EFFICIENT AND COMPACT OPTICAL AMPLIFIER USING EYDF

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Abstract: An efficient Erbium/Ytterbium doped fiber amplifier (EYDFA) is demonstrated using a 1058 nm pumping wavelength, where the amplification is assisted by the energy transfer between the Yb and Er ions. This energy transfer process allows a higher erbium doping concentration as opposed to the conventional erbium doped fiber. Therefore, the gain and noise figure is severely degraded with 1480 nm pumping, where the energy transfer cannot be achieved. The use of an optical isolator improves the small signal gain and noise figure by about 4.8 dB and 1.6 dB, respectively. By employing a double-pass configuration, higher gain can be obtained at an expense of a noise figure penalty. A gain improvement of 17.0 dB is obtained at a 20 mW and -50 dBm pump and input signal power. This indicates that the double-pass configuration is an important approach in designing an efficient EYDFA.

Keywords: *EYDFA, power amplifier, Er/Yb doped fiber amplifier*

1. INTRODUCTION

Recently, significant interest has been shown in producing a compact fiber based optical amplifier. Typically, a short length of erbium-doped fiber (EDF) with high concentration of erbium ions is used, but the high concentration is limited due to concentration quenching [1]. To overcome this limitation, an Er/Yb doped fiber (EYDF) can be utilized to increase the limits of erbium doping concentration. EYDFs are also attractive as it exhibits an intense broad absorption between 800 and 1100nm, spanning several pump wavelength source options.

In an EYDF, Yb ions are excited to the $^2F_{5/2}$ state by absorbing light at the 800 – 1100 nm range as shown in Fig. 1. Then, the energy transfer occurs between the $^2F_{5/2}$ state of the Yb ions and the $^4I_{11/2}$ state of the Er ions through energy transfer process. The now excited Er ions will decay to the $^4I_{13/2}$ state by a nonradiative process, thus forming a population inversion between the $^4I_{13/2}$ and $^4I_{15/2}$ states. Incident optical signals at the 1550 nm band will be amplified through the process of stimulated emission. Yb ions as well as Er ions have low solubility in a silica host, and because both have approximately the same ionic radius, they will cluster together. This clustering reduces the distance between the Yb ions and Er ions and allows the energy transfer to proceed with good efficiency [4]. Due to the presence of the Yb ions, the clustering of the Er ions is avoided, and also reduces the pair-induced quenching (PIQ) effect between the Er ions. This allows the increases the Er doping concentration limit.

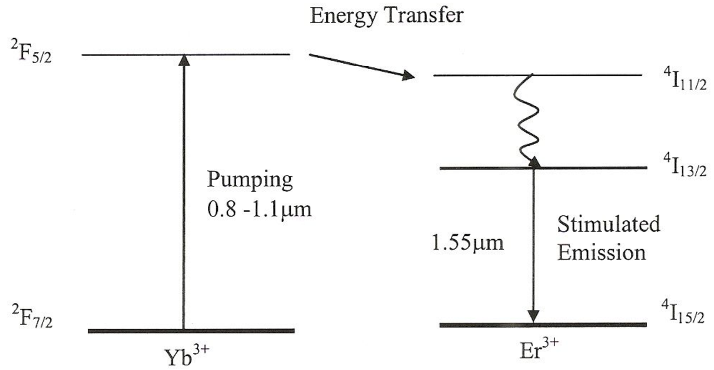


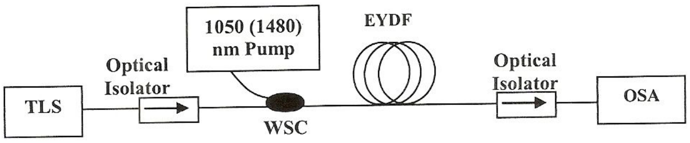
Fig. 1: Model of energy levels in an Er/Yb system.

Recently, various works on the Er/Yb doped fiber amplifiers (EYDFA) have been reported using a pump wavelength ranging from 800 to 1100 nm [5-6]. In this paper, the EYDFAs are experimented using a 1058 nm laser diode as the pumping source. The amplifier's performance is also compared against 1480 nm pumping to study the importance of the energy transfer in the performance of the amplifier. The effect of spurious reflection on the amplifier's performance is also investigated. Finally, an efficient EYDFA is demonstrated using a double-pass configuration.

