Investigation on Double Pass Amplification by Employing Zr-EDF as a Gain Medium with Different Types of Reflectors

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***Abstract*—In this paper, the amplification for double-pass operation is demonstrated by using a newly doped fiber namely as Zirconia based erbium doped fiber (Zr-EDF) with a different type of reflectors which are optical circulator and a broadband fiber mirror (BFM). The concept of double pass amplification is based on the forwarded and amplified spontaneous emission (ASE) signal that will propagate twice into the gain medium and thus will increase the gain performance in the C- and L- band region. Optical circulator and BFM are placed at the end of the cavity and used as the signal reflector to ensure that the signal will be reflected back into the gain medium, Zr-EDF. The amplification performance of single and double pass Zr-EDFA by utilizing optical circulator and BFM as signal reflectors are investigated at high and low input signal powers, -10 and -30 dBm, respectively. The double pass approach shows a better amplification performance at low input signal power of -30 dBm, compared to the high input signal power of -10 dBm. At low input signal power of -30 dBm, the maximum gain of 40.3 dB is achieved for double pass amplification at a wavelength of 1560 nm. The gain enhancement of 12.30 dB is observed between the single and double pass amplification with BFM as the reflector with the low input signal power. Instead of that, the performance analysis of double pass amplification by utilizing the optical circulator for varying the length of gain medium from 0.5 m to 2 m and pump power from 67 mW to 130 mW is further investigated. From the results, it shows that with the length of 1m Zr-EDF and 130 mW of pump power shows the optimum length and pump power due to the highest gain with lowest noise figure performance.**

***Index Terms*— Double Pass Amplifier; Zr-EDF; Optical Circulator; Broadband Fiber Mirror.**

I. INTRODUCTION

The advancement of Erbium-Doped Fiber Amplifier (EDFA) brings an enormous impact towards the application of dense wavelength division multiplexer (DWDM) in optical communications systems. For instance, EDFA is focusing on improving the amplification performance especially in long-haul transmission systems [1]. EDFA is one of the optical amplifiers that use an Erbium as a co-dopant in a host glasses to achieve wideband amplification performance in a telecommunications systems since decades ago [2]. EDFA has greatly promoted and primarily used in telecommunications systems due to its properties and advantages which are low noise figure, high gain performance, wide frequency, high efficiency, low splice loss and non-polarization insensitive. Besides being used in terrestrial, EDFA performance is also suitable to use in a submarine and free-space communications [4]. Basically, the operation of EDFA has covered the amplification in C-band (Conventional band wavelength) with the range is between 1520 nm to 1565 nm and L-band (Long band wavelength) with the range of 1570 nm to 1610 nm.[5]. Hence, EDFA performance can be concluded to efficiently amplify especially in 1550 nm wavelength region [6].

Traditionally, the design of high-gain in the optical amplifier can be achieved using a concept of the dual-stage amplifier [7]. The concept of the dual-stage amplifier is optical amplifier is divided into two parts which are the first stage amplifier produces low noise figures and the second stage amplifier provides high output power [1]. However, the dual-stage amplifier has disadvantages because of its complicated design and high cost for implementation. Hence, due to this reason, the researcher is moving to go to another approach namely double pass amplifier [1-3]. The approach of double-pass amplification will increase the performance of signal gain twice the number of amplification while propagating in the same gain medium compared to the performance of single-pass amplification [2, 8]. The double pass amplifier should be used with a good reflector in order to maintain the high amplification performance. The reflector that can be used in the double pass amplification namely Chirped Fiber Bragg Grating [9], Tunable Band-pass Filter [2], Broadband Fiber Mirror (BFM) [11], Optical Circulator [12,13] and Hi-Bi Fiber Loop Mirror [14].

