Gain-clamped double-pass S-band erbium-doped fiber amplifier

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Abstract: Gain clamping in double-pass short-wavelength band erbium-doped fiber amplifier (S-band EDFA) is demonstrated. It uses a fiber Bragg grating, which operates in conventional-band to form an oscillating laser in the cavity using an erbium-doped fiber (EDF) gain at around 1530 nm. This new technique has shown a good gain clamping effect with gain variation of less than 1.0 dB from -40 to -14 dBm input signal powers for 1500 nm signal. The gain can be controlled within 18 to 20 dB by varying a variable optical attenuator from 0 to 8 dB. Compared with an unclamped amplifier, the noise figures for small signals are slightly improved due to the suppression of amplified spontaneous emission (ASE). However, the noise figure level is still considerably high due to the double-pass scheme and unoptimised splicing between a depressed cladding EDF and a standard single mode fiber. The advantage of this gain clamped amplifier is that the oscillating light operates at wavelength outside S-band region, which prevent the wavelength division multiplexed system from being disturbed.

Keywords: S-band EDFA, depressed cladding EDF, Erbium-doped fiber amplifier, double-pass EDFA, gain clamping

Classification: Photonics devices, circuits, and systems

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1 Introduction

Short wavelength band erbium-doped fiber amplifiers (S-band EDFAs) for wavelength division multiplexed (WDM) transmission system are very attractive because the transmission capacity in conventional band (C-band) and long wavelength band (L-band) is gradually becoming insufficient and S-band is a potential candidate to extend the capacity by all means. Recently, a double-pass configuration have been proposed in order to improve the gain performance of the S-band EDFA [1]. The double-pass amplifier requires fewer components than the conventional two-stage bi-directional pumped configurations, which make it more cost-effective than the conventional single-pass amplifier. However, gain clamped characteristics are indispensable in the EDFAs for the reason that in WDM systems, the channel gains are required to be constant even though the operating conditions, such as the total input signal power and pump power, can vary significantly. The transient response is another issue that needs to be considered as large dynamic excursion can lead to errors at the receiver and degrades system performance. Therefore, the gain clamping techniques have been extensively explored for C- and L-band EDFAs to control the dynamic gain variation, including the use of tunable bandpass filter and fiber Bragg grating (FBG) to form laser in optical feedback loop [2, 3, 4]. However, there are still a lack of research work on the gain-clamped S-band EDFA. In this letter, we propose a simple and novel S-band gain-clamped EDFA using a FBG in double-pass configuration.

2 Experimental set up

The configuration of the double-pass S-band EDFA is shown in Fig. 1. A 15 m depressed cladding EDF is used to provide a high distributed loss at wavelength longer than 1525 nm for S-band amplification. The composition of the EDF's core is approximately 2.5% GeO₂, 5.5% Al₂O₃, and 92% SiO₂ with 0.15 wt.% Erbium. The depressed cladding is approximately 3% Fluorine, 0.5% P₂O₅, and 96.5% SiO₂. The numerical aperture of the core, relative to the depressed cladding, is 0.22. The background loss of EDF is less than 5 dB/Km. The EDF is pumped by 980 nm laser diode using a forward pumping scheme and the pump absorption is about 7.6 dB/m. A

Fig. 1. Configuration of the proposed double-pass gain-clamped S-band EDFA.

wavelength selective coupler (WSC) optimized for C-band operation is used to combine the 980 nm pump with the test signal. An optical circulator OC2 with port 1 connected to port 3 is employed at the output end of the EDF to allow double propagation of test signal in the system. Optical circulator OC1 is placed at the input end of the amplifier to route the amplified signal into an optical spectrum analyzer (OSA). A 90/10 coupler is used in conjunction with a broadband FBG to form an oscillating laser in the cavity for gain clamping. The broadband FBG has a reflectivity of about 99% and a bandwidth of 40 nm centered at 1545 nm. It reflects the backward ASE of wavelength around 1530 nm back into the system to oscillate in the cavity and thus clamps the gain. A variable optical attenuator (VOA) is inserted to control the oscillating light in the cavity. A tunable laser source (TLS) is used for evaluation of the amplifier performances in conjunction with an OSA.

