Malaysian Journal of Science **21**: 115-121 (2002)

-L-band ring erbium doped fiber amplifier with fiber Bragg grating

S.W. Harun, **N. Tamchek**, **T.C. Teyo**, **P. Poopalan** and **H. Ahmad**

Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia

ABSTRACT An optical gain-clamped long wavelength band (1570 ~ 1610nm) erbium-doped fibre amplifier (L-band EDFA) is demonstrated using a fiber Bragg grating. It uses a counter propagating ring resonator, in order to achieve constant gain with minimum gain variation. The clamped-gain level can be controlled to be in the range from 7.2 to 14.3dB by increasing the cavity loss from 0 to 20dB. It is found that at 10dB variable optical attenuator (VOA) loss, clamping of the gain is flat with variation of input signal power from –40 to –5dBm. The gain measured is 10.9dB, which is 30% less than the open ring gain of 15.3dB at a pumping power of 92mW. The noise figure measured is about 5.2dB. The proposed design prevents oscillating light from being coupled out, but it degrades the amplifier's noise figure and clamped gain as the dynamic range is increased.

ABSTRAK Sebuah pembesar gentian terdop-erbium yang menggunakan parutan gentian Bragg dan beroperasi dalam jalur L (L-band EDFA) telah didemontrasikan. Ianya menggunakan penghayun lingkaran dalam konfigurasi berlawanan arah untuk mencapai pembesaran tetap dengan ralat yang minima. Aras pembesaran tetap ini boleh dikawal dalam julat 7.2 hingga 14.3dB dengan meningkatkan kehilangan kuasa pada penghayun dari 0 hingga 20dB. Didapati dengan attenuator boleh ubah ditetapkan pada 10dB, pembesaran yang didapati adalah mendatar untuk perubahan isyarat masukkan dari –40 ke –5dBm. Pembesaran yang diukur adalah 10.9dB, iaitu 30% kurang daripada kes jika penghayun lingkaran dibuka, yang memberikan nilai pembesaran sehingga 15.3dB dengan 92mW kuasa pam. Nilai bisingan yang diukur adalah 5.2dB. Rekabentuk yang digunakan dapat menghalang cahaya dalam penghayun lingkaran daripada terkeluar, akan tetapi ianya meningkatkan nilai bisingan dan mengurangkan nilai pembesaran-tetap jika julat dinamik ditambah.

(erbium doped fibre; optical amplifier; L-band; gain clamping; ring resonator; fiber Bragg grating)

INTRODUCTION

Ultra-large-capacity optical transmission systems are vital to the network infrastructure in the 21st century, which will support various emerging information systems, such as Internet, mobile communication systems, digital CATV, intelligent transport system (ITS), and so on. Wavelength division multiplexing (WDM) technique employing broadband fibre amplifiers is considered the most effective solution to enlarge the transmission capacity. Recently, the so-called long wavelength band erbium-doped fibre amplifiers (L-band EDFAs) [1,2] with the extended gain region of 1570 ~ 1610nm have emerged to satisfy the hunger of transmission bandwidth while in combination with conventional band (C-band) EDFA in a single optical fibre link. The system comprises of an L-band EDFA being placed next to the C-band EDFA providing a gain spectrum from 1530nm ~ 1610nm as demonstrated by Yamada et. al. [3] and Sun et. al. [4].

In WDM networks, stabilising the channel gain constant of each EDFA in the presence of dynamic input power variation or add/drop of optical channels is very important to eliminate the power transient effects and to maintain satisfactory system performance of the surviving channels. Various gain clamping techniques have been explored, particularly for C-band EDFA to minimise power excursions, in WDM transmission systems employing EDFA. As an example, Subramaniam et. al. [5] shows gain clamping behaviour in the C-band EDFA based on ring-laser cavity, utilising fiber Bragg grating (FBG). However, there is still a lack of research effort on gain clamping technique for L-band EDFA.

