

A gain-clamped S-band erbium-doped fiber amplifier using fiber Bragg grating

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Abstract

We propose and investigate experimentally a gain-clamped S-band erbium-doped fiber amplifier module, employing a fiber Bragg grating to serve as a reflected element to lase a saturated tone injected into the module, by forward optical feedback method. In addition, different injected powers of the saturated tone are used to realize the performances of gain and noise figure for the proposed amplifier over the effectively wavelength range of 1478–1520 nm.

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1. Introduction

Broadband erbium-doped fiber amplifiers (EDFAs) were considerably interesting for high capacity transmission for wavelength-division-multiplexing (WDM) networks. Recently, the S-band (1480–1520 nm) EDFAs [1,2], the C-band (1530–1560 nm) EDFAs [3,4] or an erbium-doped waveguide amplifier (EDWA) [5,6], and the L-band EDFAs [7,8] have been demonstrated and reported. However, due to the nature of erbium-doped fibers (EDFs), the gain profiles of EDFAs present nonflat and input-dependent behaviors. Therefore, gain-clamped functions are required for EDFAs and the stable gain versus the variation of input signal power is one of the key issues in WDM networks. Several gain-clamping techniques have been reported, such as the all-optical gain-clamped method [9], or different optical filters including fiber Bragg grating filters, fiber acousto-optic filters, and tunable bandpass filters (TBFs) [3,5,8],

covering both C- and L-bands (1530–1610 nm). In addition, the gain-clamping effect by using an optical feedback technique has also been shown [1,3,5–7]. In this study, we use an S-band EDFA module [1,2] and fiber Bragg grating by forward optical feedback method over the operation bandwidth from 1478 to 1520 nm for clamping gain profiles. Moreover, the gain-clamped behavior and performance has also been investigated experimentally under different operation conditions.

2. Experiments

Fig. 1 shows the experimental setup for a gain-clamped S-band EDFA module by forward optical feedback method. The proposed structure consists of an S-band EDFA, an optical circulator (OC), a 1 × 2 optical coupler (C) with different coupling ratio, and a FBG. The C has the input coupling ratio of 90%, 80%, 70% and 50% for the input signal, respectively. A FBG is employed to serve a reflected element to lase a wavelength forward injected into the proposed amplifier for clamping gain. The S-band EDF inside EDFA

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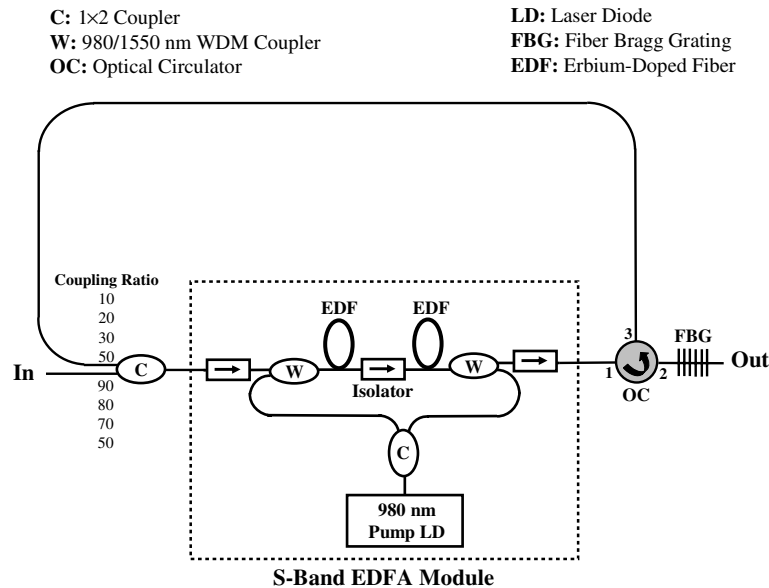


Fig. 1. Experimental setup for a gain-clamped S-band EDFA by optical feedback method.

module has a depressed cladding design in order to provide a sharp, high-attenuation, long-wavelength cutoff filter into active fibers. The erbium-doped fibers in the first and second stages have different characteristics. The fiber in the first stage has the fiber length of 20 m, and can provide low noise figure and medium gain by forward pumping. The fiber in the second stage has the fiber length of 30 m, and can produce large output power by backward pumping. In addition, the optical isolator between these two stages can reduce backward amplified spontaneous emission (ASE) and improve noise figure performance. The total pump power of this amplifier module can be up to 280 mW, while the bias current is operated at 356 mA. To realize the behaviors and performances of the proposed amplifier module, a tunable laser source (TLS) is used to probe the gain and noise figure spectra, which are observed by an optical spectrum analyzer (OSA) with a 0.05 nm resolution.

3. Results and discussion

Fig. 2 shows the gain and noise spectra of the original S-band EDFA over the wavelength region of 1478–1520 nm, while the input signal power $P_{in} = 0$, -20 , and -40 dBm. The gain and noise figure can reach 27.4 and 5.8 dB at 1504 nm for input power of -20 dBm, and the saturated output power at 1498 nm can be up to 14.3 dBm for input power of 0 dBm, as shown in Fig. 2. The noise figures are between 5.3 and 7.5 dB when the input signal power is -20 dBm in the wavelength range of 1478–1512 nm. When the input signal power are 0, -20 , and -40 dBm at 1510 nm, the observed gain and noise figure are 12.5 and 9.5, 26.2 and 6.9, and 35.2 and 6.6 dB, respectively.

