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The effect of 980 nm and 1480 nm pumping on the performance of newly Hafnium Bismuth Erbium-doped fiber amplifier

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Abstract. An experimental study on the comparison of optical amplifying performance between 980 nm and 1480 nm pumping for the newly Hafnium Bismuth Erbium co-doped fiber (HB-EDF) has been presented. A short length of 1-meter HB-EDF was used as the gain medium of the optical amplifier. 1480 nm pumping is found to provide higher attainable gain and lower noise figure compared to 980 nm pumping. At 1480 nm pumping, the average small signal gain for HB-EDFA in the single pass configuration has improved by 13.4 dB in the C-band region range from 1525 nm to 1565 nm. In the double-pass configuration, a maximum small signal gain of 36.6 dB was achieved at the wavelength of 1560 nm, this is 11.6 dB higher compared to the HB-EDFA with 980 nm pumping. The double pass HB-EDFA with 1480 nm pumping has exhibited a reduction of average noise figure by 23.4% and 29.8% for -30 dBm and -10 dBm of input signal power respectively in the C- and L-band region.

1. Introduction

The compactness of the fiber optic components is one of the important factors in the DWDM application, notably for Erbium-doped fiber amplifier (EDFA). The development of compact fiber amplifiers with a very short gain medium length has recently gained tremendous interest [1-3]. Active fiber which doped with high erbium ion concentration is in demand to realize the short gain medium length hence reduces the size and cost of the EDFA. However, the use of such highly doped erbium-doped fiber in the EDFA designs is known to have performance limitations due to the energy transfer during the up-conversion between Erbium ions. Various studies have been reported on the impact of erbium ion concentration and core composition on the performance of EDFAs [4-6]. In order to increase the limit of erbium doping concentration while maintaining the amplifying performance, several new host materials have been investigated and developed, such as Ytterbium-codoped silica based fiber [7], tellurite-based fiber [8] and Zirconia-based fiber [9]. Bismuth-based fiber has also been intensively studied for amplifier application due to its capability in providing sufficient signal gain over broad bandwidth in less than a meter length [10]. This fiber can be doped with Erbium ions concentration of more than 3000 ppm. However, Bi-EDF has a different melting temperature with the standard mode fiber, which makes it difficult to be spliced with using a standard splicing machine.

Recently, a new fabricated Hafnium-Bismuth Erbium co-doped silicate fiber (HB-EDF) which has the ability to be highly doped with 12500 wt. ppm of erbium ions concentration has been introduced [11]. The high erbium ions concentration was possible by adding Hafnium and Bismuth ions in the fiber, which minimising the ions clustering effects. Doping of Hafnium in the fiber has allowed the silicate host glass to accommodate other optically-active in NIR co-dopants such as rare-earth Er, Yb, Ho etc along with Bi [12]. In addition, the HB-EDF can be easily spliced with a standard SMF due to the similarity in melting temperature. These excellent features are suitable for realizing the ultra-compact fiber amplifiers and lasers. In an earlier work, a compact EDFA was demonstrated using a 0.5 m length of HB-EDF as the gain medium that pumped with 980 nm wavelength to operate in C-band region [13]. In this paper, we present an experimental study on the performance comparison between 980 nm and 1480 nm pumping for the Hafnium Bismuth Erbium co-doped fiber amplifier (HB-EDFA). The amplified emission and the gain characteristics of the HB-EDFA were compared in both single pass and double pass configuration.

2. Experimental

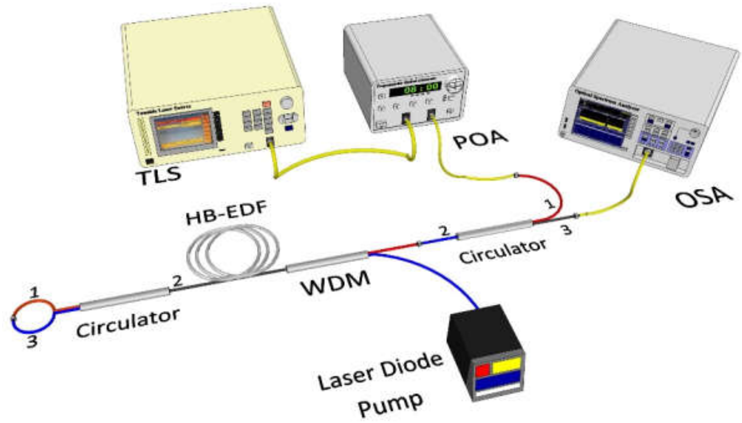


Figure 1. Configuration of the double pass HB-EDFA.

