AN EFFICIENT L-BAND ERBIUM-DOPED FIBER AMPLIFIER WITH ZIRCONIA-YTTRIA-ALUMINUM CO-DOPED SILICA FIBER

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For the first time, double-pass erbium doped fiber amplifier (EDFA) is demonstrated to provide L-band amplification using only a single gain medium of Zirconia–Yttria-Aluminum erbium Co-Doped Fiber (Zr-EDF). The gain medium of the proposed amplifier combines both of Zr and Al ions to obtains a high erbium ion concentration of 2800 ppm (parts per million) and absorption loss of 14.5 dB/m at 980 nm. At high input power of -10 dBm, a flat gain of 15.9 dB is achieved for the optimum length of 4 m with gain fluctuation of less than 1.5 dB within a wide-band wavelength region from 1550 to 1600 nm. The corresponding noise figure is maintained below 12 dB within the flat-gain region. In addition, a flat gain of 9.9 dB with gain fluctuation of less than 1 dB is also obtained for Zr-EDF long of 6 m within L-band region. Compared with the conventional silica based erbium-doped fiber amplifier (Si-EDFA), It was found that the proposed EDFA, which uses a shorter length of gain medium, can achieve slightly higher gain values and broader bandwidth, as well as a lower noise figure.

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1. Introduction

Due to the Internet and new data-communications services, the demand for bandwidth in long-haul communication networks drastically increased in recent years. L-band Erbium-doped fiber amplifiers (EDFAs) provide an attractive option for expanding bandwidth. These amplifiers, operating in the wavelength window ranges from the 1565 to 1605 nm, add more room for channels in high-data-rate dense wavelength-division multiplexing (DWDM) systems [1]. The L-band requires longer erbium-doped fibers (EDFs) to achieve the same gain as that obtained by a C-band EDFA. This is attributed to the L-band lies at the tail of the erbium amplification window where the pump conversion efficiency (PCE) is low [2]. Nowadays, attempts have been accomplished to reduce the fiber length by developing an L-band EDF with a high erbium-doping concentration. However, a high concentration of erbium ions may result in pair-induced quenching (PIQ) effects [3], which potentially degrades the noise figure for an EDFA and reduce the PCE for an EDFA. Bismuth-based erbium-doped fibers (Bi-EDFs) have been utilized as an alternative medium for L-band amplification with a short gain medium [4]. However, Bi-EDF cannot be spliced with a standard single mode fiber (SMF) using the standard splicing machine. This is attributed to the difference in their melting temperatures.

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Previously, double-pass topology was used for L-band EDFA to increase both PCE and the attainable gain in this band [5-6]. In this paper, an efficient and compact EDFA is demonstrated using an Erbium-zirconia-yttria-aluminum co-doped silica fiber (Zr-EDF) as a gain medium. This fiber was fabricated using a modified chemical vapor deposition (MCVD) process while the doping of Erbium, zirconia, yttria and aluminum ions were obtained through a solution-doping (SD) technique [7]. The Zr-EDF has an absorption loss 14.5 dB/m at 980 nm, which translates to the erbium ion concentration of 2800 wt. ppm. Compared to the conventional silica based erbium-doped fiber amplifier (Si-EDFA), the Zr-EDFA achieves a better performance with shorter length of gain medium.

2. System configuration

The experimental setup of the proposed double-pass L-band EDFA is depicted in Fig. 1, which consists of Zr-EDF as a gain medium. The Zr-EDF is forward pumped by 980 nm laser diode via a 980/1550 nm wavelength division multiplexing (WDM) coupler. In the experiment, two of an optical circulator is used. One of them is utilized as a reflector to allow double propagation of the test signal in the gain medium. The amplified signal is reflected back into the gain medium via joining port 3 with port 1 so that the light from port 2 is routed back into the same port. Another optical circulator was used to forward the input signal into the WDM and route the twice amplified signal into the optical spectrum analyzer (OSA). The performance of the proposed Zr-EDFA is achieved using a tunable laser source (TLS) in conjunction with an OSA. The programmable optical attenuator (POA) was used to obtain the accurate input signal power to the amplifier setup.