To achieve the gain clamping S-band EDFA, a FBG is located in the proposed module to lase a wavelength being a saturated tone. And Fig. 3 shows the reflective spectrum

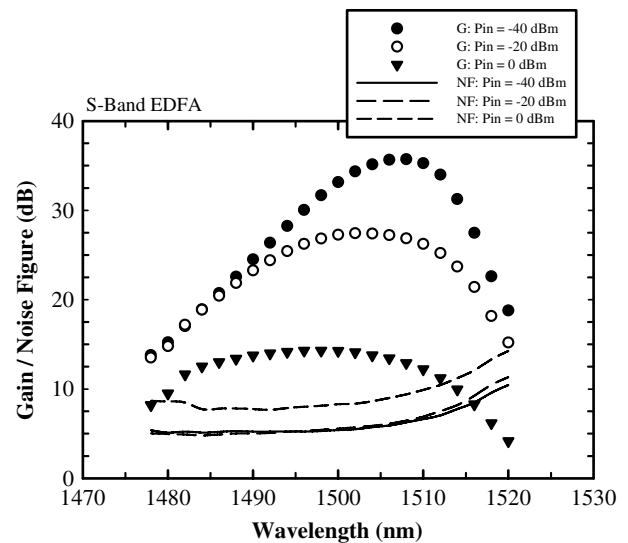


Fig. 2. Gain and noise figure spectra of the original S-band EDFA in the operation range of 1478–1520 nm, when the input signal power $P_{in} = 0$, -20 and -40 dBm.

of the FBG with the central wavelength of 1515.69 nm. The S-band FBG has ~ 2.3 nm maximum wavelength shift when the external strain is applied on the FBG. When the temperature is raised to ~ 90 °C, the wavelength variation shifts to nearly 1.2 nm. In our proposed scheme, we use an S-band FBG into the cavity loop to lase a saturated tone for clamping the gain profile. The lasing wavelength is stable in this proposed experiment when the FBG is without any temperature and strain changes. In other words, the FBG can be properly packaged to maintain the stably central wavelength avoiding the temperature and strain effect. Therefore, using different input coupling ratio of the C will govern the forward injected power level of a

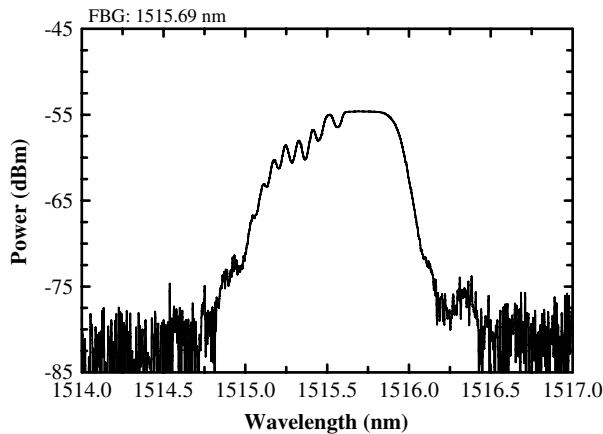


Fig. 3. The reflective spectrum of the FBG with a central wavelength of 1515.69 nm.

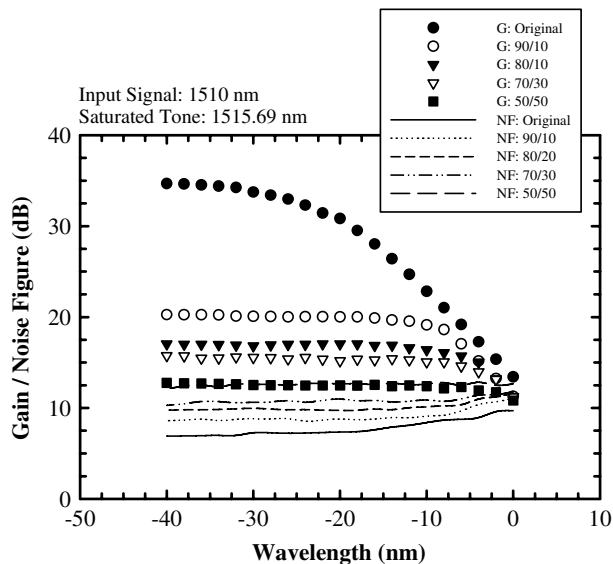


Fig. 4. Gain and noise figure characteristics versus the different power level of input signal at 1510 nm, while the lasing wavelength is at 1515.69 nm, and the input coupling ratio of C is 90%, 80%, 70%, and 50% for the input signal, respectively.

saturated tone for the clamping performance. Fig. 4 shows the gain and noise figure characteristics versus the different power level of input signal at 1510 nm, while the lasing wavelength is at 1515.69 nm, and the input coupling ratio of coupler is 90%, 80%, 70%, and 50% for the input signal, respectively. When a 90:10 coupler is employed, the gain

will be maintained constant at the input power of -15 dBm at expense of around 8.1 dB gain, and the gain will be kept at near 20.1 dB, however, the noise figures of 2.6 dB impairment are observed over the operation range. Because some passive components, placed at the signal input and output end, have higher losses in C-band and the splice point of EDF and WDM coupler possesses higher loss, the noise figure of this S-band EDFA module will be slightly degraded. From Fig. 4, the gains not only reduce and the noise figures but also degrades when the input coupling ratios of the C are below 90%.

4. Conclusion

In conclusion, a gain-clamped S-band EDFA module, using a FBG to serve as a reflected element lasing a saturated tone for clamping gain by forward optical feedback method in the operation range of 1478–1520 nm, is proposed and experimentally investigated. Different coupling ratios of an optical coupler are used to realize the performance of gain clamping. When a 90:10 optical coupler is used, the gain will be maintained constant at the input power of -15 dBm and the gain will be kept at around 20.1 dB over the operation range.

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