In this paper, design of the L-band ring erbium-doped fibre amplifier using a FBG is proposed and experimentally demonstrated for gain clamping. A backward amplified spontaneous emission (ASE) from erbium doped fiber (EDF) is routed to the ring via optical circulator, attenuated by variable optical attenuator (VOA), filtered and sent back into the EDF via a FBG and a second circulator.

EXPERIMENT SET UP

A design of the L-band ring EDFA is shown in Fig. 1. It consists of a 50m EDF, which is spliced to a wavelength selective coupler (WSC) at input end and a four-port circulator is connected at the output end of the doped fiber. The WSC combines the 980nm pump laser light from a laser diode and also the test signal from a tunable laser source (TLS), which is used to characterize the optical behaviour of the L-band EDFA. The backward ASE, which comprises mainly output in C-band is routed into the ring via a 3-port circulator, C1. This ASE is then sent back into the system via a VOA and a second circulator C2 as shown in the figure. The purpose of the VOA is to simulate the cavity loss in the system to provide an important parameter for studying the gain clamping behaviour in this system. The C2 circulator directs the ASE to the FBG, which reflects back a portion of the ASE to the EDF to form one complete oscillation. This optical input will then be amplified as it passes through the EDF, where it gets amplified again and again as it is being recycled, hence creating laser behaviour in the system. In this set up, the oscillating light propagates counter-clockwise to the TLS test signal. Thus, the oscillating light does not appear at the output port, and it does not disturb the WDM system. The output of the EDFA from the port 4 of C2 can be analysed using an optical spectrum analyser (OSA). The FBG has a centre wavelength at 1560nm, 3-dB bandwidth of 0.42nm and reflectivity of 99%. This design provides the mechanism to clamp the gain level of the L-band EDFA as discussed below.

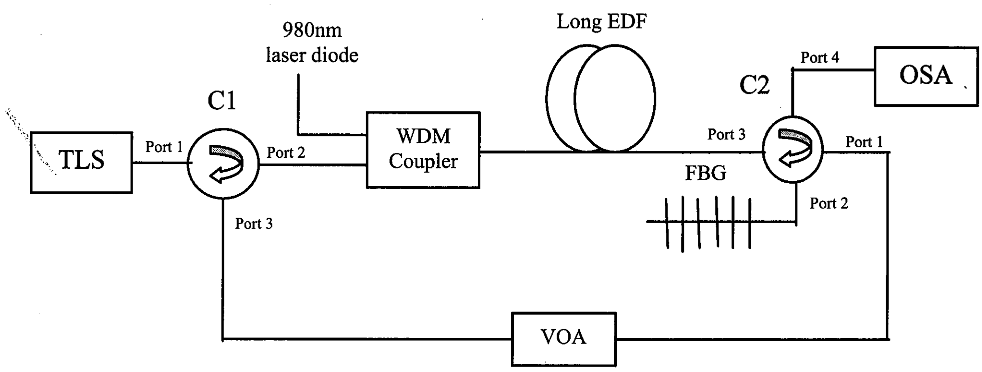


Fig. 1. Configuration of the proposed L-band ring EDFA

RESULTS AND DISCUSSIONS

The result of this design is shown in Fig. 2 with different VOA's losses which was varied from 0dB to 12.5dB. Measurements on the gain clamping were taken at different input signal power levels, from -40dBm to 0dBm at 1580nm. The 980nm pump power was fixed at 92mW. From the figure good clamping behaviour are observed at VOA's losses of 12.5dB, 10dB and 7.5dB. Although the system gain drops from 15.3dB to 10.9dB (for cavity loss of 10dB), a drop of 30%, the flatness of the gain curve at different input power level is very encouraging within 0.1dB. The gain value is limited by the availability of the 980nm pumping power. At higher cavity loss, the gain increases until the value of the open-ring system. The large amount of feedback power entering the EDF due to the low cavity loss deeply saturates the gain of the

EDF. It is well known that the gain of deeply saturated EDFA is flat over a wide wavelength range [6]. Although the present gain value of the open loop EDFA is limited to 15.3dB, this is due largely to the unoptimised EDF length and the limited power of the pump laser.

