[ME01] An Efficient and Low Noise L-band Erbium-Doped Fiber Amplifier

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Introduction

The use of the long-wavelength-band (L-band) is attractive for both increasing the capacity of wavelength division multiplexing (WDM) systems and has been used in WDM transmission experiments at over 1 Tb/s. Recently, a gain bandwidth of about 80nm has been achieved by integrating the L-band EDFA in parallel with conventional band (C-band) EDFA [1]. Moreover, the L-band EDFAs will make it possible to construct an effective WDM systems employing dispersion-shifted fiber (DSF) without the degradation caused by four-wave-mixing (FWM) [2]. The L-band erbium-doped fiber amplifier (EDFA) is studied because it can be constructed by silica-based erbium-doped fiber (EDF) and has a low linearity for WDM signals. However, L-band EDFAs have a low power conversion efficiency (PCE) compared to a C-band. Therefore, a double-pass L-band EDFA has been introduced to enhance the gain in this region [3]. Besides gain improvement, L-band EDFAs for WDM system must also be able to manage gain variation due to dynamic add/drop or abrupt failure in the system. To stabilize the gain, various techniques applying the ring laser have been investigated for single-pass EDFA [4-5]. In this letter, a novel and simple configuration of gain-clamped double-pass L-band EDFA is proposed and demonstrated using a ring resonator.

Experimental setup

The schematic diagram of gain-clamped double-pass L-band EDFA is shown in Fig. 1. It consists of two sections of erbium doped fiber (EDF1 and EDF2), two laser diodes (P1 and P2), two wavelength-selective-coupler (WSC1 and WSC2), a FBG, a C/L-band WSC and a circulator (OC). EDFs 1 and 2 having an erbium ion concentration of 400 ppm are fixed at 12 m and 50 m, respectively. 980 nm laser diodes are used to pump both EDF using a forward pumping scheme. P1 and P2 are fixed at 68 mW and 102 mW, respectively. Two WSCs are used to combine the 980 nm pump from each laser diode with the test signal. A broadband FBG with minimum reflectivity of 92% and a bandwidth of 44 nm centered at 1587 nm is employed at the output end of EDF2. It retro-passes the test signal back into the system for enhanced gain. The backward ASE from EDF2 is routed into the feedback loop via the circulator and C/L-band WSC, and passes through the FBG to form a complete ring cavity. A tunable laser source (TLS) is used for the evaluation of the amplifier performances in conjunction with an optical spectrum analyzer (OSA), which is located at L-port of C/L-band WSC. The amplifier performance is also measured for an unclamped amplifier, which is obtained by opening the ring, for comparison purposes.

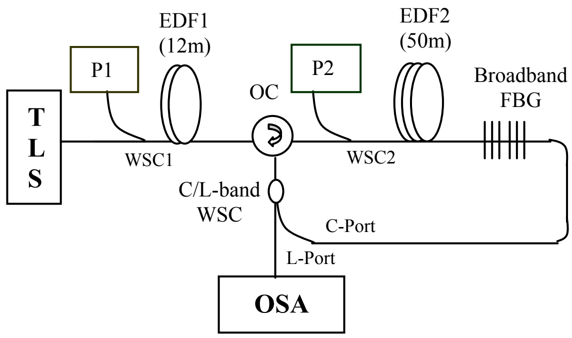

FIGURE 1 Configuration of the gain-clamped double-pass L-band EDFA.

Result and Discussions

Fig. 2 depicts the ASE spectra of the amplifier with open- and closed-ring, where the thin line represents the amplifier with closed-ring. As shown in the figure, the amplifier with closed-ring shows a lower ASE level compared to that of the open-ring. The ASE suppression is due to the laser at 1564 nm, which oscillates in the ring resonator as depicted in the figure. In a homogeneously broadened medium, laser light at certain wavelength fixed the total population inversion. Therefore the gain for the signal is dependent only on its absorption and emission cross sections. Any variations in other conditions such as pump power and input signal power are compensated for by the adjustment of the laser power. The consequence of this is that the signal experiences a constant gain, independent of pump and input signal power variations. The clamped gain levels and dynamic input power ranges depend on the ring laser intensity.

