55 dB High Gain L-Band EDFA Utilizing Single Pump Source

M. H. Al-Mansoori, W. S. Al-Ghaithi, F. N. Hasoon

Abstract**—**In this paper, we experimentally investigate the performance of an efficient high gain triple-pass L-band Erbium-Doped Fiber (EDF) amplifier structure with a single pump source. The amplifier gain and noise figure variation with EDF pump power, input signal power and wavelengths have been investigated. The generated backward Amplified Spontaneous Emission (ASE) noise of the first amplifier stage is suppressed by using a tunable band-pass filter. The amplifier achieves a signal gain of 55 dB with low noise figure of 3.8 dB at -50 dBm input signal power. The amplifier gain shows significant improvement of 12.8 dB compared to amplifier structure without ASE suppression.

Keywords**—**Optical amplifiers, EDFA, L-band, optical networks.

I. Introduction

DOPED fiber amplifiers based on erbium are one of the most efficient optical fiber amplifiers in the present development of long-haul wavelength division multiplexed (WDM) optical communication systems and fiber-to-the home (FTTH) optical networks [1]. It operates in a wide band covering C-band (conventional band) with wavelength range from (1530-1565) nm and L-band (long wavelength band) with wavelength range from (1570-1610) nm [2]-[4]. However, since the gain coefficient in the L-band is smaller than that in the C-band, longer length of the doped fiber with high pump power is used in the L-band [5]. In literature, various gain enhancement techniques have been proposed to enhance the gain of L-band optical amplifier such as using a double pass configuration with a fiber Bragg grating (FBG) or tunable band-pass filter [6], [7], using amplified spontaneous emission (ASE) end-reflectors [8], utilizing backward ASE as a secondary pump source for the un-pumped section of erbium-doped fiber (EDF) [9]. Among the other gain enhancement techniques proposed is the use of a two stage structure with a bypass isolator [10], a three-stage structure of EDF pumped by 980 nm and 1480 nm laser diodes, which can achieve 35dB of gain with 5 dB of noise figure [11] and the use of residual pump power in a three-stage configuration [12], [13]. In recent work, a flat gain bandwidth of 17 dB in L-band region using pump distribution technique and 25m of EDF length is demonstrated [14]. Even through these approaches have enhanced the gain of L-band EDFA, the enhancement is at the expense of more than one pump source, longer EDF lengths and the high number of optical components used in the amplifier structure. Therefore, it is desirable to design L-band EDFA with high gain and low noise figure using single pump source and short gain medium for simple integration with passive optical devices as well as the economic feasibility.

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In this paper, we present experimental results that demonstrate an efficient triple-pass high gain L-band erbium-doped fiber amplifier. The amplifier gain of 55 dB with noise figure less than 3.8 dB using single pump source and short EDF length is achieved. To the best of our knowledge, this is the highest gain obtained in the development of L-band EDFA using single pump source with only 8 m of EDF length. The high gain obtained is attributed to the optimization of the pump powers, the input signal power, and wavelengths and also to the suppression of the backward amplified spontaneous emission noise by using a tunable band-pass filter.

II. Experimental Setup and Operation Principle

Fig. 1 shows the experimental setup of triple-pass L-band EDFAs, which consists of input laser source, pump laser, two optical circulators (C1,C2), WDM, two erbium doped fibers (EDF1,EDF2), 3dB optical coupler, an optical isolator (ISO), and optical filter. A 980 nm pump laser is used to pump the gain medium with fifty percent of the pump power is distributed to the first stage while the remaining portion of pump power is distributed to the second stage by using a 3 dB optical coupler as depicted in Fig. 1. The length of the gain medium in the first stage and second stages are 5 m and 3 m, respectively. The first stage is pumped in forward direction while the second stage is pumped in the backward direction through a WDM, which is used to multiplex the 980 nm pump and the signal. The ISO is placed at the output port to eliminate any back reflection. A tunable band pass filter (TBPF) with 1nm bandwidth is inserted after port 3 of the first circulator (C1) to filter out the backward ASE noise from saturating the gain of the second stage. The first circulator is used to launch the original input signal to the first stage. The second circulator (C2) is used as a fiber reflector, which reflects the amplified signal at the end of first stage.

The amplified optical signal is reflected at the fiber reflector and returns to EDF1 for double-pass amplification. The input signal is then passed to EDF2 through port 3 of C1 for triple-pass amplification. The 980 nm pump laser is varied from 105 mW to 380 mW while the input signal power is varied from -50 to 0 dBm with different wavelengths. The amplifier gain and noise figure are taken at the output port of the ISO as shown in Fig. 1 and are measured by an optical spectrum analyzer (OSA).