Previously, there is very limited number of research is done in double-pass amplification especially by using BFM and optical circulator as a reflector. Thus, in this paper, the performance of double-pass EDFA by using the BFM and optical circulator as the reflectors will be investigated. The newly doped fiber, Zirconia-based Erbium Doped Fiber (Zr-EDF) will be utilized as the gain medium in this double-pass EDFA performance. Zirconia (ZrO_2) is widely used in a coating for various applications because of its mechanical strength and chemical corrosion resistance. It is also nonhygroscopic which does not demonstrate photochromic behavior and exhibits excellent transmission in the visible and near-infrared. These qualities make zirconia as excellent applications in the photonics [14]. Instead by investigating the performance of double pass Zirconia-based Erbium Doped Fiber Amplifier (Zr-EDFA) by using different reflectors, the performance of double pass Zr-EDFA is also being compared with the performance of single pass ZR-EDFA. Lastly, the performance analysis of double pass Zr-EDFA by using optical circulator is further investigated in terms of varying length of the gain medium, the power of input signal and pump power.

II. EXPERIMENTAL SETUP

In this paper, the performance of Zr-EDFA is experimentally investigated in terms of single and double-pass amplification performance. In order to understand the behavior of gain and noise figure (NF) of Zr-EDFA, the comparison between single and double-pass Zr-EDFA performance by using different reflectors which are BFM and optical circulator has been investigated. Figure 1 shows the configuration setup for double-pass Zr-EDFA by using Zr-EDF as a gain medium and the BFM as the reflector. To observe the double pass performance by using optical circulator as the reflector, the BFM will be replaced with the optical circulator by using the same configuration. The 980 nm laser diode is used to provide optical pump power in a forward pumping and combines with the incoming signal via 980/1550 nm wavelength division multiplexer (WDM). A WDM is used to compile the input signal and pumping signal that will be propagating through the gain medium.

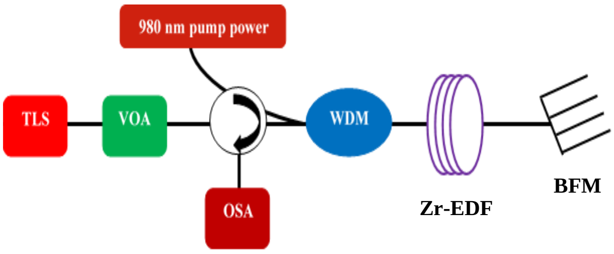

Figure 1: The configuration setup of double-pass amplification

An optical circulator is used to route the optical signals that travel in opposite direction by joining port 3 to port 1. The BFM is placed at the end of Zr-EDF to utilize as a fiber loop mirror or signal reflector to reflect back forwarded and amplified spontaneous emission (ASE) signal into the cavity. The signals are reflected back to be amplified twice in the gain medium, Zr-EDF, which is the active element of the amplifier and thus will enhance the double pass amplification performance. Instead of that, the broadband fiber mirror is used in double pass amplification to ensure that double propagation of the signal. Next, the BFM is changed with an optical circulator in order to study the performance of double-pass Zr-EDFA between BFM and an optical circulator. By using a tunable laser source (TLS), the input signal wavelength is obtained in conjunction with variable optical attenuator (VOA) which controlled the input signal power. The optical spectrum analyzer (OSA) is used to analyze the performance amplification of Zr-EDFA.

III. RESULTS AND DISCUSSION

Figure 2 shows the gain and NF performance of single and double pass Zr-EDFA where the input signal power is fixed at-30 dBm, the lower input signal power. In this experiment, the signal wavelength is varied in C-and L-band wavelength region which is from 1520 nm to 1620 nm. The gain medium, Zr-EDF is fixed at length of 1 m and is pumped by 980 nm laser diode with the pump power of 130 mW. The performance of double-pass Zr-EDFA are investigated by using different reflectors; BFM and an optical circulator.

