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Gain control in S-band erbium-doped fiber amplifier using a fiber bragg grating

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Abstract: A gain-clamped short wavelength band erbium-doped fiber amplifier (S-band EDFA) is demonstrated utilizing a fiber Bragg grating (FBG). The amplification in S-band is achieved using an erbium-doped fiber (EDF) with depressed cladding design, which suppressed amplified spontaneous emission (ASE) at longer wavelength. The gain clamping is achieved by routing back the forward ASE into the feedback loop as to create a ring laser. The clamped gain is controlled using a variable optical attenuator (VOA) as to generate a gain of 14.6 to 25.2 dB for input signal at 1504 nm. At VOA = 0 dB, the gain is clamped at 14.6 dB with a gain variation of less than ±0.5 dB for input signal at 1504 nm with power dynamic range of −40 to −5 dBm. The noise figure penalty is less than 0.8 dB in this amplifier since the laser is arranged to be co-propagated with the signal.

Keywords: S-band EDFA, depressed cladding EDF, Erbium-doped fiber amplifier, gain-clamped amplifier

Classification: Photonics devices, circuits, and systems

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1 Introduction

The sudden increase in traffic due to various application such as internet, multimedia, video on demand and electronic banking has in a way causes constraint on the available bandwidth. The bandwidth requirement increases with time resulting in constant upgrading of existing networks. The current network which utilizes C- (1540-1560 nm) and L- (1560-1610 nm) bands will be exhausted in the near future. Intention to expand this window into shorter wavelength has taken pace lately. They are numerous interests in developing the S-band amplifiers covering region from 1480 to 1510 nm. Currently intense research has been done on the development of Raman amplifiers along side with conventional optical amplifier based on Tm-doped fiber [1, 2, 3]. While these amplifiers have enabled impressive gain, noise figure and system performance, they have not matched conventional erbium-doped fiber amplifiers (EDFAs) in terms of efficiency, simplicity, reliability and cost. Recently, S-band EDFAs have been demonstrated either using a conventional erbium-doped fiber (EDF) with a multistage configuration [4] or utilizes a depressed cladding EDF [5]. The ultra wideband EDFA can be achieved by integrating the S-, C- and L-band EDFAs.

In addition to wideband operation, EDFAs must also exhibit gain clamping. This is due to the fact that in a WDM network, the total average input power to an EDFA can vary in time as a result of channel add/drop, network reconfiguration or fault, thereby degrading amplifier performance (through the modification of the average inversion level which causes gain tilt and dynamic gain variation) and system performance. In an earlier report, Yeh et. al. demonstrated the gain-clamped S-band EDFA using a Fabry-Perot Filter [6]. In this paper, a new design of a gain clamped S-band EDFA is proposed using a fiber Bragg grating (FBG), which can exhibit a better gain clamping effect and smaller gain variation.

2 Experimental set up

The configuration of the gain clamped S-band EDFA is shown in Fig. 1. It consists of two sections of depressed cladding EDFs (EDF1 and EDF2), two laser diodes (P1 and P2), two wavelength selective couplers (WSC1 and WSC2), an isolator, a 90/10 coupler, a circulator and an FBG. EDFs 1 and 2 are fixed at 15 and 20 m respectively. Both EDF has a depressed cladding design with peak absorption of 7.6 dB/m in the 980 nm band. 980 nm laser diodes are used to pump both EDFs using the forward pumping scheme. The pump powers of P1 and P2 are optimized at 85 mW and 190 mW, respectively for high gain. Two WSCs (optimized for C-band operation) are used to combine the 980 nm pump from each laser diode with the test signal. An optical isolator is used to prevent backward propagating ASE from the second stage from depleting the population inversion at the input of the first stage fiber. An FBG with a reflectivity of 99.9% and a 3 dB bandwidth of 0.26 nm centered at 1500 nm is employed at the output end which acts as a laser wavelength feedback and also a rejection filter. It reflects a portion of the

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forward ASE back into system. The reflected portion is allowed to oscillate in a ring cavity and hence creating laser at the Bragg center wavelength. The ring cavity is formed by connecting the port 3 of the circulator to the variable optical attenuator (VOA), which is connected to the 10% port of the coupler. The VOA provides the required cavity loss needed to study the gain clamping behavior in this system. The amplifier performance is also measured for the open ring system for comparison purpose.

