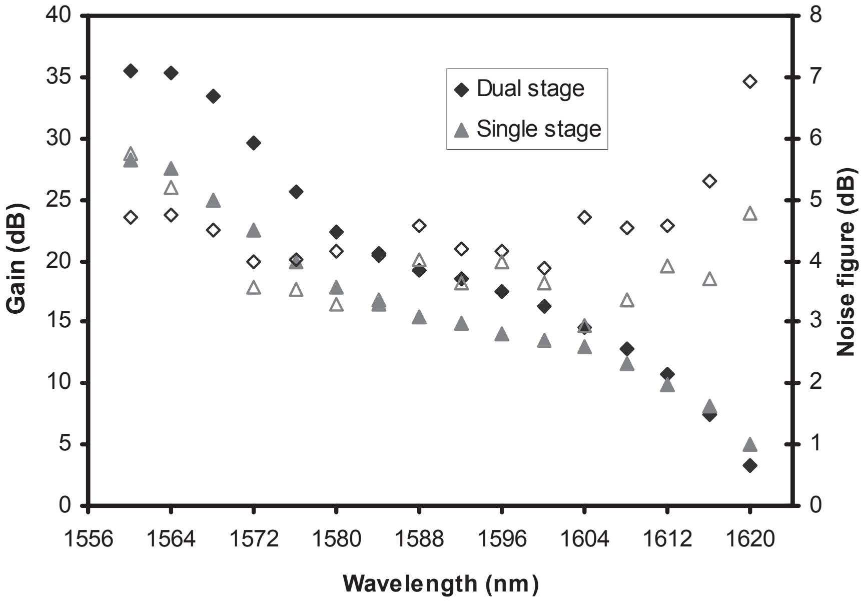

Figure 5 Gain (closed) and noise figures (clear) as functions of input signal wavelength

4.0 CONCLUSION

Gain enhancement is demonstrated in L-band EDFA by splitting EDF into two stages. An optical isolator is inserted between the first and second stages to eliminate any backward amplified spontaneous emission (ASE). The amplifier has improved the small signal gain for the 1580 nm signal by 5.5 dB at the expense of a 0.3 dB noise figure penalty compared to a conventional SS amplifier. The noise figure penalty is due to the insertion loss of the optical isolator. The optimum pump power ratio for the first pump was experimentally determined to be 33%. A maximum gain improvement of 8.3 dB was obtained at a signal wavelength of 1568 nm while the signal and total pump powers were fixed at –30 dBm and 92 mW, respectively.

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