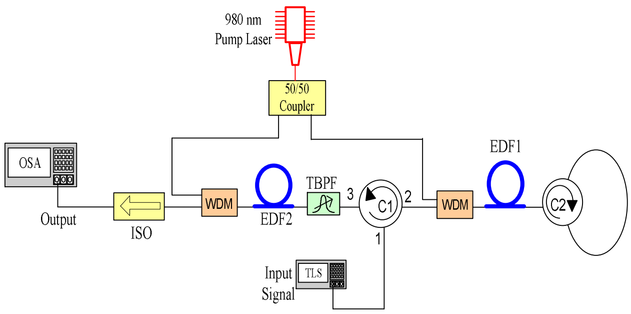

Fig. 1 Experimental setup of triple-pass L-band erbium-doped fiber amplifier with a single pump source

III. Result and Discussion

The input signal power, wavelengths, EDF length and pump power play an important role in obtaining high amplifier gain with low noise figure. To get high amplifier gain, we used a TBPF after the first stage to suppress the backward ASE noise from saturating the gain of the second stage. We vary the 980 nm pump power from 105 mW to 381 mW. Fig. 2 shows the effect of 980 nm pump powers on the amplifier gain at different input signal powers of 0 dBm, -10 dBm, -30 dBm and -50 dBm. The wavelength of the input signal is fixed at 1570 nm.

From this figure, we can see that the gain of the EDFA increases with the increasing of the 980 nm pump power and then goes to saturation after a certain level of the pump power. At the saturation region, the increase in the gain becomes smaller due to the high power that provides population inversion for all the erbium ions in the fiber. In this region any increase on the 980 nm pump power does not contribute much to the improvement of gain as shown in Fig. 2. For input signal power of -50 dBm, the gain increases from 10.8 dB to 55 dB when the pump power increase from 105 mW to 380 mW, respectively. This is because the erbium ion population inversion increases with the increment of EDF pump power. In addition, the amplifier gain is increased with the decrement of the input signal power. The effect of the input signal wavelength on the amplifier gain is also investigated. Fig. 3 shows the amplifier gain against input signal wavelength at different input power of 0 dBm and -50 dBm. The 980 nm pump power is fixed at 314 mW. Within the tuning range of the TBPF, the input signal wavelength is varied from 1550 nm to 1585 nm in step of 5 nm.

At low input signal, the amplifier gain is a strong function of the signal wavelength due to the variation of the absorption and emission cross-sections with wavelength [2]-[5]. For L-band, the signal at longer wavelengths experiences a lower gain in comparison to shorter ones. As shown in Fig. 3, the highest gain is obtained at 1565 nm input signal wavelength with power of -50 dBm. This is due to the higher absorption and emission at 1565 nm wavelength. At longer wavelengths, the gain coefficient is reduced due to the low absorption and emission coefficient. In addition, the amplifier gain is reduced with the increment of the input signal power.

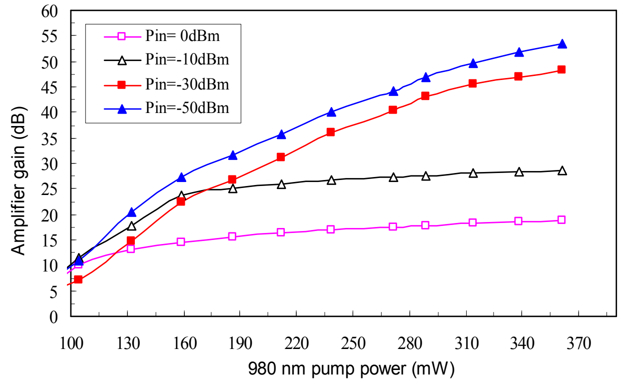

Fig. 2 Amplifier gain against 980 nm pump power at different input signal powers for 1570 nm signal wavelength

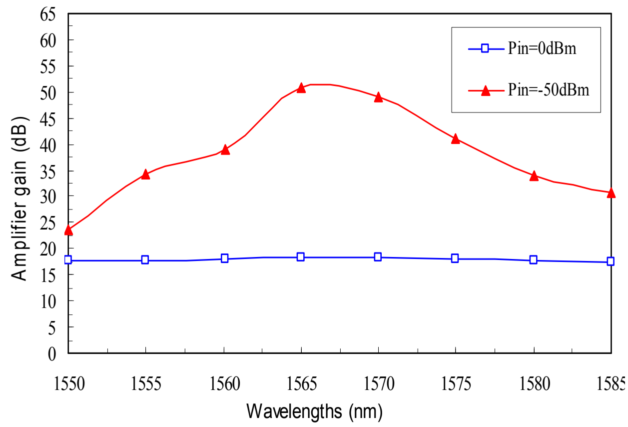

Fig. 3 Gain against input signal wavelength at 314 mW pump power with different input signal power of 0 dBm and -50 dBm

