



Gain-clamping erbium-doped waveguide amplifier module using optical feedback technique

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Abstract

A forward optical feedback technique for gain-clamping erbium-doped waveguide amplifier has been proposed and experimentally investigated. Three different saturated tones are selected in this proposed structure over the operation range from 1530 to 1550 nm to realize the amplification behaviors. Therefore, a dynamic range of input signal power from -9 to -40 dBm at 1552 nm is obtained when different power level and lasing position of the saturated tone are applied. In addition, the gain clamping performance has also been investigated experimentally under different operation conditions such as the lasing wavelength, the cavity loss and the input signal wavelength.

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1. Introduction

Broad band erbium-doped fiber amplifiers (EDFAs) were considerably interesting for high-capacity transmission for wavelength-division-

multiplexing (WDM) networks. Recently, S-band (1480–1520 nm) EDFAs [1], C-band (1530–1560 nm) EDFAs [2] or erbium-doped waveguide amplifier (EDWA) [3], and L-band EDFA [4] have been proposed and investigated. 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

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one of the key issues in WDM networks. Several gain-clamping techniques have been reported, such as the all-optical gain-clamped method [5], or different optical filters including fiber Bragg grating filters, fiber acousto-optic filters, and tunable band-pass filters (TBFs) [2,3,6], covering both and bands (1530–1610 nm). In addition, the gain-clamping effect by using an optical feedback has been shown [1–3,5]. In this letter, we present a gain-clamping C-band EDWA module with forward optical feedback method over the operation bandwidth from 1526 to 1570 nm. In addition, the gain clamping behaviors and performances have also been investigated experimentally under different operation conditions.

2. Experiments and results

In an homogeneously broadened gain medium, lasing action at a wavelength fixes the total population inversion, therefore, the gain for all the wavelengths are only dependent on their absorption and emission cross sections and the overlapping factor. Any variation in input signal powers will be compensated by the properly adjustment of the lasing signal power. As a result, each signal wavelength experiences a constant gain through this amplified system, independent of signal power variation caused by operation such as channel adding or dropping. Based on this principle, the proposed experimental setup of the gain-clamping EDWA is illustrated in Fig. 1. This apparatus comprises two optical couplers: C_1 and C_2 , a tunable bandpass filter (TBF), and an EDWA module (produced by Teem Photonics) with uncooled laser pump. However, C_1 has an input coupling ratio of 90%, and C_2 has an output coupling ratio of 90%, 80%, 70%, 50%, respectively.

The EDWA has the advantages of the EDFA, such as low noise figure, low polarization dependence, and no crosstalk between WDM channels. Besides, this EDWA module can generate high gain in very short optical path, and 15 dB gain can be obtained in the gain medium of only 5 cm. Furthermore, this EDWA module has the feature of 4.5 dB noise figure over the entire C-band, 15 dB small signal gain, 12 dBm output power

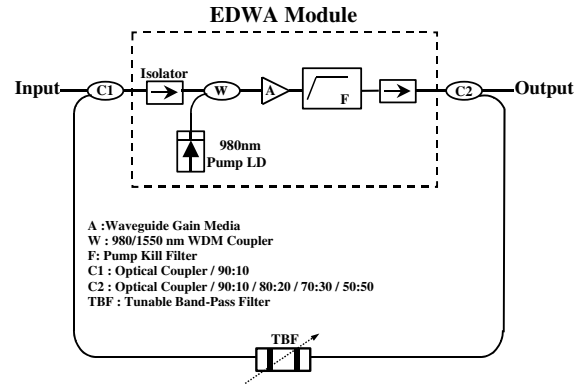


Fig. 1. Experimental setup for the proposed gain-clamping EDWA module with forward optical feedback method.

when the single-pump scheme (as shown in Fig. 1) is used, and the pump current of 440 mA is applied at ambient temperature. In addition, optical isolators can reduce backward amplified spontaneous emission (ASE) and improve noise figure performance. In view of compactness and functionalities, fiber wavelength-division multiplexers (FWMs), pump kill filter, uncooled laser pump and optical isolators are all attached directly into the EDWA module. Therefore, the size of this packaged block is just about 40 cm³ and is 1/5 the typical size of EDFA. 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 is observed by an optical spectrum analyzer (OSA). Fig. 2 shows the gain and noise figure spectra of the original EDWA in Fig. 1 over the bandwidth of 1526–1570 nm when the input signal power $P_{in} = 0, -15, -30$ dBm, respectively. Therefore, the gain and noise figure can achieve 33.2 and 4.2 dB at 1534 nm while the input signal power is -30 dBm. The saturated output power at 1542 nm can experience 11.2 dB for input power of 0 dBm, but the noise figure is 7.1 dB as seen in Fig. 2. However, the gain of >10 dB is observed in Fig. 2 when the input signal power of >-15 dBm over the wavelengths of 1526–1570 nm.