From the output in Figure 2, the performance of double-pass amplification by using BFM as the reflector shows the highest gain performance compare to the double-pass amplification by using circulator as the reflector. This is due to the usage of BFM which reflect back the transmitted signal into the cavity while the optical circulator will route and circulate back the signal into the cavity. It also can be seen that both double pass performance shows the higher gain performance compared to the single-pass amplification. The average gain that obtained from 1520 to 1620 nm wavelength for single pass Zr-EDFA, double pass Zr-EDFA with circulator as a reflector and double-pass Zr-EDFA with BFM as reflector are 17.15, 18.34 and 25.3 dB, respectively. It is shown that the gain in the double pass of Zr-EDFA gives a better performance compared to the single-pass Zr-EDFA. At 1560 nm input wavelength, the maximum gain of Zr-EDFA performance of 28.0 dB, 34.4 dB and 40.3 dB is achieved with the single pass and double pass optical circulator and BFM, respectively. The gain enhancement of 12.30 dB is observed in the double-pass Zr-EDFA performance. The gain enhancement is achieved between the difference of maximum gain of double and single pass amplification. The maximum gain of double pass performance is observed in double pass performance by using BFM as the reflector. This is because of the double propagation of the transmitted signal inside the gain medium in the double pass approach. This double propagation of the signal in the gain medium will increases the effective length of the amplifier, the amplified spontaneous emission (ASE) level and thus the amplification performance.

Besides that, the gain in single and double pass amplification seems to be higher at the C-band region and start to decrease in the L-band region. This is because of the effect of the gain saturation that occurs inside the gain medium. As the pump power increases, or the pump power decreases, the erbium inversion level also reduced and hence, the gain of the amplifier will be reduced. Instead of that, this condition is due to the emission characteristic of the gain medium when pumped with the wavelength of 980 nm which will decrease the amplification in L-band region. However, the NF in single pass amplification is observed to be higher compared to the double pass amplification. This is due to the ineffective population inversion that occurred especially when there are not enough atoms have been pumped to the excitation levels.

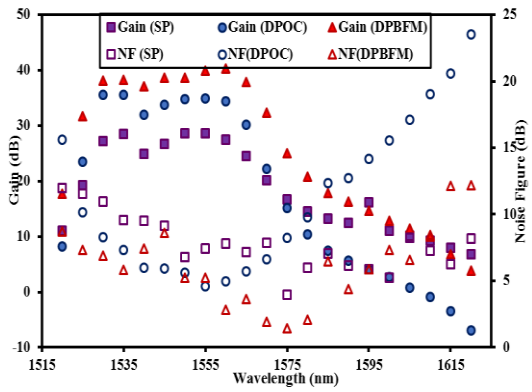

Figure 2: Gain and noise figure spectra for the single and double pass Zr-EDFA for both reflectors at the low input signal power of -30 dBm

Figure 3 shows the gain and NF of the single and double pass Zr-EDFA where the input signal power is fixed at the -10 dBm (high input signal power). The signal wavelength is varied from 1520 to 1620 nm which is in C- and L-band wavelength region. In this experiment, the length of Zr-EDF is fixed at 1 m and the pump power of 980 nm laser diode is fixed at the 130 mW. As shown in the figure, the high input signal gain shows the better performance in term of gain improvement with the double pass amplification compared to single pass amplification. Besides that, the double-pass amplification by using BFM as the reflector also shows the higher gain compared to the double pass amplification by using optical circulator as the reflector. Both double pass amplifications show the better performance compare to the single pass amplification. The average gain from 1520 nm to 1620 nm wavelength for single pass amplification, double pass amplification by using optical circulator and BFM as the reflector are 12.84 dB, 14.80 dB and 15.90 dB, respectively. At input wavelength of 1560 and 1565 nm, the maximum gains of 20.0 and 21.3 dB are achieved with the single and double pass amplification by using BFM as the reflector, respectively. The gain enhancement for this high input signal power is observed to be 1.3 dB. This gain enhancement is lower compared to the gain enhancement with the low input signal power. This is because of the small gap between the amplifier output and input power of the Zr-EDFA. This is proof by Equation (1):

$$Gain\ (dB) = Pout\ (dBm) - Pin\ (dBm) \qquad (1)$$

where Pout and Pin are the amplifier output and input power, respectively. The NF in single pass amplification is observed to be higher compared to both double pass amplification performance. As mentioned earlier, this is due to the ineffective population inversion. This mechanism will lead to insufficient stimulated emission process and thus increase the NF. The following experiments are the performance analysis of double pass amplification by using optical circulator as the reflector.