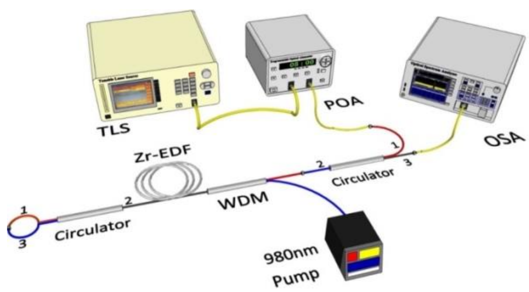

Fig. 1. Configuration of double-pass L-band EDFA with the highly doped Zr-EDF.

3. Results and discussion

At first, the performance of the double-pass L-band Zr-EDFA is investigated at three different doped fiber lengths; 2 m, 4 m and 6 m. In the experiment, the 980nm pump power is fixed at 140 mW. Fig. 2 shows the amplified spontaneous emission (ASE) spectrum of the amplifier L-band Zr-EDFA. As shown in the figure, the optimal power of the ASE is observed with the Zr-EDF length of 4 m. As the Zr-EDF increases above 2 m, the operating wavelength shifts to the L-band region due to a quasi-two level absorption effect. However, the ASE power is lower at 6 m long of Zr-EDF compared to length of 4 m. This is attributed to the insufficient pump power to pump the large number of Erbium ions. The remaining Erbium ions absorbs photons in 1550 nm region and saturates the ASE emission.

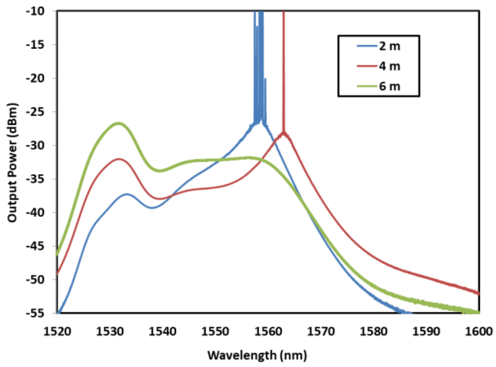

Fig. 2. ASE spectra of the double-pass L-band EDFA at three different Zr-EDF lengths.

Figs. 3 and 4 show the gain and noise figure performances for the L-band EDFA when the input signal powers are fixed to -30 dBm and -10 dBm, respectively. At low input signal power of -30 dBm, it is found that the length of 4 m obtains the best amplification performance. At Zr-EDF length of 4 m, the maximum gain of 35.3 dB is obtained at wavelength of 1565 nm. The noise figure is maintained below 9 dB within the L-band region. However, at the length of 6 m, the gain spectrum shifts to longer wavelength but with lower values. This is attributed to pump attenuation along the gain medium. At the tail of the fiber, there is a loss for the signal due to insufficient pump power to support population inversion. The noise figure spectrum is relatively higher with 6 m long of Zr-EDF due to the gain reduction.

At high input signal power of -10 dBm, it is found that the optimal gain spectrum is also achieved at 4 m length of Zr-EDF. At length of 4 m, a flat gain of 15.9 dB is achieved with gain fluctuation of less than 1.5 dB within a wide-band wavelength region from 1550 to 1600 nm. The corresponding noise figure is maintained below 12 dB within the flat-gain region. Meanwhile, a flat gain of 9.9 dB with gain fluctuation of less than 1 dB is also achieved within L-band region for the amplifier configured with 6 m long Zr-EDF.