Figure 1 shows the experimental setup of the optical fiber amplifier in the double pass configuration. A 1 meter length of Hafnium Bismuth Erbium-doped fiber (HB-EDF) was used as the gain medium of the amplifier. The EDF was drawn from the over cladded preform using fiber drawing technique at a temperature of 2000 °C. The preform of HB-EDF was fabricated through deposition of porous silica layers. The layers were formed by modified chemical vapor deposition (MCVD) followed by the solution doping (SD) process to integrate co-dopants in the fiber core. The fiber core glass of HB-EDF contains 6.0 wt% Al_2O_3, 1.23 wt% Er_2O_3, 2.2 wt% HfO_2 and 0.035 wt% Bi_2O_3. The HB-EDF is highly doped with erbium ion concentration of 12500 wt. ppm with peak absorption rate of 100 dB/m at 980 nm, and 150 dB/m at 1480 nm.

The HB-EDF was forward pumped by a 980 nm laser diode (LD) to provide amplification in both C and L-bands. An optical circulator C1 was located at the other end of the HB-EDF to reflect the signals back to the gain medium and allow double propagation. Another optical circulator C2 was used to extract the double amplified output signal. A tunable laser source (TLS) was used in conjunction with an optical spectrum analyzer (OSA) to characterize the HB-EDFA. The programmable optical attenuator (POA) was used to obtain the accurate input signal power. The experiment was repeated using the 1480 nm pumping, the amplified spontaneous emission (ASE) and the amplifying performance were compared and investigated. The performance of the double-pass HB-EDFA was then compared to that of the single-pass HB-EDFA, which is obtained by removing the circulator C1 and measuring the amplified signal at the output end of the HB-EDF.

3. Results and Discussion

Firstly, the observation of the ASE spectra at various length of gain medium of the amplifier was performed at a maximum pump power of 170 mW as shown in figure 2. The length of HB-EDF was fixed at 0.2 m, 0.5 m and 1 m respectively, and they were forward pumped at 980 nm pump wavelength in the single pass configuration. As illustrated in the figure, both HB-EDFA with a gain medium length of 0.2 m and 0.5 m provide emissions in the C-band region range from 1520 nm to 1580 nm. However, the emission wavelength shifted to a longer range when the length of the HB-EDF increased to 1 m. The ASE level of the HB-EDFA with 0.5 m length of HB-EDF was around 10 dBm higher compared to the HB-EDF with 0.2 m length of gain medium. This is attributed to the enhancement of the population inversion of the Erbium ions in the fiber, which increases with the EDF length.

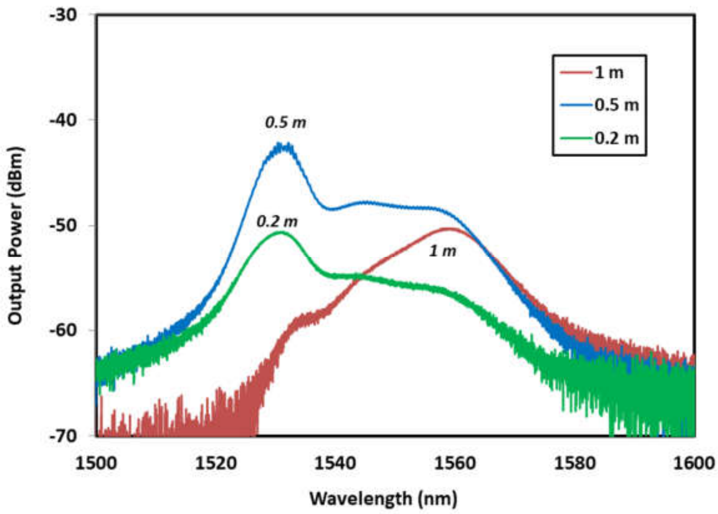


Figure 2. ASE spectrum for various lengths of HB-EDF which were pumped at 170 mW of 980 nm LD in single pass configuration.

Next, the gain and noise figure performance of the single pass HB-EDFA was investigated at three various lengths of HB-EDF, 0.2 m, 0.5 m and 1 m as shown in figure 3. The three HB-EDFs were forward pumped by a 980 nm laser diode at the pump power of 140 mW. It is shown that the average gain has improved by 2.6 dB when the length of the HB-EDF increased from 0.2 m to 0.5 m. The gain spectrum of both HB-EDFAs cover a wide range from C-band at 1520 nm to L-band at 1600 nm. When the length of the HB-EDF increased to 1 m, the amplification region shifts to a longer wavelength. This is due to quasi-level system process in HB-EDFA whereby the shorter wavelengths photons are absorbed to emit at longer wavelengths.

