Pis'ma v ZhETF, vol. 77, iss. 9, pp. 555 – 557

Effect of injection of C-band ASE on L-band erbium-doped fiber amplifier

S. W. Harun[1], *N. Tamchek, P. Poopalan, H. Ahmad*

Photonics Laboratory, Department of Physics, University of Malaya, 50603 Kuala Lumpur, Malaysia

Submitted 13 March 2003

The effect of injecting conventional band (C-band) amplified spontaneous emission on the performance of long wavelength band erbium-doped fiber amplifier (L-band EDFA) is demonstrated. It uses a circulator and broadband fiber Bragg grating (FBG) to route C-band ASE from a C-band EDFA. Injection of a small amount of ASE (attenuation of 20 dB and above) improves the small signal gain with a negligible noise figure penalty compared to that of an amplifier without the ASE injection. A maximum gain improvement of 3.5 dB is obtained at an attenuation of 20 dB. At very large amounts of ASE injection (attenuation of 0 dB), the gain of the amplifier is clamped at 15.2 dB from −40 to −10 dBm with a gain variation of less than 0.3 dB. The saturation power is also increased from −8 dBm (for without ASE injection) to 2 dBm (VOA = 0 dB) with a slight noise figure penalty. These results show that the ASE injection technique can be used either for gain improvement or gain clamping in L-band EDFA.

PACS: 42.60.Da, 42.81.–i, 42.81.Wg, 42.81.Uv

Introduction. The erbium-doped fiber amplifier (EDFA) moved very quickly from invention in 1987 to the cornerstone of high speed long-haul networks. The need to extend the bandwidth of dense wavelength division multiplexing system has resulted in research aimed at transmitting outside the conventional wavelength band (also known as the C-band, ranging from 1530 nm to 1565 nm). Transmission in the region 1570 nm –1610 nm (referred to as the L-band), which effectively doubles the potential bandwidth, has been reported [1]. The L-band EDFA can be combined with a C-band EDFA in parallel configuration to increase the range of amplification wavelength region. However, the L-band lies at the tail of the erbium amplification window, where the inversion rate is low. Therefore, various research efforts have been explored to enhance the amplification characteristics in the L-band EDFA [2, 3].

As the complexity of the networks increases in multiplex system networking, a major potential problem associated with the amplifier is a need for the control of the gain of EDFAs due to circumstances such as faults, adding and dropping of wavelength and rerouting. In these cases, the total input signal power to the amplifier varies abruptly causing the dynamics of the population inversion to change accordingly. Therefore, the amplifier gain increases or reduces with the potential to cause receiver saturation or bit error rate increment. Thus a gain-clamping mechanism is desired. To date, there have been various research efforts to clamp the gain in C- and L-band EDFA [4, 5]. In this paper, we demonstrate the effect of injecting C-band ASE on L-band EDFA. This ASE injection technique shows a possible application either for gain improvement or gain clamping in L-band EDFA.

Experimental set up. The experimental setup is shown in Fig.1. The erbium-doped fiber (EDF) used in

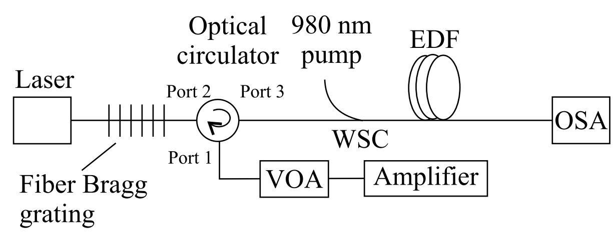

Fig.1. Experimental set up

the experiment is commercially available and has a numerical aperture of 0.22, cut-off wavelength of 920 nm and peak absorption of 6.1 dB/m at 1531 nm. The length of EDF is fixed at 50 m. A 980 nm laser diode is used as a pump source with a maximum pump power of 92 mW at the EDF input end. The wavelength selective coupler (WSC) combines the input test signal and the 980nm pump into the EDF. The C-band ASE from a C-band EDFA is fed into the EDF section using an optical circulator and a fiber Bragg grating. At the amplifier input end, a broadband fiber Bragg grating with a center wavelength, bandwidth and reflectivity of 1545 nm, 40 nm and 99% respectively, is employed as a broadband reflector. The forward ASE light from the C-band

[1] e-mail: wadi72@yahoo.com

EDFA is routed by the optical circulator, reflected by the grating and then co-propagates with the signal. A variable optical attenuator (VOA) is used to control the power level of the launched C-band ASE. A tunable laser source is used for the evaluation of the amplifier performance in conjunction with an optical spectrum analyzer (OSA), which uses the interpolation technique to evaluate noise figure.