3 Result and discussion

The gain and noise figure characteristics as functions of input signal power for the gain clamped amplifier is shown in Fig. 2. Measurements of the gain and noise figure were performed at different input signal power levels, from -40 to 4 dBm at 1500 nm. The pump power is fixed at 103 mW. For the amplifier with VOA close, the small signal gain was obtained at 26 dB and degrades as the input signal power increases. On the other hand, gains for the amplifier with VOA open are clamped at small input signals. For instance, at $\text{VOA} = 2$ dB, the gains are clamped at about 20.0 dB with gain variation of less than 1.0 dB, for all input signal powers from -40 to -14 dBm. This gain clamping is due to the incorporation of the FBG, which reflects the ASE of wavelengths above 1525 nm. This will create an oscillating laser at wavelength around 1530 nm between the FBG and OC2. The laser operates at this wavelength due to the C-band ASE level is highest at this region. This oscillating laser fixed the average population inversion by extracting the energy stored in the amplifier due to the homogeneous broadening [5]. In a homogeneously broadened medium, the lasing action fixes the total population inversion. Any variation in other conditions, such as the input signal power, would be compensated by the adjustment of the lasing power [6]. This is especially

Fig. 2. The measured gain and noise figure against input signal power at various VOA settings.

true when the input signal power is low (lower than the laser output power level) as shown in Fig. 2. However, as the input signal power is increased, the laser power is decreased and becomes extinguished hence the gain is no longer clamped. The clamped gain can also be controlled within 18 to 24 dB by varying the VOA from 0 to 8 dB as shown in Fig. 2. The gain variation under gain clamping is less than 1 dB and it is generated due to the inhomogeneous gain medium. This variation, if high, will cause transient response, which in turn increases bit error rate of the system.

On the other hand, noise figures measured for the gain clamped amplifier are about 9.5 to 11.0 dB in the gain clamped region, which is slightly better compared to that of the case with VOA close. These values are relatively high due to the insertion loss of the 90/10 WDM coupler and unoptimised splicing between the depressed cladding EDF and the standard single-mode fiber, which is estimated to be more than 1 dB. The double-pass scheme also contributes to the noise figure due to the double-propagation of signal in the EDF, which reduces the population inversion at the input part of the amplifier. The low population inversion contributes to higher noise in the input end and the noise is amplified in the amplifier, which resulted in the higher overall noise figure. The noise figure of the gain clamped amplifier is lower than that of the unclamped amplifier (VOA close), because the laser power compressed the ASE power strongly and the operation point of the amplifier fell in the dip region of the original noise profile [7]. Fig. 2 also shows the noise figure curve has a dip at -26 dBm input signal power region, which is attributed to the interplay between self-saturation by backward ASE and self-induced saturation [7].

The gain and noise figure spectra of the unclamped and clamped amplifier are shown in Fig. 3. The input signal and pump powers are fixed at -30 dBm

Fig. 3. The gain and noise figure spectra at various VOA settings.

and 103 mW, respectively. The gains for the gain clamped amplifier are reduced due to the laser extracting the energy stored in the amplifier. At wavelength below 1500 nm, the gain clamped amplifier shows a higher noise figure compared to that of unclamped amplifier (VOA close) as shown in Fig. 3. This is attributed to the ASE compression at these wavelengths, which is very small because they are located far away from the oscillating laser. The lower gain also contributes to the higher noise figure at this region. The advantage of the both gain clamped system is that the oscillating laser does not appear at the output port since it operates at wavelength of around 1530 nm, which is outside of S-band region. This prevents the WDM system from being disturbed by the oscillating laser.

4 Conclusion

A gain clamping is demonstrated in double-pass S-band EDFA by incorporating of FBG. The FBG reflects the C-band ASE to oscillate in the cavity between the FBG and OC2 for gain clamping. The clamped gain can be controlled to be within 18 to 24 dB by varying the VOA from 0 to 8 dB. At VOA = 2 dB, the gain curves for the amplifier are clamped at about 20.0 dB, for all input signal powers from -40 to -14 dBm with gain variation of less than 1.0 dB. The corresponding noise figure is slightly improved compared with an unclamped amplifier. However, the noise figure level is still considerably high due to the double-pass scheme and unoptimised splicing. The advantage of this gain clamped scheme is that the oscillating light operates at C-band region and does not disturb the operation of WDM system.