TBF is placed into the intercavity to provide different lasing wavelength (saturated tone) in this proposed configuration by proper adjustment to clamp gain value. TBF has an insertion loss of

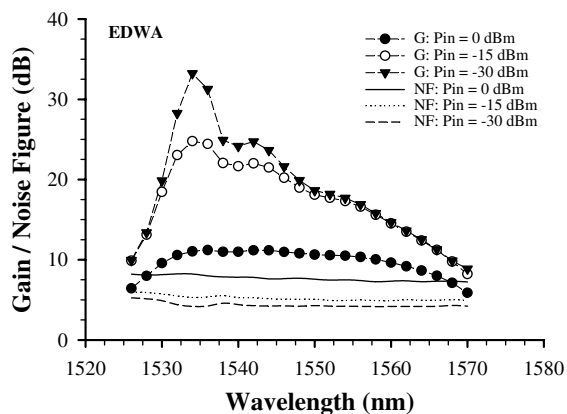


Fig. 2. Gain and noise figure spectra of the original EDWA in Fig. 1 over the bandwidth of 1526–1570 nm when the input signal power $P_{in} = 0, -15, -13$ dBm, respectively.

<0.45 dB and a 30 nm effective tuning range in C-band from 1530 to 1560 nm. Fig. 3 shows the lasing powers of three different wavelengths (resolution is 0.05 nm), 1530, 1540 and 1550 nm, for the proposed setup with forward optical feedback while the output ratio of C_2 is 70%, respectively. The inset of Fig. 3 is amplified spontaneous emission (ASE) spectrum of original EDWA. Different saturated tone is used in the proposed structure to investigate the power- and position-dependent for gain-clamping behaviors.

Fig. 4(a)–(c) show the measured gain and noise figure characteristics versus the different power level of input signal at 1552 nm while the lasing wavelength at 1530, 1540 and 1550 nm, and the output ratio of C_2 is 90%, 80%, 70%, 50%, respectively. The gain clamping effect is observed when various saturated tones are employed. From Fig. 4, the noise figure of ~ 2.8 dB impairment are observed that is mainly induced by gain saturation of the lasing wavelength and the insertion loss of C_1 and C_2 . Because some 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 EDWA module will be slightly degraded. Therefore, compared with the C- and L-bands gain-clamping EDFAs [1,2,4–6], the noise figure of gain-clamping EDWA was also slightly higher than that of them.

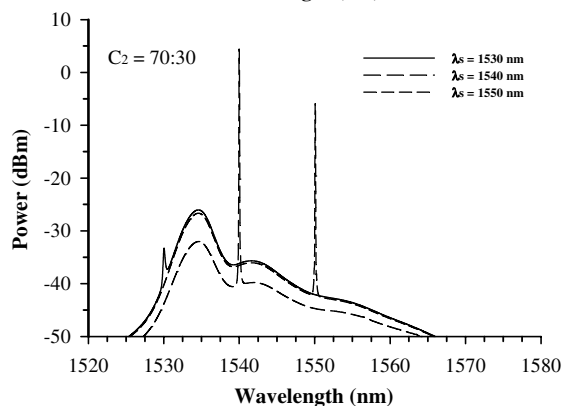
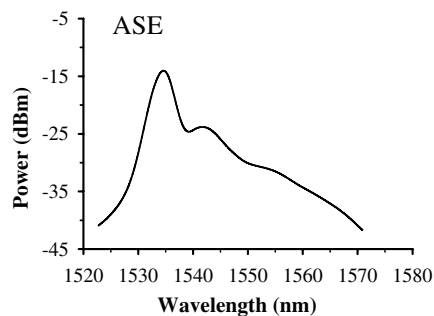


Fig. 3. Lasing powers of three different wavelengths (resolution is 0.05 nm), 1530, 1540 and 1550 nm, for the proposed setup with forward optical feedback while the output ratio of C_2 is 70%, respectively, and the inset is ASE spectrum of original EDWA.

In Fig. 4(a), the gain will be kept constant at the input power P_{in} of -20 dBm at the expense of around 4.1 dB gain, when the output ratio of C_2 is 90% and lasing wavelength is 1530 nm, and the gain can be maintained at ~ 13.6 dB. Fig. 4(b) exhibits the gain clamped at the input power of -15 and -9 dBm with lasing wavelength is 1540 nm, and the gain will stay at ~ 12.8 and ~ 11.3 dB, respectively, when the output ratio of C_2 is 80% and 70%. It also shows the gain starting to clamp at $P_{in} = -5$ dBm while the output ratio of C_2 is 50%, however, the gain value will be less than the revealed noise figure. Then, Fig. 4(c) indicates that the gain can be kept constant (>12.5 dB gain) at the input power P_{in} of -18 dBm when output ratios of C_2 used is $>70\%$. As a result, a dynamic range of input signal power from -9 to -40 dBm and the constant gain of ~ 11.3 dB are retrieved for the optical feedback scheme when