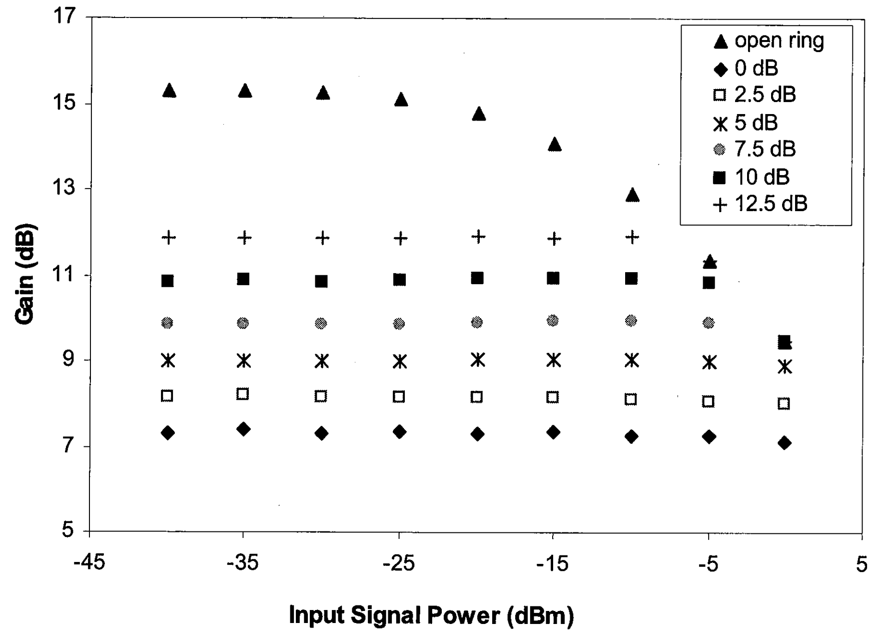


Fig. 2. Gain as a function of input signal power for various VOA losses

Figure 3 shows the variation of the noise figure at different signal input power. From the figure, it can be seen that the noise figure for VOA's loss at 10dB stays reasonably flat at 5.2dB for small signal gain amplification. But at VOA's loss of 5dB, the noise figure tends to be slightly higher at an average value of 5.5dB. The noise figure increases with the reduction of cavity loss. This is attributed to the increment of oscillating laser power in the lower cavity loss which can induce an incomplete population inversion of EDF, (the inversion parameter $n_{sp} = N_2 / (N_2 - N_1)$ increases, where N_2 is the population density of upper state and N_1 is the population density of the lower state) leading to the noise figure degradation. From the measurements it is found that the best VOA's loss that will give a flat clamping effect with a low noise figure of 5.2dB is at VOA's loss of 10dB. Figure 4 shows an output spectrum from the amplifier when the input 1580nm signal power, 980nm pump power and VOA loss were fixed at –30dBm, 92mW and 10dB, respectively. As is seen in the figure, a strong laser action is present which is reflected from components or connectors/splices between components. There is about a 20dB difference between the signal and reflected laser intensities. It is believed that the use of superior components as well as optimised connectors/splices will totally eliminate even the reflected laser power.

Figure 5 shows the gain and noise figure as a function of signal wavelength at different VOA's losses. As seen in Fig. 5(a), the closed loop EDFAs have a flatter spectrum compared to the open ring amplifier, and the VOA's loss of 0dB shows a flattest spectrum with variation less than 1.2dB within the range from 1568 to 1604nm at the expense of the reduced gain. This is probably due to the laser consuming more energy as the oscillating laser power is increased. On the other hand, Fig. 5(b) shows that the closed loop EDFAs have a higher noise figure than the open ring EDFA and the noise figure increases with the reduction of VOA's loss especially at shorter wavelengths region. This is due to the same reason as explained above