The performance of the amplifier structure is also investigated at different input signal powers. Fig. 4 shows the amplifier gain against input signal power at different EDF pump power. The input signal wavelength is fixed at 1570 nm. In this work, three different pump powers are applied and the signal power is increased from –50 dBm to 0 dBm. From Fig. 4, it is seen that EDFA gain decreases with increasing signal input power. At -50 dBm input signal and 380 mW of 980 nm pump power a gain of 55 dB with noise of 3.8 dB is obtained. The population inversion level is dependent on the input signal power where the inversion is decreased as the input signal power is increased [9]. In addition, high input signal stimulates excited erbium-ions very fast and consequently the erbium-ions population depletes at the beginning of the fiber. Therefore, the pump power is unable to replenish the inversion of ions to the higher level as fast as the signal depleting the excited ions [7], [8]. In Fig. 4 (b), the variation of noise figure is given as a function of input signal power for a fixed wavelength of 1570 nm and different EDF pump powers. In this experiment, the input signal power varies from -50 dBm to 0 dBm in step of -5 dBm. The graph shows that the amplifier noise figure increases with increasing input signal power above -10 dBm. For signal powers from -40 dBm to -15 dBm, the noise figure is maintained.

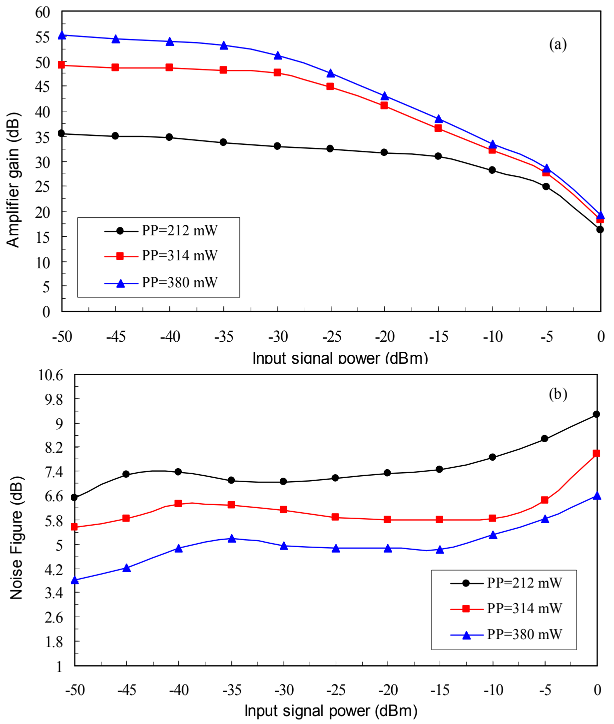

Fig. 4 (a) Amplifier gain and (b) noise figure against input signal power at 1570 nm wavelength with different pump powers of 212 mW, 314 mW, and 380 mW

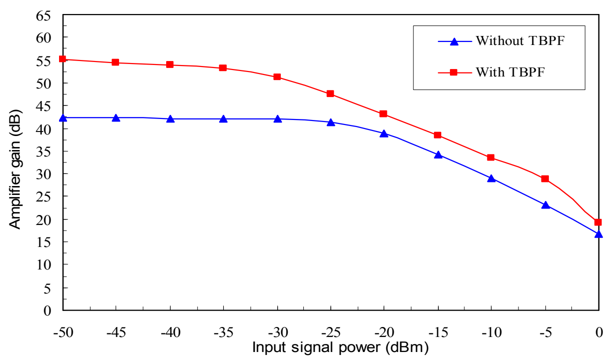

Fig. 5 Amplifier gain against input signal power at 1570 nm wavelength with and without TBPF at 380 mW pump power

To prove the enhancement of the amplifier gain due to the use of TBPF, we study the performance of the amplifier with TBPF and without TBPF. The main function of the TBPF is to suppress the backward ASE noise from interning the second stage of the amplifier structure. Thus, the gain saturation due the ASE noise is eliminated. Fig. 5 shows the amplifier gain against input signal power with and without a TBPF at 380 mW of EDF pump power. At low input signal of -50 dBm, the amplifier gain is improved to about 12.8 dB. The measured gain shows significant improvement compared to amplifier structure without ASE suppression for input signal below -25 dBm. The maximum gain obtained from the experiment is 55 dB with noise figure of about 3.8 dB at 1570 nm wavelength with EDF pump power of 380 mW.

IV. Conclusion

We have studied the performance of a triple-pass L-band EDFA using a single pump source for different input signal powers, signal wavelengths and EDF pump powers. High gain with low noise figure optical amplifier is obtained using a single pump source and short gain medium. By including a TBPF between the amplifier stages, we obtain a high signal gain of 55 dB with noise figure less than 3.8 dB. The use of TBPF in the correct position shows significant improvement in the amplifier gain compared to amplifier structure without TBPF. A gain improvement of 12.8 dB is achieved at low input signal of -50 dBm.

Acknowledgment

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