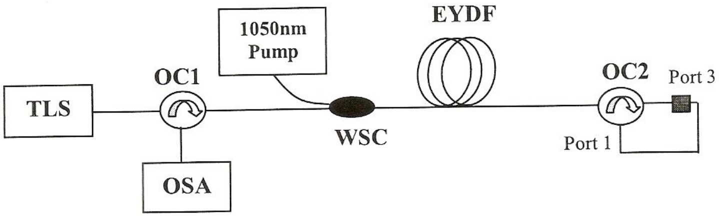
2. EXPERIMENT

Figure 2 (a) shows the configuration of the typical EYDFA. The EYDF used in this experiment is commercially available with an Er and Yb concentration of 1000 and 45000 ppm respectively and a cutoff wavelength of 1032 nm. The EYDF is then pumped with a 1058 nm laser diode in a forward pumping scheme. A wavelength selective coupler (WSC) is used to combine the pump light with the test signal. Isolators are incorporated at both the input and output ends of the amplifier as to avoid spurious reflection. A tunable laser source (TLS) in conjunction with an optical spectrum analyzer (OSA) is used to evaluate the amplifier's performance. The amplifier's performance result is then compared with a similar EYDFA configuration pumped at 1480 nm. The gain and noise figure are also characterized for this amplifier without optical isolators. The experiment is then repeated for a double-pass configuration, in which two optical circulators, OC1 and OC2 are located at input and output ends of the amplifier, respectively as shown in Fig. 2(b).

OC1 is used to route the amplified signal into an OSA and also to block any spurious back reflection. OC2 is used to retro-pass the test signal back into the EYDF by connecting ports 3 and 1 together.



(a) Typical single-pass EYDFA.



(b) Double-pass EYDFA.

Fig. 2: Configurations of EYDFA (a) single-pass (b) double-pass.

3. RESULTS AND DISCUSSION

Figure 3 shows the forward ASE spectrum of the single-pass EYDFA at different EYDF lengths. The pump power is fixed at 120 mW and EYDF length is varied from 3 m to 13 m. As illustrated in the figure, the optimum length of the EYDF should be in the range from 4 to 6 m. The highest peak at -4.5 dBm is obtained for a wavelength at 1535 nm with an EYDF length of 5 m. The ASE level starts to decrease once the fiber length exceeds this length. In comparison to an EDFA, the ASE spectrum of an EYDFA rises more steeply around the 1534 nm region as depicted in Fig. 3. Therefore, lasing is easily achieved in this region in the presence of spurious reflections. This is the reason why the spurious reflections have to be avoided by placing the isolators in the setup.

As a result of the Yb which has a strong absorption band from 800 to 1100 nm, the EYDF must be pumped using a light source with a wavelength matching the absorption band of Yb. This is so that the energy transfer from the $^2F_{5/2}$ state of the Yb ions to the $^4I_{11/2}$ state of Er ions takes place. For comparison purpose, experiments are also carried out with the pumping of the EYDF using a 1480 nm laser diode, which is unaffected by Yb absorption. Figure 4 shows gain and noise figure spectra of the single-pass EYDFA of Fig. 2(a) at different pumping wavelengths of 1058 nm and 1480 nm. The EYDF length is fixed at 5 m and the input signal and pump powers are fixed at -30 dBm and 120 mW respectively. As shown in the figure, the gain and noise figure under 1058 nm pumping is much better compared to that under 1480 nm pumping. For instance, the gain increases by about 20 dB at wavelength of 1536 nm. The corresponding noise figure is also reduced by 11 dB. This shows that the energy transfers between the Yb to Er ions plays a very important role in achieving high gain and low noise figure in the EYDFA. This implies that pumping at 1058 nm is more effective as compared against pumping at 1480 nm. The proposed EYDFA operates in C-band region ranging from 1520 to 1560nm.