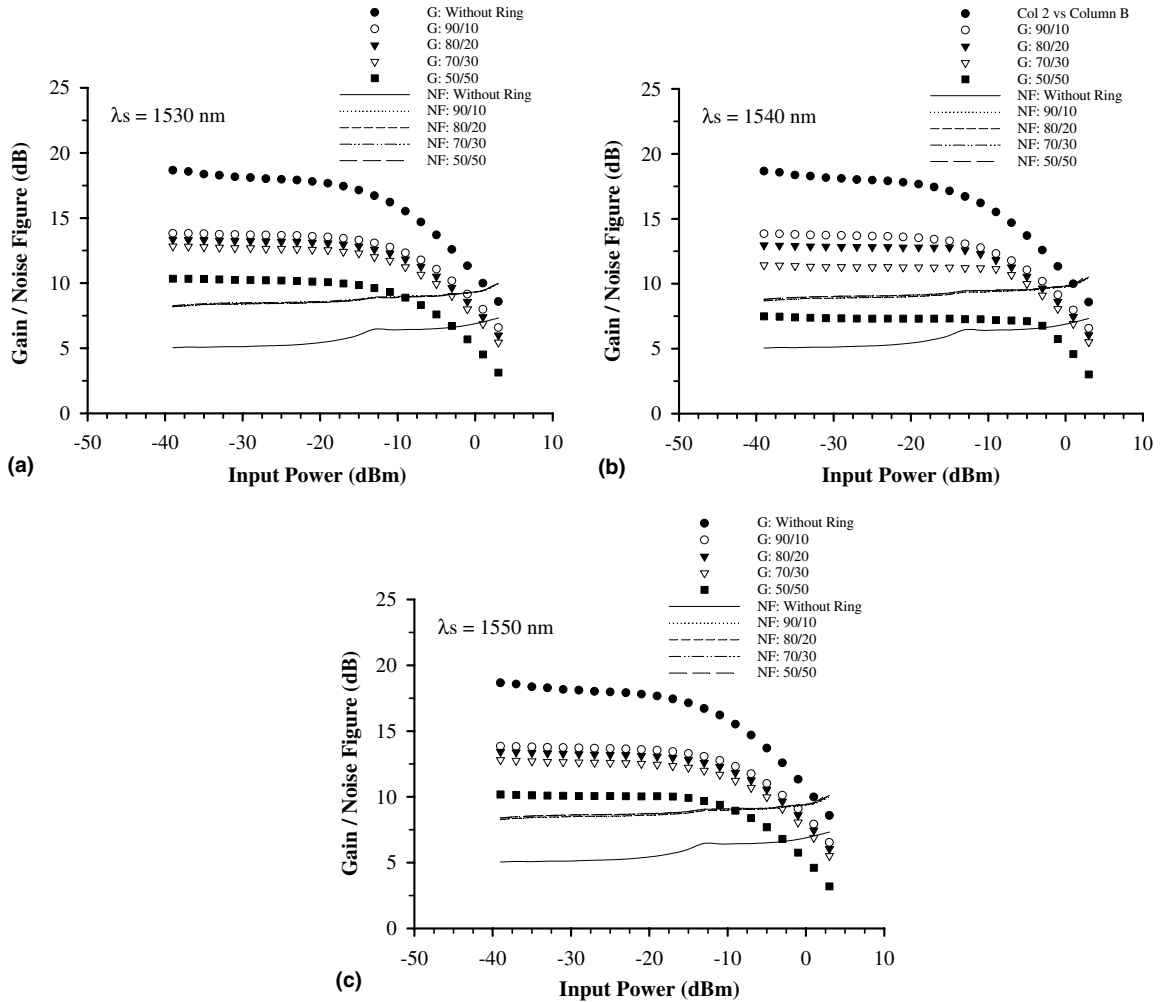


Fig. 4. Gain and noise figure characteristics versus the different power level of input signal at 1552 nm while the lasing wavelength at: (a) 1530 nm, (b) 1540 nm and (c) 1550 nm, and the output ratio of C_2 is 90%, 80%, 70%, 50%, respectively.

the lasing wavelength is 1540 nm and the output ratio of C_2 is 70%.

3. Conclusion

We have proposed and experimentally investigated an all-optical feedback technique for gain-clamping erbium-doped waveguide amplifier (EDWA). Three different saturated tones are selected in this proposed structure over the operation range from 1526 to 1570 nm to demonstrate

the amplification performances. A dynamic range of input signal power from -9 to -40 dBm and the constant gain of ~ 11.3 dB at 1552 nm are retrieved for the optical feedback scheme when the saturated tone is 1540 nm and the output ratios of C_2 is 70%. Moreover, the gain-clamping performance has also been investigated experimentally under different operation conditions such as the lasing wavelength, the cavity loss and the input signal wavelength. Therefore, the gain-clamping EDWA module might to benefit the applications of WDM network in future.

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