Indian J. Phys. **77B** (5), 545-547 (2003)

AN INTERNATIONAL JOURNAL
IJP

Gain clamped L-band EDFA with injection of C-band ASE

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Received 30 January 2003, accepted 24 June 2003

Abstract : 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 large amount of ASE reduces and clamps the small signal gain with a small noise figure penalty compared with those without the ASE injection. With the ASE injection, the gain of the amplifier is clamped at 15.2dB from –40 to –10dBm with a gain variation of less than 0.3dB. The saturation power is also increased from –8dBm to 2dBm. Those results show that the ASE injection technique can be used for gain clamping in L-band EDFA

Keywords : Gain clamping, optical amplifier, L-band EDFA, population inversion, amplified spontaneous emission

PACS Nos. 42.55.Wd, 42.60.Da, 42.60.Fc; 42.81.-i

1. Introduction

The need to extend the bandwidth of dense wavelength division multiplexing (DWDM) 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]. Integration of L-band erbium-doped fiber amplifier (EDFA) in parallel with C-band EDFA allows a gain bandwidth as high as 80nm to be achieved [2].

As the complexity of the networks increases in DWDM networking, a major potential problem associated with the amplifier is a need for the control of the gain of EDFA's due to circumstances such as faults, adding and dropping of wavelength and re-routing. 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 [3, 4]. In this paper, we propose an injection scheme for gain clamping by injecting C-band ASE on single stage L-band EDFA.

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2. Experimental set-up

Figure 1 details our experimental set-up. The erbium-doped fiber (EDF) used in the experiment is commercially available and has a numerical aperture (NA) of 0.22, cut-off wavelength of 920nm and peak absorption of 6.1 dB/m at 1531 nm. The length of EDF is fixed at 50m. A 980nm laser diode is used as a pump source with a maximum pump power of 92mW 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 FBG with a center wavelength, bandwidth and reflectivity of 1545nm, 40 nm and 99% respectively, is employed as a broadband reflector. The measured reflection spectrum of the FBG is shown in Figure 2. The forward ASE light from the C-band EDFA is routed by the optical circulator, reflected by the

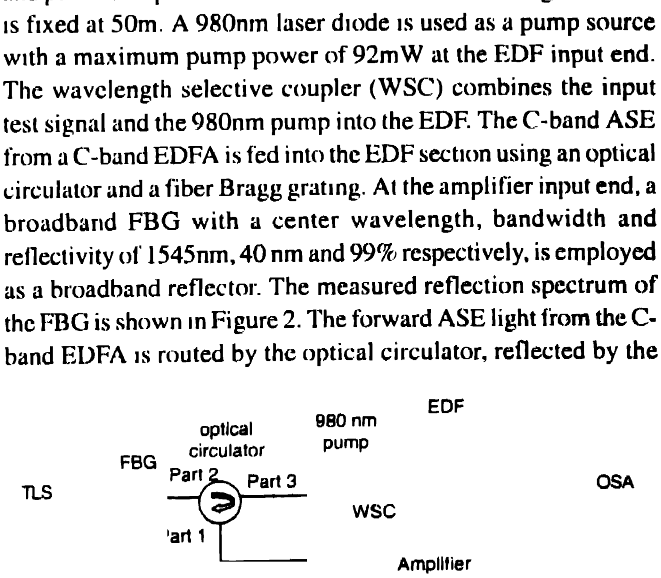

Figure 1. Experimental set-up.

grating and then co-propagates with the signal. A tunable laser source (TLS) 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.