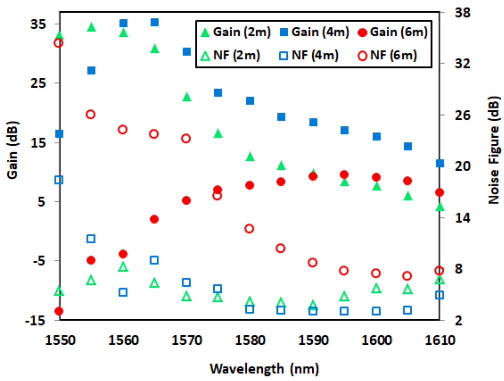

Fig. 3. Gain and noise figure performances with various lengths of Zr-EDF at input signal power of -30 dBm and pump power of 140 mW.

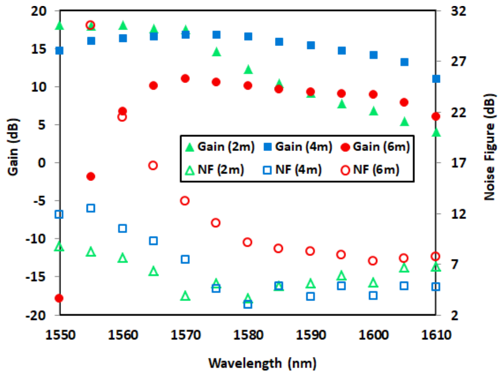

Fig. 4. Gain and noise figure performances with various lengths of Zr-EDF at input signal power of -10 dBm and pump power of 140 mW.

Figs. 5 and 6 show the gain and noise figure performances against pump power for both input signals power of -30 dBm and -10 dBm, respectively. In the experiment, the input signal wavelength is fixed at 1580nm and the pump power is varied from 10 to 170 mW. It is observed that the amplifier operating at input signal power of -10 dBm requires high pump power compared to that of at input signal power of -30 dBm, to obtain saturation state. As shown in Fig. 5, the saturation gain occurs when the pump power is increased beyond 80 and 130 mW for Zr-EDF lengths of 2 m and 4 m, respectively. However, the saturation effect requires over limited pump power for the length of 6 m. Fig. 6 shows the saturation gain occurs when the pump power is increased beyond 100 mW for length of 2 m Zr-EDF. However, the saturation effect requires over limited pump power for both lengths of 4 m and 6 m.

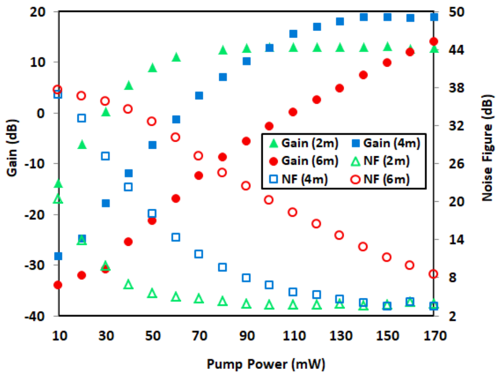

Fig. 5. Gain and noise figure performance of L-band EDFA against pump power at input signal power of -30 dBmm).

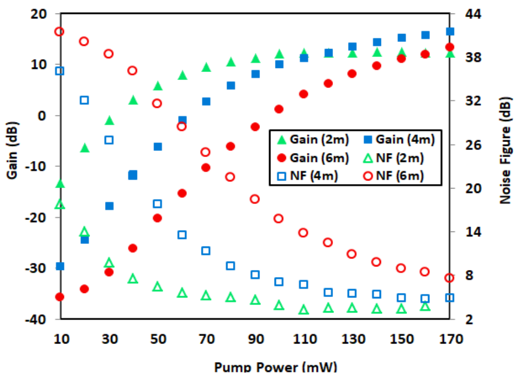

Fig. 6. Gain and noise figure performances of L-band EDFA against pump power at input signal power of -10 dBm.

