Low noise gain-clamped L-band erbium-doped fiber amplifier by utilizing fiber Bragg grating

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A novel gain-clamped long wavelength band (L-band) erbium-doped fiber amplifier (EDFA) is proposed and experimented by using a fiber Bragg grating (FBG) at the input end of the amplifier. This design provides a good gain clamping and decreases noise effectively. It uses two sections of erbium-doped fiber (EDF) pumped by a 1480-nm laser diode (LD) for higher efficiency and lower noise figure (NF). The gain is clamped at 23 dB with a variation of 0.5 dB from input signal power of −30 to −8 dBm for 1589 nm and NF below 5 dB is obtained. At the longer wavelength in L-band higher gain is also obtained and the gain is clamped at 16 dB for 1614 nm effectively. Because the FBG injects a portion of backward amplified spontaneous emission (ASE) back into the system, the gain enhances 5 dB with inputting small signal.

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The L-band erbium-doped fiber amplifier (EDFA) is one of the key devices for dense wavelength division multiplexing (DWDM) systems, because it increases the amplification wavelength range by combining with C-band EDFA[1−3]. However, due to the long erbium-doped fiber (EDF) and the off-erbium-emission-peak nature of L-band signals, these L-band amplifiers suffer from excessive pump power consumption by amplified spontaneous emission (ASE), especially by the backward propagating ASE. It is because that L-band EDFA has much lower signal gain efficiency than C-band EDFA. Relying on co-propagating C-band seed technique, several schemes have been designed to overcome this effect in L-band EDFA[4,5].

Previously, a section of low Er^{3+} concentration EDF pumped by 980-nm laser diode (LD) was adopted such as the representative configuration of Ref. [3] but the length of EDF was too long. Though well gain-clamped performance based on a fiber Bragg grating (FBG) was obtained, the long EDF length increases noise figure (NF)[6]. Because of using low ion concentration in the EDF, the gain falls clearly at the wavelength above 1610 nm. Furthermore, it was found that the backward propagated ASE reflected by FBG degrades the noise directly[7].

In this Letter, for the sake of getting better noise characteristics, the configuration with two sections of EDF, 20-m-length high concentration EDF combined with 11-m-length common EDF is introduced and experimented. A 1480-nm LD is used as pump source to provide higher pump absorptivity[8]. In comparison with conventional design, a better performance in gain clamping is obtained. At the input signal of 1589 nm, the gain is clamped at 23 dBm from −30 to −8 dBm and the NF is below 5 dB. FBG reflects the backward ASE into the EDF and small signals are input, therefore the gain is enhanced by 5 dB. The saturation output power for 1589 nm is 7 dBm. Comparing with the previous schemes, higher gain is observed at the longer wavelength in L-band. The gain is clamped at 16 dB and NF is below 5 dB for 1614 nm.

The configuration of the gain-clamped EDFA is shown in Fig. 1. It consists of two sections of EDF pumped by a 1480-nm LD, a 1480/1590-nm wavelength division multiplexer (WDM) and a FBG spliced to the input section. In comparison to Ref. [3], this design adopts two sections of shorter EDF with high Er^{3+} concentration. The 20-m-length EDF has peak absorption of 24 dB/m at 1531 nm while the numerical aperture (NA) is 0.22. The 11-m-length EDF has peak absorption of 16.7 dB/m at 1531 nm while the NA is 0.22 and the cut-off wavelength is 945 nm. The 1480-nm LD is used to pump both EDFs for higher pump absorptivity than 980-nm LD.

The reflection spectrum of the FBG measured by an Anritsu MS9710B optical spectrum analyzer (OSA) is shown in Fig. 2 (0.6—1.75 μm, 0.07-nm resolution). The center wavelength and bandwidth are 1552.04 and 0.56 nm, respectively.