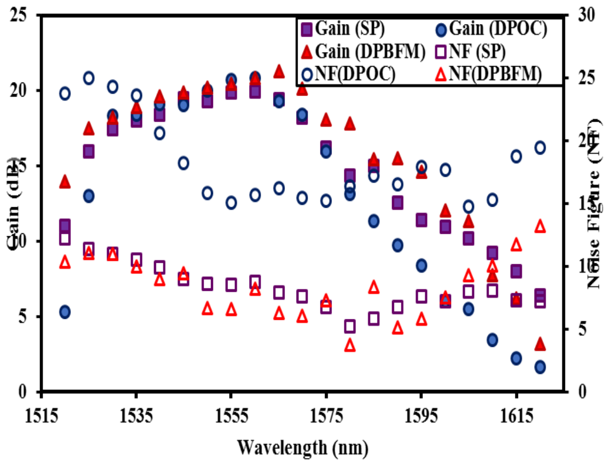

Figure 3: Gain and noise figure spectra for the single and double pass Zr-EDFA for both reflectors at the low input signal power of -10 dBm

Figure 4 shows the gain and noise figure performance of the double pass Zr-EDFA by using optical circulator where the input signal power is fixed at -30 dBm which is the low input signal power. In this experiment, the signal wavelength is varied from 1520 nm to 1620 nm.The length of the gain medium, Zr-EDF is varied from 0.5 m to 2 m and the pump power of 980 nm laser diode is fixed at the 130 mW. As shown in the figure, the gain is moving toward a longer wavelength region as the Zr-EDF length is increased from 0.5 m to 2 m. However, the gain starts to reduce when entering the L-band regions. This can be concluded that the Zr-EDF is efficiently amplified only in C-band region compared to the L-band region while varying the gain medium length from 0.5 m to 2 m. This is due to insufficient population inversion that starts to occur when entering the L-band region and hence leads to decrease in the amplification performance. Instead of that, this insufficient population inversion is occurred due to the power of the transmitted signal is seem to be too small after propagating at a certain length of the gain medium and thus will lead the gain medium start to absorb the signal rather than amplify it. From the figure, it also can be observed that the gain medium with 1 m length shows the highest gain and low noise figure performance compared to the other length. The average gain performance obtained from the wavelength region of 1520 nm to 1620 nm for 0.5 m, 1 m and 2 m are 15.81 dB. This average gain is obtained by taking the average of 14.98 dB, 17.15 dB and 15.30 dB with 0.5 m, 1 m and 2 m, respectively. The maximum gain of 20.66 dB, 34.43 dB and 35.36 dB is observed at a wavelength of 1560 nm with the gain medium length of 0.5 m, 1 m and 2 m are, respectively.

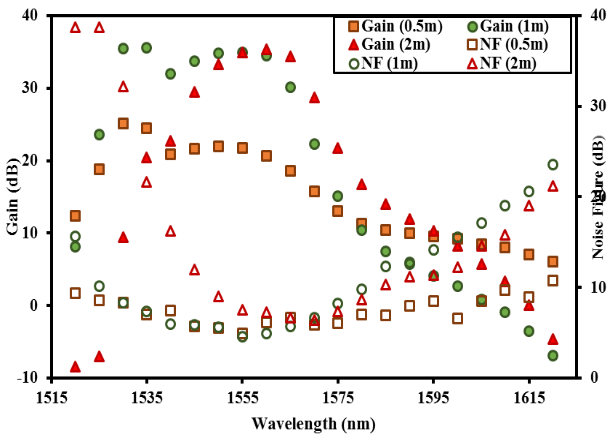

Figure 4: Gain and noise figure of the double-pass Zr-EDF by using optical circulator as the reflector for different lengths of gain medium with input signal fixed at -30 dBm