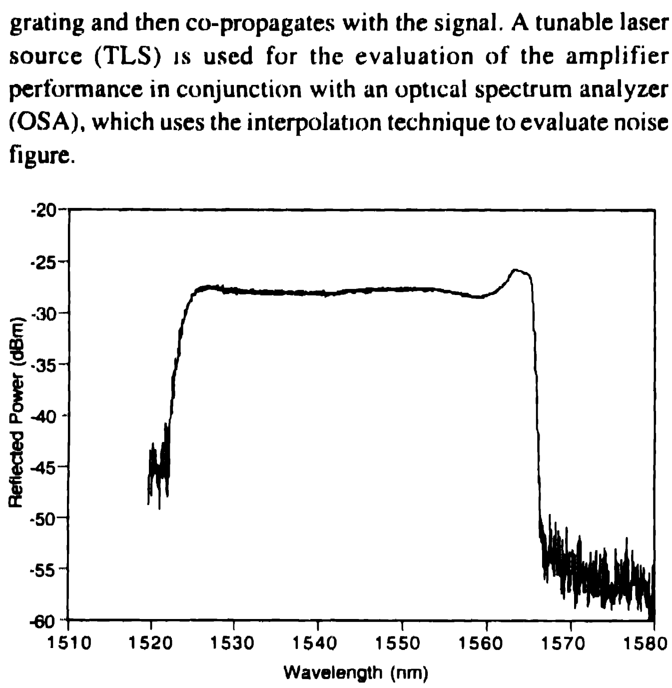

Figure 2. Reflection characteristics of the FBG

3. Result and discussion

Figure 3 depicts the ASE spectra of the amplifier with and without an injection of C-band ASE, where the thin line represents the amplifier with the ASE injection. The pump power is fixed at 92mW. As is apparent in the figure, the amplifier with an ASE injection at C-band shows a lower ASE level than that of the amplifier without ASE injection, at L-band region (above 1567nm). This reduction of L-band ASE is obtained due to the injection of a large amount of C-band (1525 nm to 1567nm) ASE that causes limitation of population inversion at the longer wavelength region. *The large increase in ASE below 1567nm is due to the FBG. The excess power of the injected C-band ASE is included in the measured output ASE.*

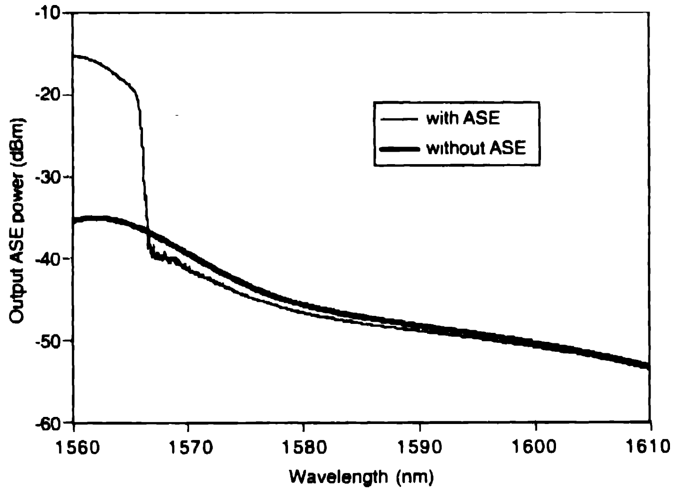

Figure 3. ASE spectra of the L-band EDFAs with the pump power of 92mW

Figure 4 shows the optical gain and noise figure characteristics as functions of input signal power. The pump power and signal wavelength are fixed at 92mW and 1580nm, respectively. The amplifier with an ASE injection shows a constant gain compared with those for the amplifier without an ASE injection, represented by the filled triangles. The gain is clamped at 15.2dB from −40 to −10dBm with gain variation of less than 0.3dB. The saturation power is also increased from −8 to 2dBm with the ASE injection. However, the gain level is decreased compared to those without ASE injection. Inset of Figure 4 shows an injected C-band ASE spectrum, where the maximum power of −20dBm is shown at 1531nm. The L-band amplification mechanism is made possible by the intra-Stark level multi-phonon transitions and re-absorptions that transfer energy from the short wavelength (C-band) to the longer wavelength (L-band). Therefore, injecting a large amount of C-band ASE into EDF section depletes the number of ions in ground state. This limits the population inversion, which is turn reduces gain, thereby clamping the gain.