Result and discussion. Fig.2 depicts the ASE spectra of the amplifier with and without injection of C-band ASE, where the thick line represents the amplifier without injection of C-band ASE. The pump power is fixed at 92 mW. As apparent in the figure, the amplifier with a large amount of ASE injection (VOA = 0 dB) shows a lower L-band ASE than that of the amplifier without ASE injection, at L-band region (above 1567 nm). This reduction of L-band ASE is obtained due to the injection of a large amount of C-band (1525 nm to 1567 nm) ASE that causes limitation of population inversion at the longer wavelength region. However, the injection of low power of ASE (VOA = 20 dB) dramatically increases the ASE level at the L-band region. The ion population inversion is increased by this amount of ASE through energy transfer from short wavelengths to longer wavelength.

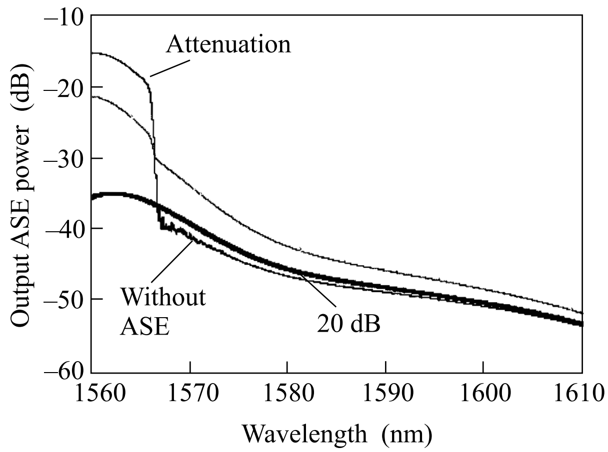

Fig.2. ASE spectra of the amplifier with and without of C-band ASE

Figures 3 and 4 show the optical gain and noise figure characteristics at 1580 nm respectively, as a function of input signal power against the VOA losses. The pump power is fixed at 92 mW. The characteristic of the amplifier without the injection of backward ASE is also shown for comparison. Inset of Figs.4 and 5 shows the small signal gain and noise figure against the VOA loss respectively, when input signal and wavelength are fixed at −30 dBm and 1580 nm. At attenuations of 20 dB and above, the gain level increases with the amount of the injected ASE power as shown in Fig.3. The small signal gain improvement of 3.5 dB is obtained for the attenuation of 20 dB compared to the amplifier without

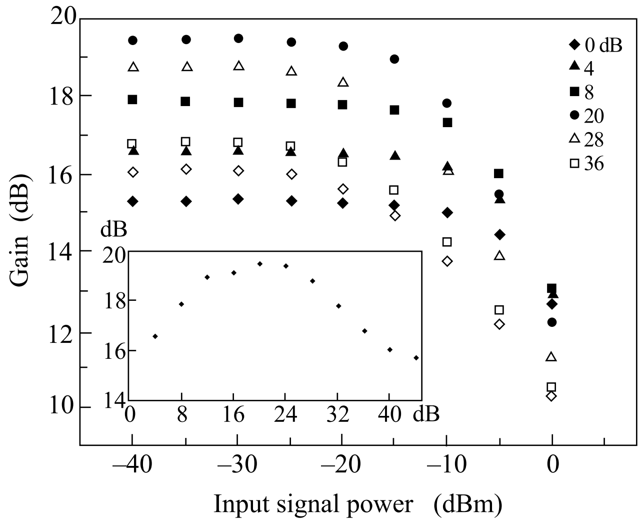

Fig.3. Gain as a function of input signal power at various VOA losses (◊ – without ASE). Inset: Gain against the VOA loss

the ASE injection. Fig.5 shows an injected ASE spectrum at attenuations of 0 and 20 dB. The ASE power is −40 dBm at 1531 nm for the attenuation of 20 dB. This amount of ASE has increased the population ion inversion at the input end of the EDF, and hence, improves

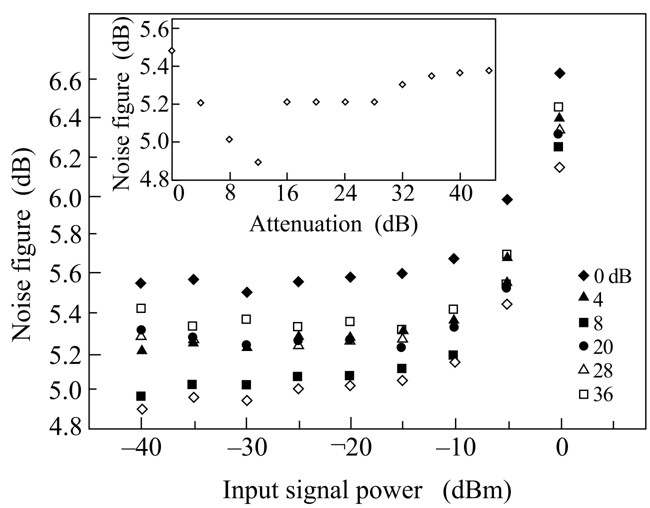

Fig.4. Noise figure as a function of input signal power at various VOA losses (◊ – without ASE). Inset: Noise figure against the VOA loss