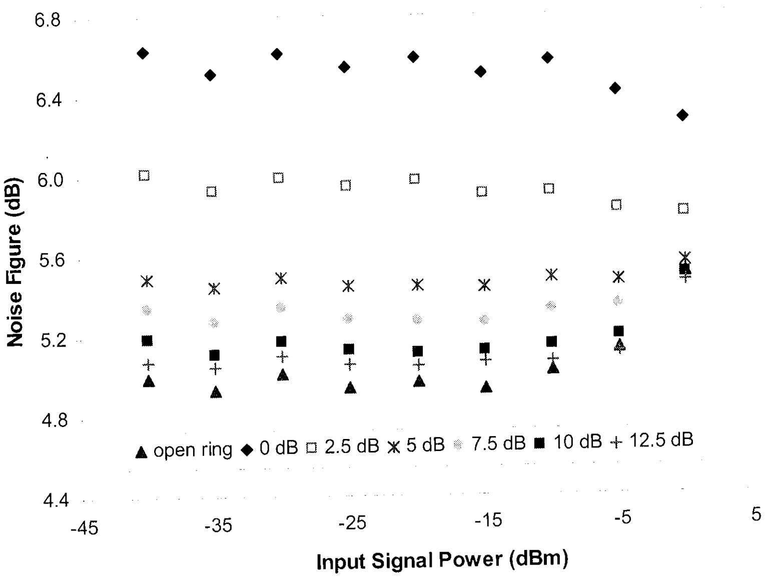


Fig. 3. Noise figure as a function of input signal power for various VOA losses