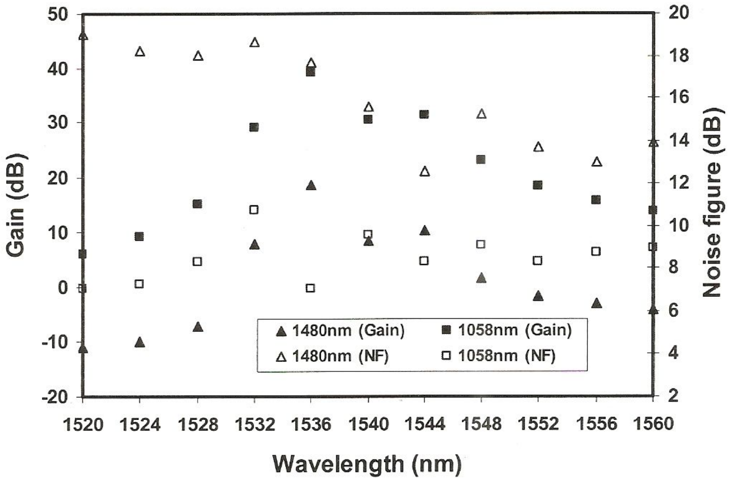


Fig. 3: ASE spectra of the EYDFA at different doped fiber length.

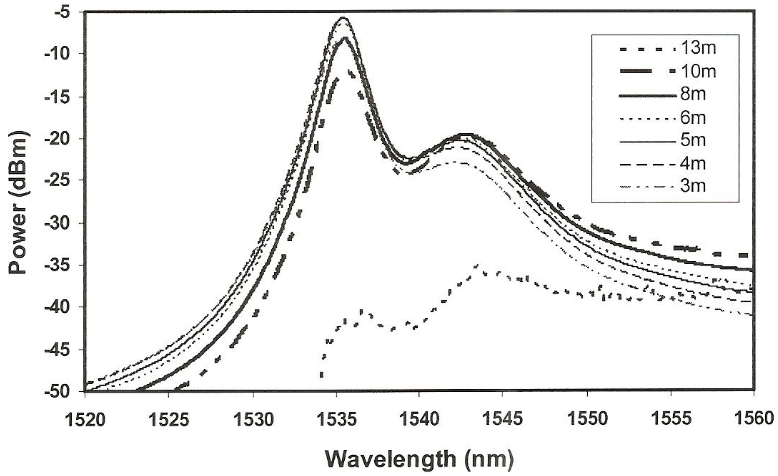


Fig. 4: Gain and noise figure spectra of the EYDFA at different pumping wavelength.

In the second part of the experiment, the effect of spurious reflections on the performances of EYDFA is investigated by comparing the gain and noise figure of the amplifiers configured as in Fig. 2 (a) by removing the optical isolators at both ends. The result of these measurements is shown in Fig. 5 which compares the gain and noise figure against the input signal power for single-pass amplifiers. This was done with and without optical isolators. The EYDF length, 1058 nm pump power and signal wavelength is fixed at 5 m, 120 mW and 1544 nm, respectively. As illustrated in Fig. 5, the small signal gain is improved by about 4.8 dB with incorporation of optical isolators. An oscillating laser output is observed at 1534 nm when the isolators are removed. This is due to the spurious reflections and this laser saturates the gain at 26.5 dB for cases of input signal powers lower than -15 dBm. At high input signal powers (above -15 dBm), the amplification process is more dominant in amplifying the input signal and less energy is available for the oscillating laser at 1534 nm. This eventually leads to the cavity loss exceeding the gain for this wavelength, thus inhibiting the oscillation. From Fig. 5, the gain for the input signal for both cases (with and without isolators) is the same due to saturation. On the other hand, the noise figure is improved at all input signal powers tested by incorporation of isolators as shown in the figure. The maximum noise figure improvement of 1.6 dB is obtained at input signal power of -30 dBm. In the case of without isolators, the oscillating laser limits the population inversion in the amplifier, which leads to an increase in the noise figure. These results show that the employment of optical isolator is an important component to consider when designing an EYDFA.