the L-band signal gains. This technique shows that the injection of C-band ASE (total power should be less than −14.1 dBm) can be utilized to enhance the L-band performance. Besides gain improvement, this technique also produces almost negligible noise figure penalties as shown in Fig.4. However the gain level is decreased for higher amounts of ASE (< 20 dB of attenuation). At attenuation of 0 dB (total ASE power of 6 dBm), the gain is clamped at 15.2 dB from −40 to −10 dBm with gain variation of less than 0.3 dB. The saturation power also increases from −8 dBm (for without ASE injection) to 2 dBm (VOA =0 dB). The ASE power is measured to be −20 dBm at 1531 nm for attenuation of 0 dB as shown in Fig.5. The L-band amplification mechanism is made possible by the intra-Stark level multi-phonon

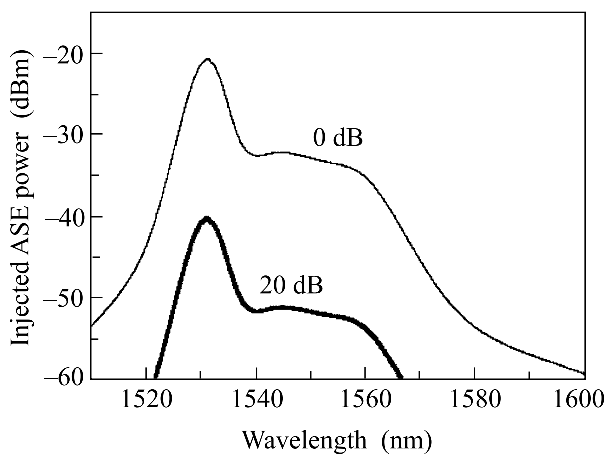

Fig.5. Injected C-band ASE spectrum at attenuations of 0 and 20 dB

transitions and re-absorptions that transfer energy from the short wavelength (C-band) to the longer wavelength (L-band). Therefore, injecting a large amount C-band ASE into EDF 1 depletes the number of ions in ground state. This limits the population inversion, which in turn reduces gain, thereby clamping the gain. A lower VOA loss enables a higher injected ASE power, which severely degrades the amount of available inversion. The noise figure for the gain clamped amplifier (VOA = 0 dB) is slightly higher at an average value of 5.5 dB, compared to the unclamped amplifier (without injection of ASE). A large amount of injected ASE induces an incomplete population inversion in the EDF as given by the inversion parameter $n_{sp} = \{\sigma_e(\lambda)N_2\}/\{\sigma_e(\lambda)N_2 - \sigma_a(\lambda)N_1\}$, where σ_e is the emission cross section, σ_a is the absorption cross section, N_2 is the population density of the upper state and N_1 is the population density of the lower state, which leads to the noise figure degradation.

Conclusion. The effect of injecting C-band ASE on a L-band EDFA is demonstrated in this paper. Compared to the amplifier without ASE injection, the L-band EDFA has shown a small signal gain improvement of 3.5 dB at attenuation of 20 dB with a negligible noise figure penalty. With the ASE injection at attenuation of 0dB, the gain of the amplifier is clamped at 15.2 dB from −40 to −10 dBm with gain variation less than 0.3 dB. The saturation power is increased from −8 dBm (for without ASE injection) to 2 dBm (VOA = 0 dB) with slightly noise figure penalty. This ASE injection technique has showed a possible application either for gain improvement or gain clamping in L-band EDFA.

1. Y. Sun, J. W. Sulhoff, A. K. Srivastava et al., Electron. Lett. **33**, 1965 (1997).
2. S. W. Harun, P. Poopalan, and H. Ahmad, IEEE Photon. Technol. Lett. **14**, 196 (2002).
3. J. Lee, U.-C. Ryu, S. J. Ahn, and N. Park, IEEE Photon. Technol. Lett. **11**, 42 (1999).
4. T. Subramaniam, M. A. Mahdi, P. Poopalan et al., IEEE Photon. Technol. Lett. **13**, 785 (2001).
5. S. W. Harun, N. Tamchek, P. Poopalan, and H. Ahmad, Jpn. J. Appl. Phys. **41**(7B), L836 (2002).