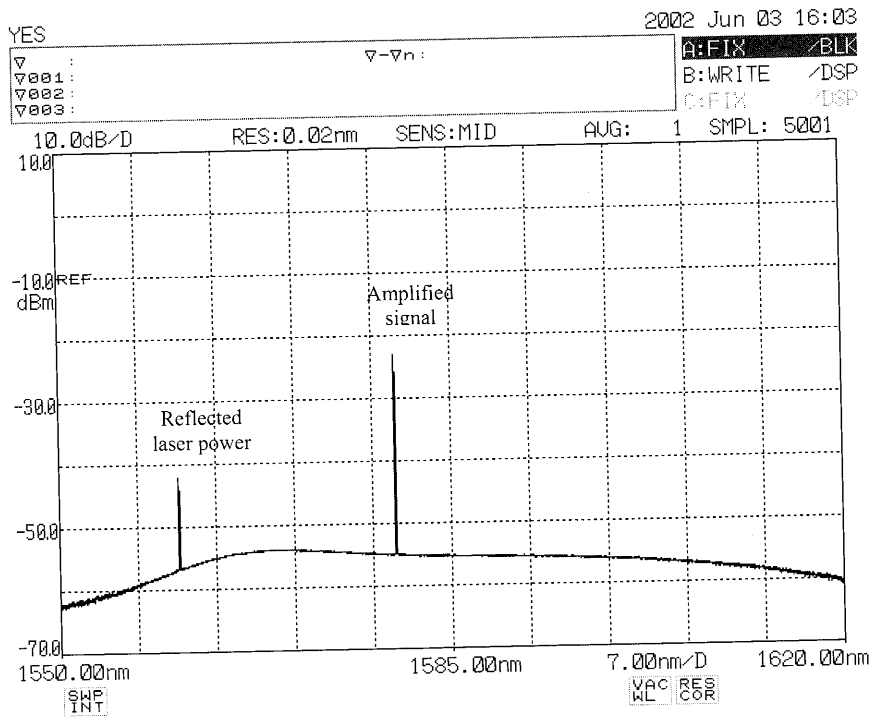
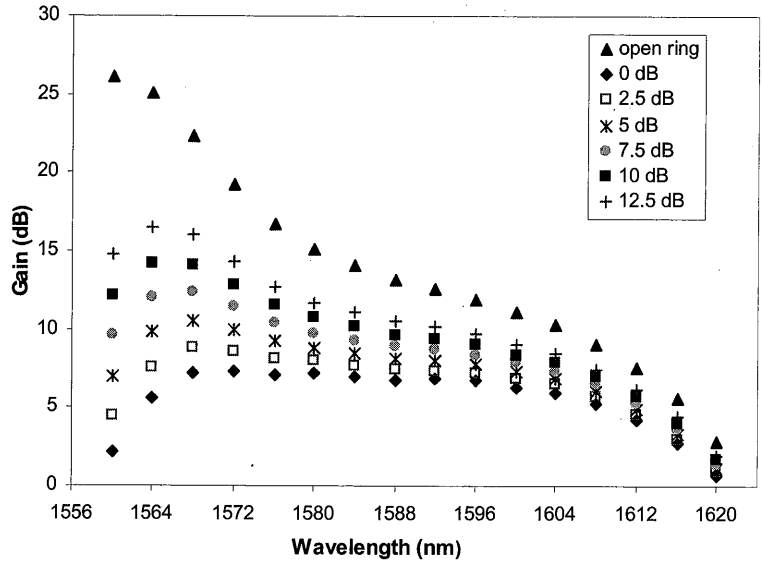
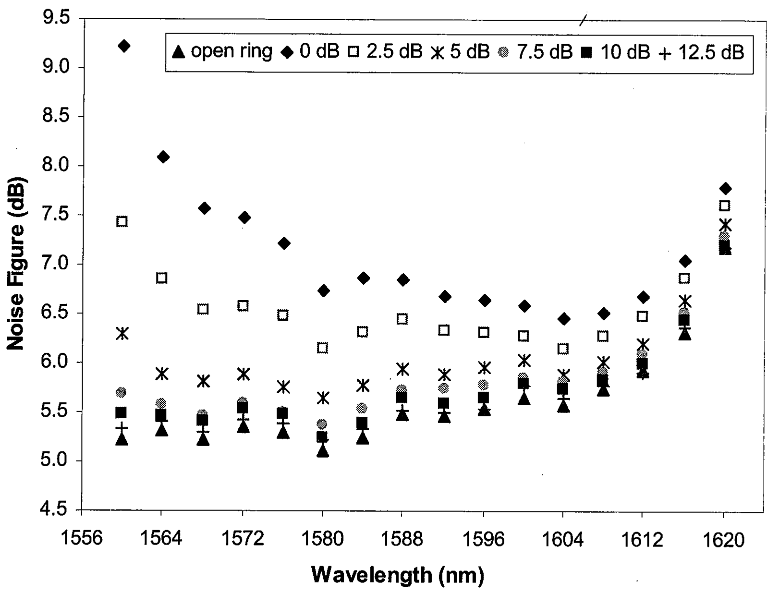