Figure 6 shows the gain (solid symbols) and noise figure (clear symbols) against the pump power of the experimented single-pass (Fig. 2(a)) and double-pass (Fig. 2(b)) configurations. The EYDF length, input signal power and wavelength are fixed at 3 m, -50 dBm and 1536 nm respectively. As shown in the figure the double-pass amplifier shows a higher gain in comparison with the single-pass amplifier. The maximum gain improvement of 17.0 dB was obtained at 20 mW pump power. However, the gain improvement reduces as the pump power increases as shown in the figure. This improvement is attributed to the increase of the effective EYDF length, which is caused by the double propagation of input signal in the double-pass configuration. However, both double-pass amplifiers show a higher noise figure compared with that of the single-pass amplifier. The maximum noise figure increment of 2 dB was obtained at a pump power above 50 mW. The noise figure penalty is attributed to the higher backward propagating ASE at the input part of the amplifier. The ASE reduces the population inversion at the input part of amplifier and therefore increases the noise figure for the double-pass amplifiers. These results show that the employment of EYDFAs with double-pass scheme will play an important role in development of practical compact optical amplifiers.

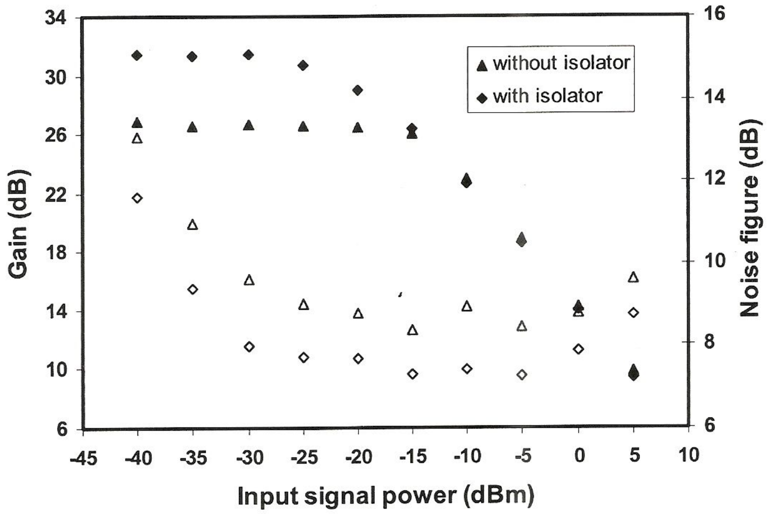


Fig. 5: Gain and noise figure as a function of input signal power for the EYDFAs configured with and without optical isolator.

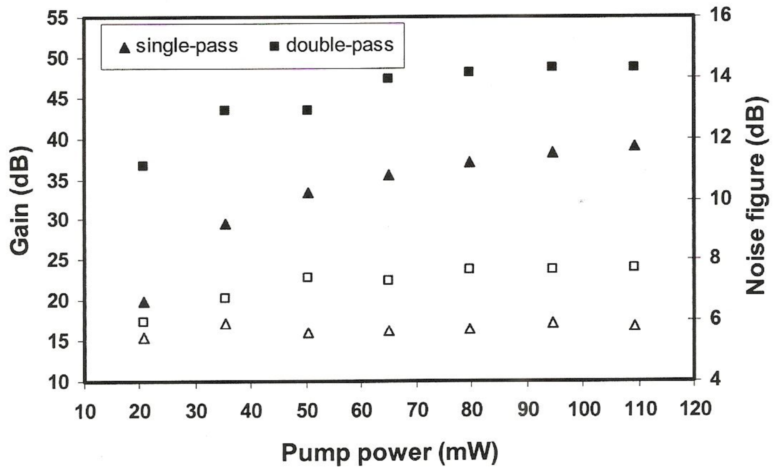


Fig. 6: Gain and noise figure against pump power for EYDFAs configured with single-pass and double-pass.

4. CONCLUSION

An EYDFA operating at 1550 nm band is demonstrated using a 1058 nm pumping wavelength. The amplification is achieved via energy transfer from Yb to Er ions and thus increases the erbium doping concentration that is imposed by concentration quenching in EDF. However, if the EYDF is pumped by 1480 nm, the energy transfer cannot be utilized, which in turn severely degrades the gain and noise figure. The use of optical isolator prevents the onset of oscillating laser which is created by spurious reflections. Hence, the small signal gain and noise figure of the single-pass EYDFA are improved by about 4.8 dB and 1.6 dB respectively, compared with the amplifier configured without the isolator. The small signal gain is further improved by employment of double-pass scheme at the expense of the noise figure. Compared with the single-pass EYDFA, the gain improvement of 17 dB is obtained at 20 mW and -50 dB of pump and input signal powers. The double-pass scheme offers an economical solution to high efficiency, compact and high gain EYDFAs.

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