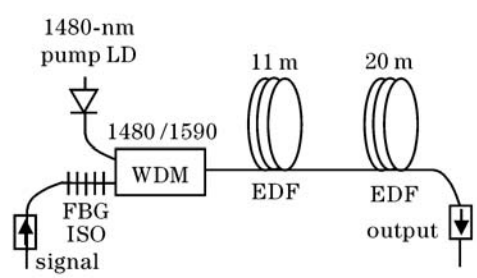

Fig. 1. Configuration of the gain-clamped L-band EDFA with FBG.

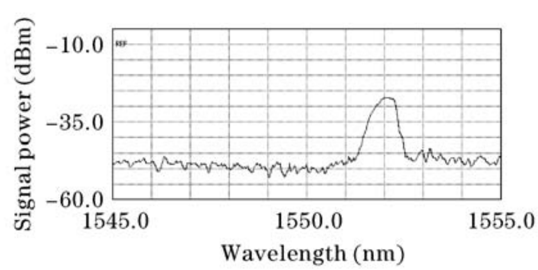

Fig. 2. Reflection spectrum of the FBG.

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The output signal power against input signal power is measured by an optical power meter (NOYES OPM4), and it is shown in Fig. 3 for 1589 and 1614 nm. Gain measurement is performed at different input signal power levels, from −30 to −2 dBm. The output does not increase linearly when the input power reaches a certain degree. At this time, the gain enters the saturated state then begins to decrease rapidly.

The gain and NF at 1589 nm are measured by an OSA and an optical power meter. The gain and NF against pump power under the input power of −30 dBm is plotted in Fig. 4. The gain against pump power for different signal powers is plotted in Fig. 5. In comparison with the configuration without FBG, as long as the pump power is large enough, the gain is clamped at 23 dB. The L-band mechanism is made possible by intra-Stark-level multi-phonon transitions which transfer energy from the short wavelength to longer wavelength. Therefore, incorporation of a FBG causes saturation since the reflected spectra constitute a high level signal. This saturation limits the population inversion which inturn reduces the number of multi-phonon transitions, thereby clamps the L-band gain. Besides, the figure indicates that NF is about 5 dB when pump power exceeds 50 mW.

Figure 6 shows the gain and noise characteristics against input signal power at 1589 nm. A good gain clamping behaviour is observed for the system with FBG. For the maximum pump power of 180 mW, the gain of the output signal is clamped at 23 dB with a gain variation of less than 0.5 dB till the input signal power level reaches −8 dBm. Because the FBG reflects the backward C-band ASE power, the gain is enhanced by 5 dB.

In addition, higher gain at longer wavelength is observed in the experiment. In most studies, the gain was below 10 dB at the wavelength above 1610 nm. Figure 7 shows the gain and NF against pump power under the input power of −30 dBm at 1614 nm. The gain and NF against signal power is plotted in Fig. 8. At different input signal power levels, from −30 to −8 dBm, the gain is clamped at 16 dB with a variation of 1 dB and the NF is below 5 dB with pump power of 180 mW. The result indicates that adoption of the high Er^{3+}-concentration fiber and 1480-nm pump source can improve the gain and noise characteristics in the longer signal wavelength effectively.

A new configuration of gain-clamped L-band EDFA has been proposed and experimented by using a FBG. A 1480-nm LD is adopted as pump source for higher

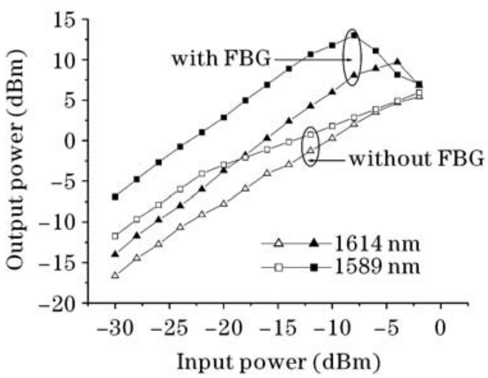

Fig. 3. Output power variations with the input power at 1589 and 1614 nm.