Fig. 4. Output spectrum of the proposed amplifier



(a) Gain



(b) Noise figure

Fig. 5. Gain and noise figure as a function of signal wavelengths: (a) gain (b) noise figure

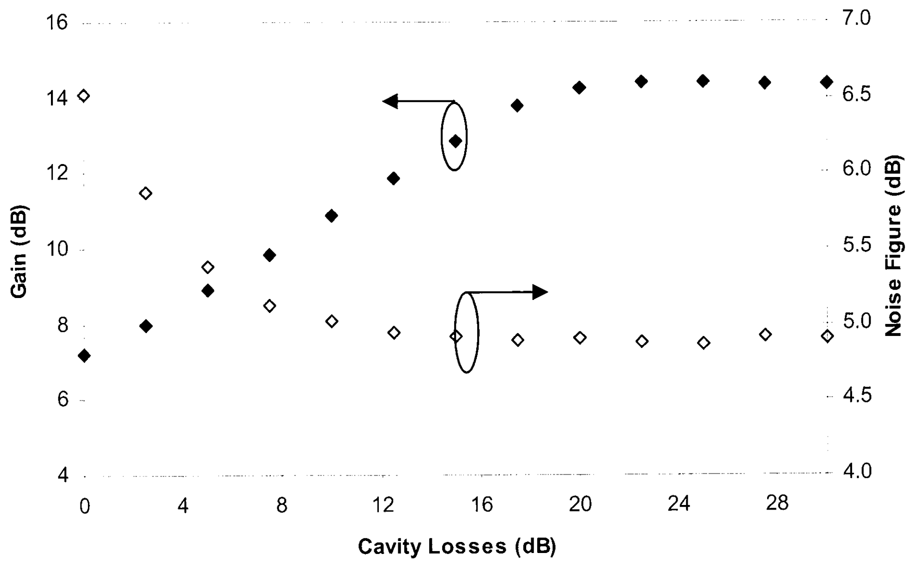


Fig. 6. Gain (shaded) and noise figure (clear) against various cavity losses.

The gain and noise figure against various cavity losses for the 1580nm signal is shown in Fig. 6. The signal and pump powers are fixed at -30dBm and 92mW, respectively. By varying the cavity losses, the clamped gain is controlled to be in the range from 7.2 to 14.3 dB as depicted in the figure. An increase in cavity loss means a decrease in the oscillating laser power and this will reduce clamping effect and increases the clamped gain. As seen in the figure, the gain is a monotonically increasing function of cavity loss. As per tuning efficiency, a clamped gain is varied for a different attenuation value in the laser cavity with allowable linearity, 0.36dB/dB on average. We find that when cavity loss is above 20dB, the optical gain becomes consistent at 14.3dB and the corresponding noise figure is 4.9dB. In this region, the cavity is operating below the laser threshold. Therefore, the condition for clamping effect is not satisfied. On the other hand, the noise figure decreases with cavity losses at cavity losses less than 12 dB but constant after this region.

CONCLUSION

A design of L-band gain clamped EDFA based on ring laser cavity using a fiber Bragg grating has been presented. A stable gain clamped effect was observed at a cavity loss of 10dB providing a constant gain signal power from –40dBm to –5dBm. The clamped-gain level can be tuned from 7.2 to 14.3dB by increasing the cavity loss using the VOA. However the noise figure is degraded as the oscillating laser power increases due to the limitation of population inversion. This L-band gain-clamped EDFA in combination with C-band gain-clamped EDFA in a parallel configuration may find important applications in DWDM broadband systems and networks to provide constant gain with minimum gain variation in the presence of dynamic input power variation and add/drop of optical channel. The advantage of this amplifier design is that the oscillating light does not appear at the output port of the amplifier.

REFERENCES

1. Ono, H., Yamada, M., Sudo, S. and Ohishi, Y. (1997). "1.58µm band Er^{3+}-doped fiber amplifier pumped in the 0.98 and 1.48 µm bands," *Electron. Lett.* **33**: 876-877.
2. Ono, H., Yamada, M. and Ohishi, Y. (1997). "Gain-flattened Er^{3+}-doped fiber amplifier for a WDM signal in the 1.57-1.60 µm wavelength range," *IEEE Photon. Technol. Lett.* **9**: 596-598.

3. Yamada, M., Ono, H., Kanamori, T., Sudo, S. and Ohishi, Y. (1997). "Broadband and gain flattened amplifier composed of a 1.55 μm-band and a 1.58 μm-band Er^{3+}-doped amplifier in a parallel configuration," *Electron. Lett.* **33**: 710-711.
4. Sun, Y., Sulhoff, J.W., Srivastava, A.K., Zyskind, J.L., Strasser, T. A., Pedrazzani, J. R., Wolf, C., Zhou, J., Judkins, J.B., Espindola, R.P. and Vengsarkar, A.M. (1997). "80nm ultra-wideband erbium-doped fibre amplifier", *Electron. Lett.* **33**: 1965-1967.
5. Subramaniam, T., Mahdi, M.A., Poopalan, P., Harun, S.W. and Ahmad, H. (2001). "All-Optical Gain-Clamped Erbium-Ring Lasing Amplifier with Laser Filtering Technique," *IEEE Photon. Technol. Lett.* **13**: 785 - 787.
6. Desurvire, E. (1993). *Erbium-Doped Fiber Amplifier: Principles and Applications*, New York: Wiley.