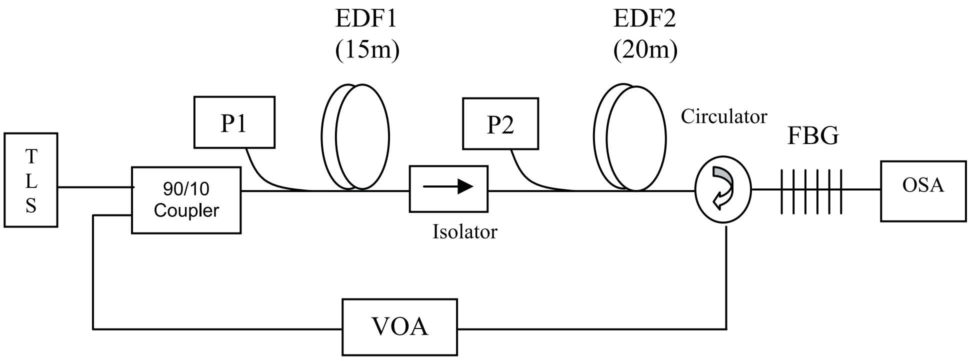

Fig. 1. Configuration of the gain clamped S-band EDFA

3 Result and discussion

Fig. 2 depicts ASE spectrum of the gain clamped and unclamped S-band EDFAs with the total pump power of 275 mW, where the solid line represents the ASE spectrum of the gain-clamped amplifier. As shown in the figure, the amplifier with gain clamped shows a lower S-band ASE compared to that of the unclamped (open ring). The ASE suppression is observed due to the existence of laser at 1500 nm, which leaks out as shown in Fig. 2. The lasing effect will lock the population inversion in both of EDFs (EDF1 and EDF2) taking the case of homogeneously broadened system. The high ASE power and amplification in S-band region for both amplifiers are achieved by suppressing ASE at 1530 nm gain peak and longer wavelength using a depressed cladding EDF with a fundamental-mode cutoff wavelength of about 1525 nm. The fiber has two claddings – the inner and outer claddings with large and small index difference, respectively. Compared with the outer cladding index, the index of inner cladding is suppressed to -0.0053 and the core index is increased to $+0.011$ to provide a high distributed loss for wavelengths longer than 1525 nm. Therefore, the gain at the longer wavelength is completely suppressed and a usable high net gain can be achieved in S-band region. The S-band amplification cannot be realized using a standard EDF because a strong ASE at the 1530 nm gain peak.

Figs. 3 (a) and (b) show gain and noise figure as functions of input signal power for different VOA settings. The total pumps power and input signal wavelength were fixed at 275 mW and 1504 nm, respectively. As shown in the figure, the gain-clamped amplifier shows a constant gain at a low input power compared with the unclamped amplifier (an open-ring). For instance,

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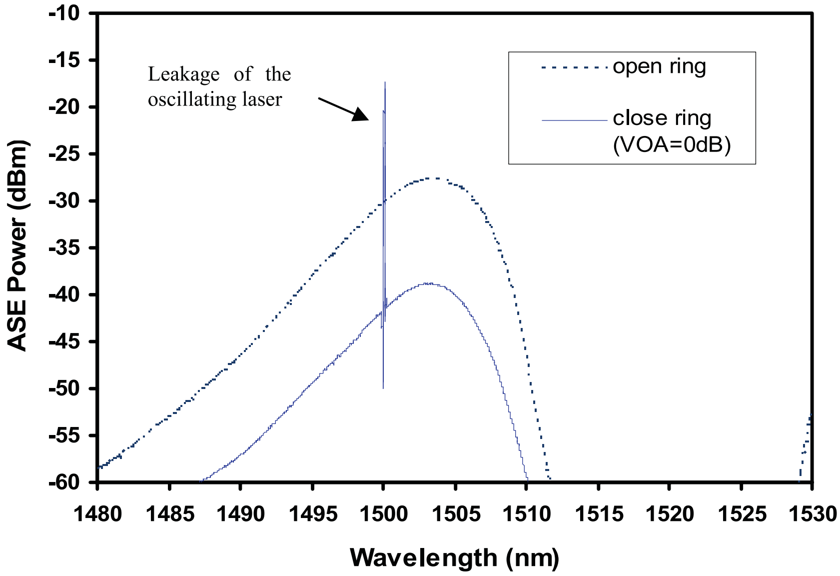

Fig. 2. ASE spectra for both gain-clamped and unclamped S-band EDFAs

at VOA = 0 dB, the gain is clamped at 14.6 dB with a gain variation of less than ±0.5 dB in the input signal power dynamic range from −40 to −5 dBm. The gain variation is much smaller compared to the previous design [6] which exhibits a gain variation of more than ±0.8 dB. The clamping effect is due to the laser operating in 1500 nm wavelength, which oscillates in the ring resonator. 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 an 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 input signal power variations. The clamped gain levels and dynamic input power ranges depend on the ring laser intensity and can be adjusted by changing the VOA setting. The clamped gain varies from 14.6 to 25.2 dB with the change in the VOA setting from 0 to 10 dB, as shown in Fig. 3 (a). For the open ring amplifier, the unsaturated gain obtained is 27.9 dB and degrades as the input signal power increases. Compared to the unclamped amplifier, the gains for the gain clamped amplifier are reduced due to the extraction of the energy stored in the amplifier by the laser. Compared to the previous design [6], this amplifier shows a better gain-clamping effects, whereby the gain can be suppressed up to 14.6 dB.