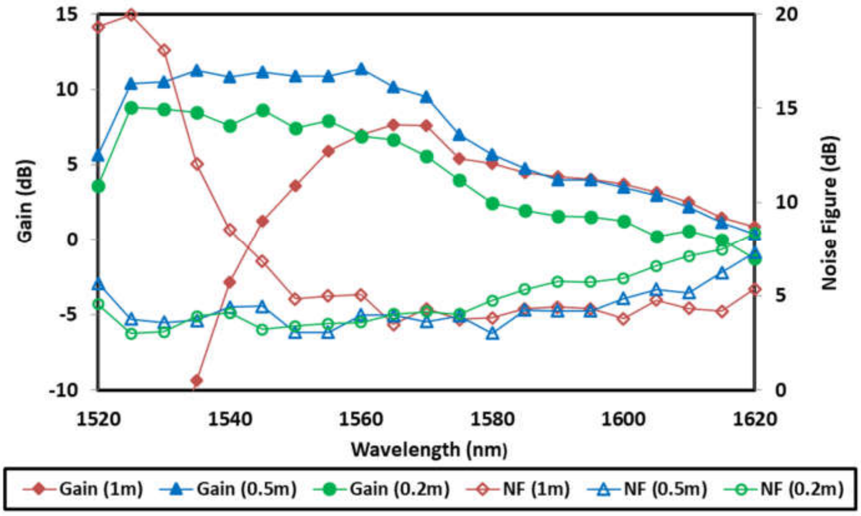


Figure 3. Gain and Noise figure characteristics of the single pass HB-EDFA with various lengths of HB-EDF, measured at high input signal power of -10 dBm.

A 1 m length of HB-EDF was used to study the effect of the laser diode pump wavelength on the performance of the HB-EDFA. The HB-EDF in the single pass configuration was first pumped by a 980 nm laser diode at the maximum pump power of 170 mW. The experiment was repeated with a 1480 nm laser diode pump for comparison. Figure 4 compares the ASE spectrum of the HB-EDFA which pumped at two different wavelengths, 980 nm and 1480 nm respectively. It is shown that the power level of the amplified spontaneous emission was higher at 1480 nm pumping. This is attributed to the higher optical power conversion efficiency at 1480 nm pumping due to the single photon conversion process of erbium amplification. 1480 nm photons excite the erbium ions directly to the metastable energy level $^4I_{13/2}$ which give rise to the population inversion of the Erbium ions in the fiber.

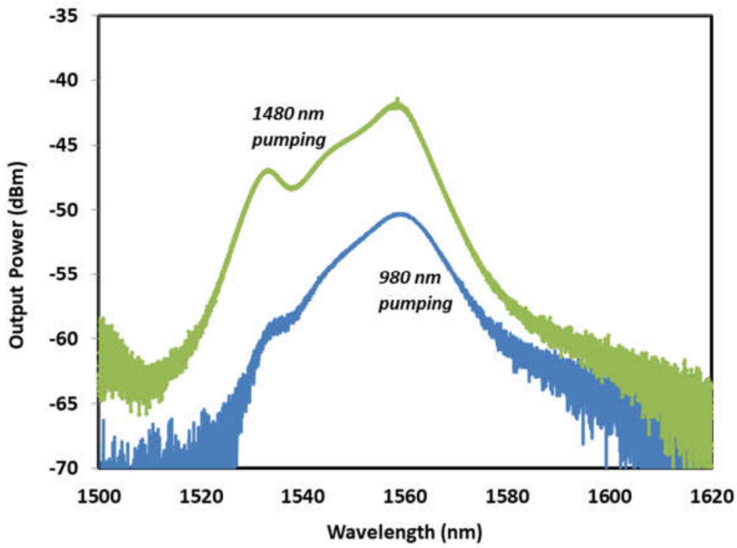
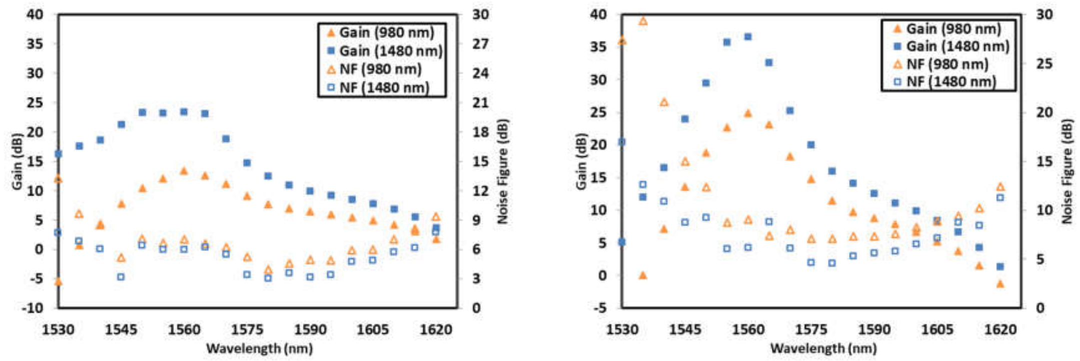


Figure 4. Comparison of the ASE Spectrum of the single pass HB-EDFA at two pumping wavelengths.