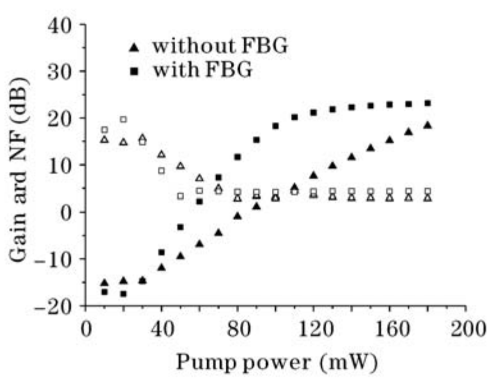

Fig. 4. Gain (shaded) and noise figure (NF) (clear) against pump power at the input power of −30 dBm (1589 nm).

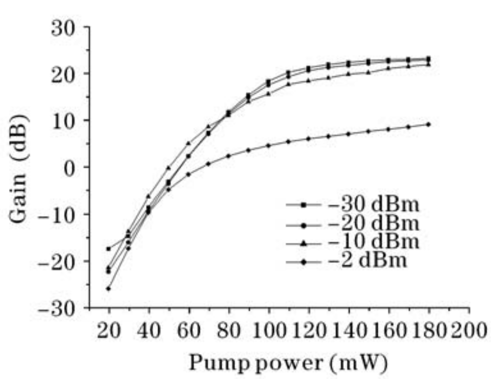

Fig. 5. Gain against pump power for various input signal powers (1589 nm).

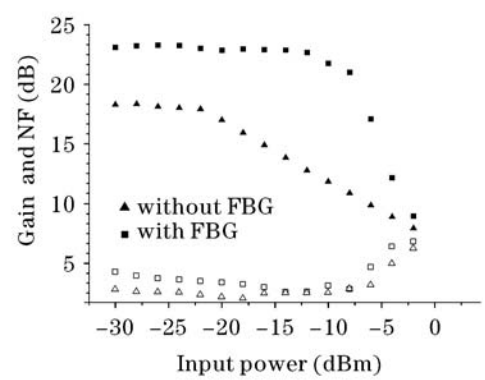

Fig. 6. Gain (shaded) and NF (clear) against the input signal power at 1589 nm.

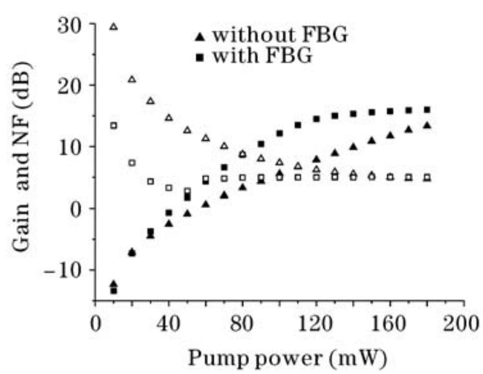

Fig. 7. Gain (shaded) and NF (clear) against pump power at the input power of −30 dBm (1614 nm).

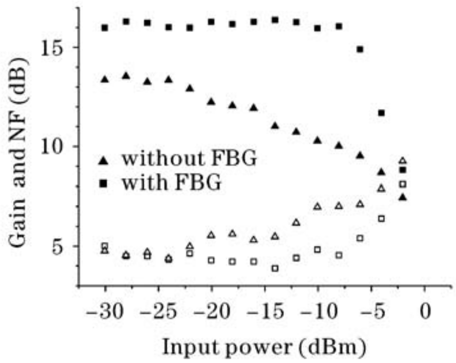

Fig. 8. Gain (shaded) and NF (clear) as a function of input power at 1614 nm.

pump absorptivity. Two sections of shorter EDF with high concentration are used as gain medium for decreasing the noise caused by the FBG. The gain is clamped at 23 dB with a variation of 0.5 dB from input signal power from −30 to −8 dBm at 1589 nm and the NF is below 5 dB. At the longer wavelength in L-band, higher gain is obtained. Gain is clamped at 16 dB and NF is below 5 dB for 1614 nm. By further optimization of the EDF length, the center wavelength, reflectivity, and bandwidth of FBG, this system is predicted to be able to perform better and achieve the function of gain clamping.

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