On the other hand, Fig. 3 (b) shows that the noise figures of the gain-clamped amplifiers are slightly higher compared with that of the unclamped open-ring amplifier which is a consequence of the gain-clamping effect. The laser power compressed the ASE power strongly and causes changes to the spontaneous emission factor, $n_{sp} = N_2/(N_2 - N_1)$, where N_2 and N_1 are the population density of the upper and lower states, respectively. This leads to the noise figure degradation. The noise figures vary from 9.0 to 9.6 dB within the dynamic input signal power range, which is approximately 0.2 ∼ 0.8 dB

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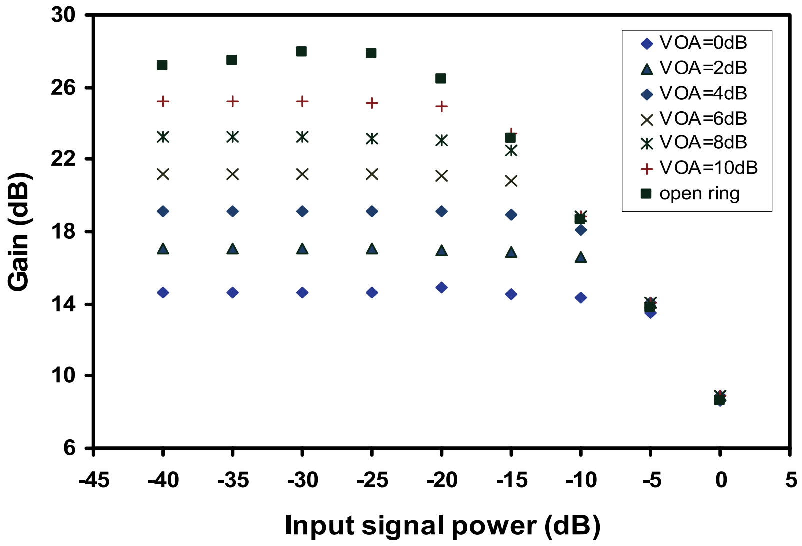
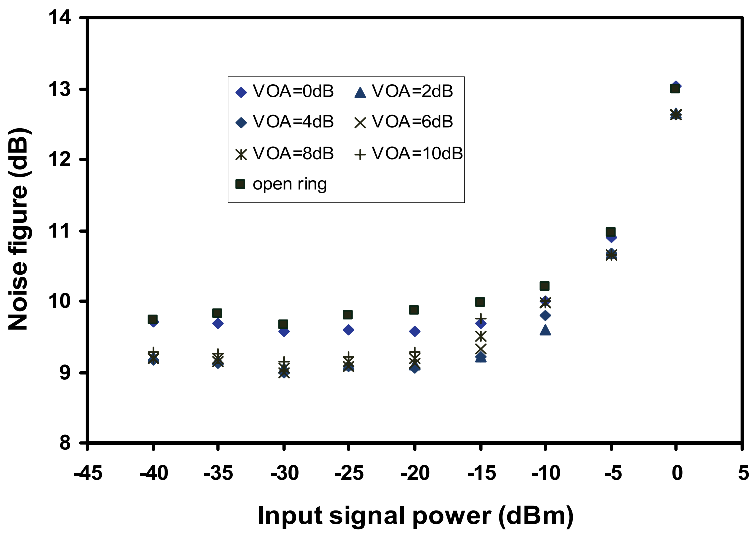


(a) gain



(b) noise figure

Fig. 3. Gain and noise figure as functions of input signal power at various VOA settings (a) gain (b) noise figure

higher than that of the unclamped open-ring amplifier for the gain clamped amplifiers. The noise figure penalties are considerably very small due to the laser is co-propagating with the test signal in the proposed amplifier. This gain-clamped amplifier is also operable at other wavelengths in S-band region.

4 Conclusion

A gain-clamped S-band EDFA is demonstrated using a depressed cladding EDF with a FBG in a ring configuration. The EDF suppresses the ASE at

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longer wavelengths, thereby enabling the S-band amplification. The FBG is used in conjunction with a circulator to create a ring laser in the cavity for gain clamping. The clamped gain can be controlled to be in the range from 14.6 to 25.2 dB by varying the VOA settings from 0 to 10 dB. At VOA = 0 dB, the gain is clamped at 14.6 dB from −40 to −5 dBm with a gain variation of less than ±0.5 dB and a noise figure penalty of less than 0.8 dB. The gain variation and gain clamping effect are better in this design compared to the gain-clamped EDFA with the Fabry-Perot Filter. This amplifier is very useful in the future S-band applications.

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