Figure 5 shows the gain and noise figure performances of the double pass Zr-EDFA by using optical circulator where the input signal power is fixed at -10 dBm which is at high input signal power. The performance is investigated in the wavelength region of 1520 nm to 1620 nm which is at C- and L- band wavelength region. The length of the gain medium, Zr-EDF is varied from 0.5 m to 2 m and the 980 nm laser diode is pumps with the pump power of 130 mW. Based on the figure, the gain for 2 m length of Zr-EDF give the highest amplification performance compare to the other length of the gain medium. The average gain of 12.22 dB is obtained in the wavelength region of 1520 nm to 1620 nm with the highest peak of 24.98 dB is observed at 1560 nm. As the length of Zr-EDF increase, the gain spectrum shifts to a longer wavelength due to the re-absorption process in the gain medium. This is due to the power of signal propagating in C-band region is absorbed to emit at the L-band region. Meanwhile, the shortest length of 0.5 m Zr-EDF presents lower gain and NF performance.

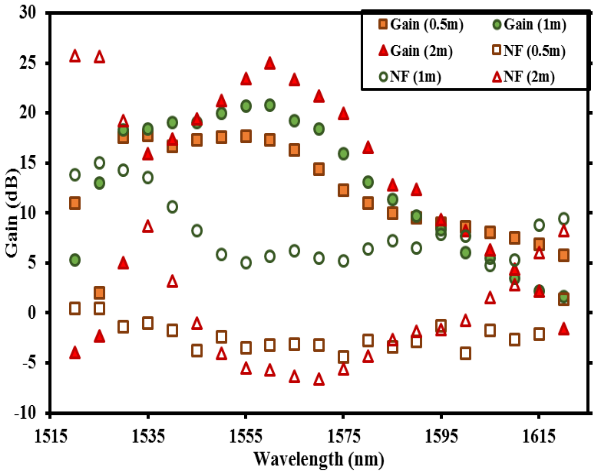

Figure 5: Gain and noise figure of the double-pass Zr-EDF by using optical circulator as the reflector for different lengths of gain medium with input signal fixed at -10 dBm

Figure 6 shows the gain and noise figure performance of the double pass Zr-EDFA by using optical circulator as the reflector where the input signal power is fixed at the low input signal power, -30 dBm. This experiment is carried out in the wavelength region from 1520 nm to 1620 nm. The length of the gain medium, Zr-EDF is fixed at 1 m while the 980 nm laser diode is pump with varying pump power from 61 mW to 130 mW. Based on the figure, the gain performance of Zr-EDFA is increased with the increase of the pump power especially in C-band wavelength region and start to decrease in L-band wavelength region. As mentioned earlier in the previous experiment, this is due to the insufficient population inversion. From this experiment, it is also observed that the pump power of 130 mW gives the highest gain performance compared to other pump power. This is due to the increase in pump power that provides the sufficient population inversion for erbium ions to be fully excited in the gain medium. This condition happens because of the gain is depends on the average inversion level of the erbium ion population. When the pump power increases, more atoms are excited to higher pump level. For instance, as shown in the figure, at a wavelength of 1560 nm, the maximum gain is achieved with 23.42 dB, 30.81 dB and 34.42 dB with the pump power of 61 mW, 87 mW and 130 mW, respectively. However, the NF is observed to be higher with increasing pump power. This is due to the NF penalty that attributes to the higher counter propagating ASE at the input part of the Zr-EDFA. This has made the population inversion reduced at the input part of the Zr-EDFA and therefore increases the NF of the Zr-EDFA.