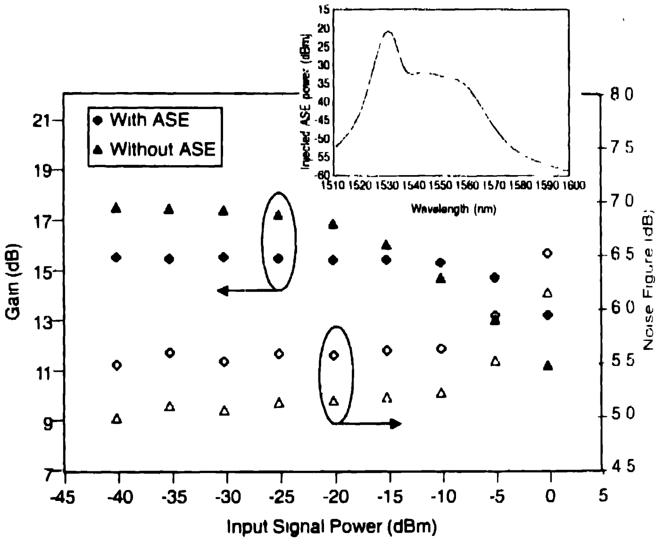

Figure 4. Gain (closed) and noise figure (clear) as functions of input signal power (Inset spectrum of an injected C-band ASE).

The noise figure for the gain clamped amplifier is slightly higher at an average value of 5.5dB at small input signal power, compared to the unclamped amplifier (without injection of ASE) as shown in Figure 4. A large amount of the 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. Figure 5 shows a gain and noise figure as functions of input signal wavelength. The input signal power is fixed at - 30dBm. The gain reduction is observed for the gain clamped amplifier particularly at shorter wavelengths. The noise figure penalty also is higher at shorter wavelengths. This is attributed to the gain clamping effect which is greater at the shorter wavelengths.

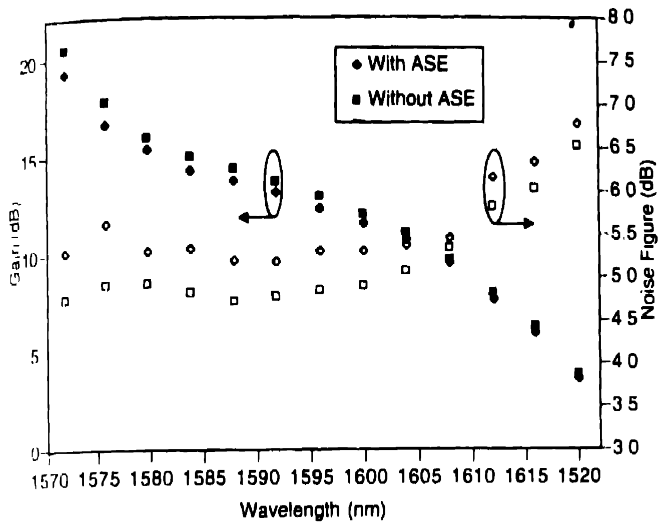

Figure 5. Gain (closed) and noise figure (clear) as functions of input signal wavelength

4. Conclusion

The effect of injecting C-band ASE on a L-band EDFA is demonstrated in this paper. With an ASE injection, the L-band EDFA has shown a constant gain at small input signal power with a small noise figure penalty. The gain of the amplifier is clamped at 15.2dB from –40 to – 10dBm with gain variation of less than 0.3dB. The saturation power is also increased from – 8dBm to 2dBm with the injection of C-band ASE. However, the noise figure for the gain clamped amplifier is slightly higher at an average value of 5.5dB at small input signal power, compared to the unclamped amplifier. This ASE injection technique has showed a possible application for gain clamping in L-band EDFA.

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