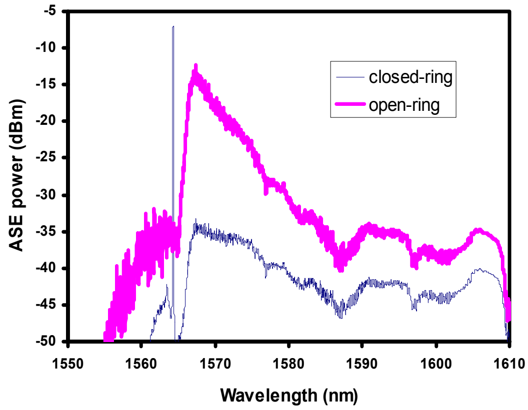

FIGURE 2 ASE spectra for both gain-clamped and unclamped L-band EDFAs.

Fig. 3 shows the gain and noise figure as a function of input signal power for both closed-ring and open-ring amplifiers. The signal wavelength is fixed at 1580 nm. For the open-ring amplifier, the unsaturated gain obtained is 29.6 dB and degrades as the input signal power increases. On the other hand, good gain clamping behavior is observed for the closed-ring amplifiers. The gain is clamped at 18.6 dB for all input signal powers from -40 dBm to -8 dBm with gain variation of less than ±0.1 dB. This clamping effect is due to the fixed population inversion set by the oscillating laser in the closed-ring. The clamped gain level is relatively higher in this double-pass gain-clamped system than in conventional single-pass gain-clamped EDFAs [4]. This is attributed to the fact that the test signal is amplified twice in different directions in the second stage of the system, and the total gain is significantly increased due to the increase in effective EDF length. The output power is measured in the range of -21.4 to +10.4 dBm as input signal power increases from -40 to -8 dBm.

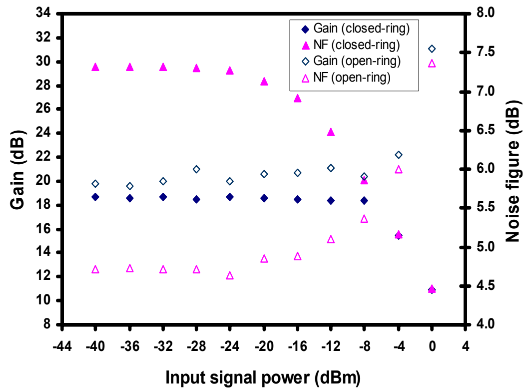

FIGURE 3 Gain and noise figure (NF) as a function of input signal power.

On the other hand, the noise figure shows an increment in the gain-clamped amplifier compared to the unclamped amplifier. The noise figure penalty is due to the limited population inversion, which causes changes in 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 noise figure degradation. The noise figure varies from 5.8 to 6.0 dB within the dynamic input signal powers range, which is about 0.5 ~ 1.2 dB higher compared to that of open-ring amplifier. For input signal powers within the dynamic range, the significant noise figure penalties are induced by the intense ring laser light passing through the EDF. However, for input signal power above the dynamic range, the noise figures are primarily dominated by the self-induced saturation. The slight noise figure degradation at these input powers is attributed to the regenerative backward ASE. However, the noise figures are still relatively lower in the proposed amplifier compared to that of another double-pass amplifier [3] due to the incorporation of pre-amplifier (forward pumped EDF1) in front of a double-pass amplifier. Since the circulator (OC1) prevents the amplified signal and backward ASE from propagating into the EDF1, the population inversion of the input part of the amplifier is hardly affected by the intense lights, therefore, the noise figure could be kept low.

Conclusion

A gain-clamped double-pass L-band EDFA with high clamped gain and low noise figure has been presented using a ring laser. The broadband FBG operating at L-band region is used to retro-pass the test signal back into the system for enhanced gain. The gain clamping is achieved by routing back the backward C-band ASE into the EDF to create ring laser. The gain is clamped at 18.6 dB from -40 to -8 dBm with a gain variation of less than ±0.1 dB and a noise figure of less than 6 dB.

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