Figure 7 illustrates the gain and NF performances of double-pass Zr-EDFA by using optical circulator as the reflector. The input signal power is fixed at -10 dBm. This experiment is employing the 1 m long of Zr-EDF as the gain medium and the 980 nm laser diode is set with pump power varying from 61 mW to 130 mW. As mentioned earlier, the gain is increased as the pump power is increased. This happens due to the sufficient of population inversion that will make the atom to highly excited to the higher level with the increment of the pump power. Instead of that, the gain performance is observed to have a higher difference in lower pump power compared to the higher pump power. For instance, at the wavelength of 1560 nm, the signal gain is observed to increase from 12.03 dB to 20.42 dB as the pump

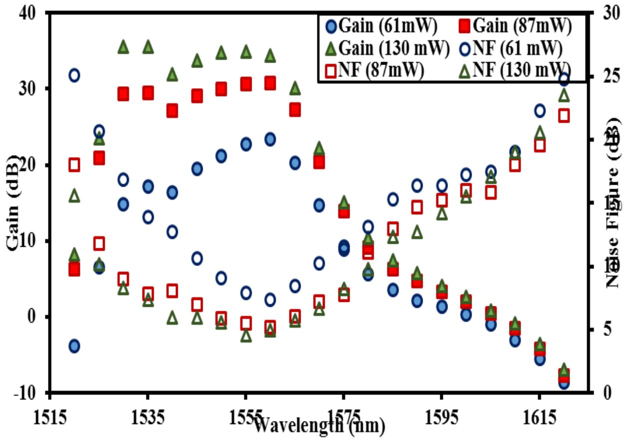

Figure 6: Gain and noise figure of the double-pass Zr-EDF by using optical circulator as the reflector for different pump power with input signal fixed at -30 dBm

power is increased from 61 mW to 87 mW while a small difference of signal gain is observed from 20.42 dB to 21.82 dB as the pump power increase from 87 mW to 130 mW. This is due to sufficient population inversion occurred in C-band wavelength region compared to the L-band wavelength region.

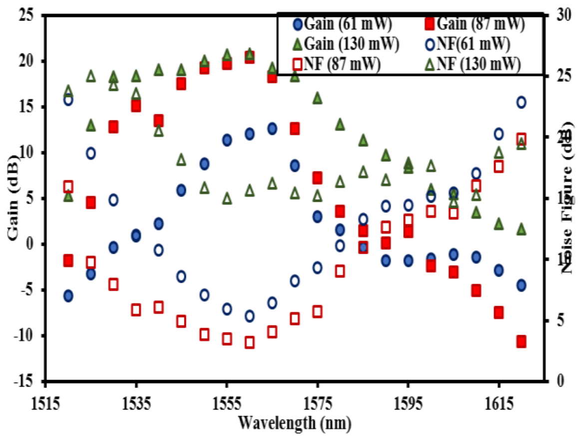

Figure 7: Gain and noise figure of the double-pass Zr-EDF by using optical circulator as the reflector for different pump power with input signal fixed at -10 dBm

IV. Conclusion

The performances of the Zr-EDFA with single and double pass amplification are successfully demonstrated at -10 dBm and -30 dBm for high and low input signal power, respectively. The double-pass Zr-EDFA by utilizing the Zr-EDF as the gain medium, optical circulator and BFM as the reflectors show the better gain performance compared to the single-pass Zr-EDFA in both input signal powers. This is due to the properties of double pass amplifier that has the definition of double propagation of transmitted and ASE signal are reflected back into the Zr-EDF as the gain medium. Besides that, the performance of double-pass amplification with utilizing optical circulator is successfully demonstrated in different lengths of the gain medium and pump power. Based on the results, 1 m length of Zr-EDF and the highest pump power of 130 mW show the better amplification performance. The gain performance in low input signal power is observed to produce a better gain performance compared to high input signal power in terms of maximum and average gain. At low input signal power of -30 dBm, the maximum and average gain of 40.3 and 12.3 dB are achieved at a wavelength of 1560 nm for double pass Zr- EDFA with using BFM as the reflector, respectively.

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