Fig. 7 shows the gain and noise figure fluctuations when 1580 nm input signal power is varied from −40 dBm to -5 dBm for the three proposed lengths. In this experiment, the pump power is fixed at 140 mW. It is shown in the figure that the optimum length of 4 m obtains the higher gain with slightly gain variations compared to other lengths. However, the gain decreases rapidly beyond input signal power of -15 dBm. This is attributed to the depletion of excited state ions quicker than the pump can restore it when high input signal power is applied.

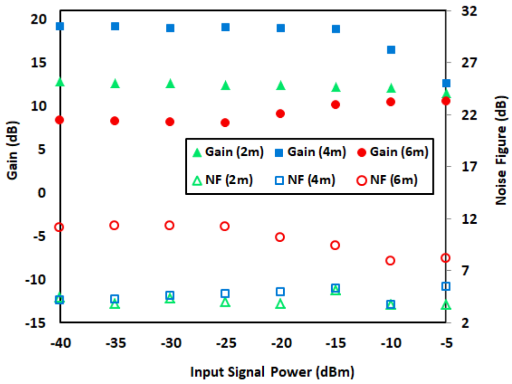

Fig. 7. Gain and noise figure characteristics of the L-band EDFA against input signal power.

Finally, the performance of the L-band EDFA is compared with the conventional silica based EDFA (Si-EDFA). Si-EDFA uses a commercial IsoGain^{TM} I-25 fiber as the gain medium. It has an absorption loss of 23 dB/m at 980 nm, which can be translated to Erbium ions concentration doping of 2200 wt ppm. For fair comparison in the experiment, the lengths of the Zr-EDF and Si-EDF are fixed at the optimum length of 4 and 9 m, respectively. Fig. 8 compares the gain and noise figure characteristics between both amplifiers when the input signal and pump power is fixed at -10 dBm and 140 mW, respectively. As shown in the figure, the proposed Zr-EDFA achieves a relatively higher gain compared to Si-EDFA. This is attributed to the population inversion which is higher in the shorter length of Zr-EDF as well as the efficient use of pump power with a shorter gain medium. The gain spectrum also broadens with Zr-EDFA. This is attributed to the enhancement of the inhomogeneous distribution of erbium ion sites and the suppression of signal excited state absorption (ESA). On other hand, the noise figures of the Zr-EDFA are lower compared to those of Si-EDFA. This is attributed to the higher gain and lower loss characteristics of the shorter gain medium.

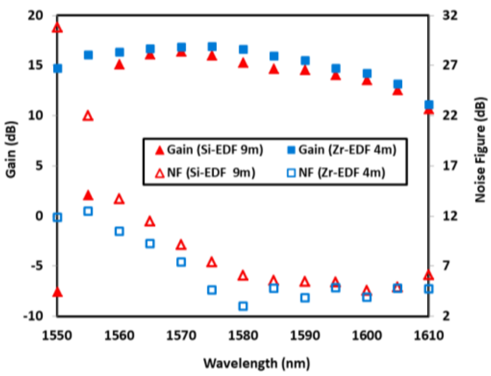

Fig. 8. Comparison of the gain and noise figure performances between the proposed L-band EDFA and the conventional Si-EDFA at input signal power of -10 dBm and pump power of 140 mW.

4. Conclusions

The performance of double-pass L-band Zr-EDFA is investigated for three various lengths, using only a single gain medium of Zr-EDF. The optimum length is obtained for L-band region with the Zr-EDF length of 4 m when the pump power is fixed at 140 mW. At high input power of -10 dBm, a flat gain of 15.9 dB is achieved for the length of 4 m with gain fluctuation of less than 1.5 dB within a wide-band wavelength region from 1550 to 1600 nm.

The corresponding noise figure is maintained below 12 dB within the flat-gain region. In addition, a flat gain of 9.9 dB with gain fluctuation of less than 1 dB is also obtained for Zr-EDF long of 6 m within L-band region. Compared with the conventional Si-EDFA, It was found that a Zr-EDFA, which uses a shorter length of gain medium, can achieve slightly higher gain values and broader bandwidth, as well as a lower noise figure.

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