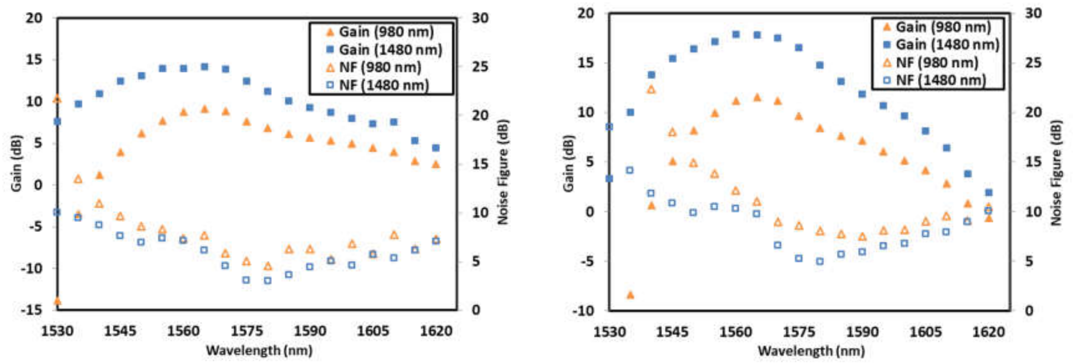
Figure 5 compares the gain and noise figure characteristics of the HB-EDFA which was forward pumped by 980 nm and 1480 nm pump wavelength respectively at a maximum pump power of 170 mW. The amplifier used the 1 m length of HB-EDF as gain medium, and both gain and NF were measured at low input signal power of -30 dBm. As shown in figure 5(a), higher gain spectrum was observed when the HB-EDF was pumped at 1480 nm. For instant, the average gain increased by 13.4 dB in the C-band region range from 1525 nm to 1565nm. However, along the L-band region range from 1570 nm to 1620 nm, the average gain improvement reduced to 3.8 dB due to the insufficient pump power which results in a decline of population inversion at the longer part of the HB-EDF. On the other hand, an improvement in noise figures of HB-EDFA in both single pass and double pass configuration were observed with the 1480 nm pumping, which has reduced by 19.2% and 23.4% respectively.

The performance of single pass HB-EDFA was compared with the double pass configuration at low input signal power of -30 dBm as shown in figure 5(b). In the double pass configuration, the signals were doubly propagated through the gain medium, which increases the population inversion resulting in a double increment of the gain. For instance, the gain of the HB-EDFA which was pumped at 1480 nm increased from 23.5 dB to 36.6 dB at 1560 nm due to the double-propagating of the signal. The corresponding noise figure for the double pass configuration is reasonably higher by an average of 2.8 dB from 1530 nm to 1620 nm when compared to the single pass configuration. This is attributed to the higher counter propagating ASE at the input part of the amplifier which reduces the population inversion and therefore increases the noise figure.



(a) Single Pass HB-EDFA (b) Double Pass HB-EDFA

Figure 5. Gain and noise figure characteristics of the HB-EDFA at input signal power of -30 dBm.



(a) Single Pass HB-EDFA (b) Double Pass HB-EDFA

Figure 6. Gain and noise figure characteristics of the HB-EDFA at input signal power of -10 dBm.

The gain and noise figure characteristic at input signal power of -10 dBm for HB-EDFA with different pump wavelengths are shown in figure 6. Compared to the gain spectrum in figure 5, the gain spectrum are relatively flat at high input signal power of -10 dBm. For HB-EDFA which was pumped at 1480 nm in single pass configuration, a flat-gain of around 12.1 dB was obtained with gain variation of ± 2.5 dB within the wavelength region from 1535 to 1590 nm. However, the gain improvement is not significant at a higher input signal of -10 dBm, where the average gain of the double pass amplifier is measured to be around 3.2 dB higher than the single pass amplifier from 1535 to 1590 nm. This indicates that the effect of the population inversion is larger at smaller input signals whereas high input signals suppress the population inversion and thus reduce the attainable gain. The noise figure is relatively higher at the shorter wavelength due to the lower gain and higher loss characteristics associated with the shorter wavelength region.

4. Conclusion

The effect of the pumping wavelength on the spontaneous emission and the amplifying performance of the HB-EDFA has been investigated. 1480 nm pumping was found to provide higher attainable gain and lower noise figure compared to 980 nm pumping. At 1480 nm pumping, the average small signal gain for HB-EDFA in the single pass configuration has improved by 13.4 dB in the C-band region range from 1525 nm to 1565 nm. The peak small signal gain was measured to be 36.6 dB at 1560 nm for the double pass HB-EDFA using 1 m length of HB-EDF as the gain medium. The corresponding noise figure of the HB-EDFA at 1480 nm pumping was observed to be 31.8% lower over the 980 nm pumping.

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