S Band Gain-Clamped Erbium-Doped Fiber Amplifier by Using Optical Feedback Method

Chien-Hung Yeh, Chien-Chung Lee, Chih-Yang Chen, and Sien Chi

***Abstract*—We have proposed and experimentally demonstrated an S band gain-clamped erbium-doped fiber amplifier, which provides an operation range from 1480 to 1520 nm by using an optical feedback method. The behavior and performance of gain clamping in S band have also been investigated experimentally under different operation conditions.**

***Index Terms*—EDFA, gain-clamped, S band.**

I. Introduction

WIDE-BAND erbium-doped fiber amplifiers (EDFAs) have been intensively studied for wavelength-division-multiplexing (WDM) systems. The stabilized gain versus the variation of input signal power is one of the key issues for WDM networks. Several gain-clamping techniques have been reported, such as the all-optical gain-clamped method [1], or different optical filters including fiber Bragg grating filters, finer acoustooptic filters, and tunable bandpass filters (TBFs) [2]–[4], covering both C and L bands (1530–1610 nm). In addition, the gain-clamping effect by using an optical feedback has been shown [1], [3], [4]. Recently, an S band (1450–1530 nm) amplification technique, which employs the erbium-doped silica fiber with depressed cladding design and 980-nm pump laser to generate EDF gain extension effect, has been reported [5]. Therefore, the gain clamping technique is expected to extend to S band by using this S band amplifier module. In this letter, we present a gain-clamped S band amplifier with a forward optical feedback configuration over the operation range from 1480 to 1520 nm. The gain clamping behaviors have also been investigated experimentally.

II. Experiments and Disscussions

In an homogeneously broadened 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 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,

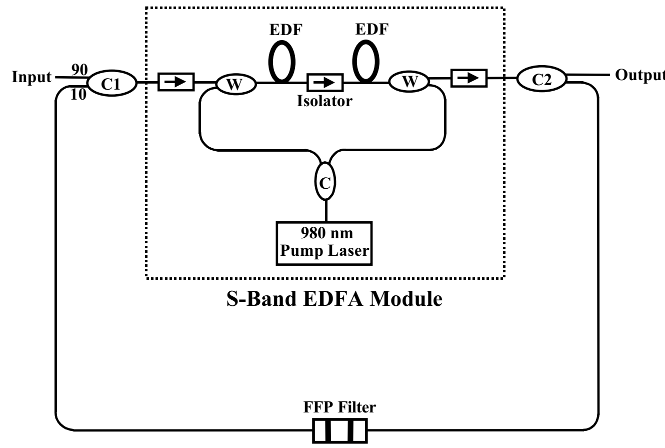

Fig. 1. Experimental setup of S band EDFA module with forward optical feedback for gain clamping.

Fig. 1 shows the experimental setup of S band amplifier module with forward optical feedback for gain clamping. The system consists of an S band amplifier module composed of two-stage amplifiers and a power-sharing 980-nm pump laser, two 1 × 2 optical couplers: C_1 and C_2, and a FFP filter. However, C_1 with an input coupling ratio of 90% and C_2 with an output coupling ratio of 95%, 90%, 80%, and 70%, respectively. A tunable laser source (TLS) is used to probe the gain spectrum of this proposed amplifier module. The S band erbium-doped fiber (EDF) inside the amplifier module has a depressed cladding design in order to provide a long wavelength cutoff filter for the fundamental mode (near 1530 nm) of the fiber. Then, the composition of the core is approximately 2.5% GeO_2, 5.5% Al_2O_3, and 92% SiO_2, 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. However, the EDFs in the first and second stages have different characteristics. The EDFs 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. The total pump power of this amplifier module can be up to 280 mW while the bias current is operated at 356 mA. In addition, the optical isolator between these two stages can reduce backward amplified spontaneous emission (ASE) and improve noise figure performance. The evolution from a standard EDFA to this S band design by the introduction of a continuous long wavelength cutoff filter in the EDF. Although the spectrum indicates strong gain at S band wavelengths, the gain cannot be realized because of strong ASE

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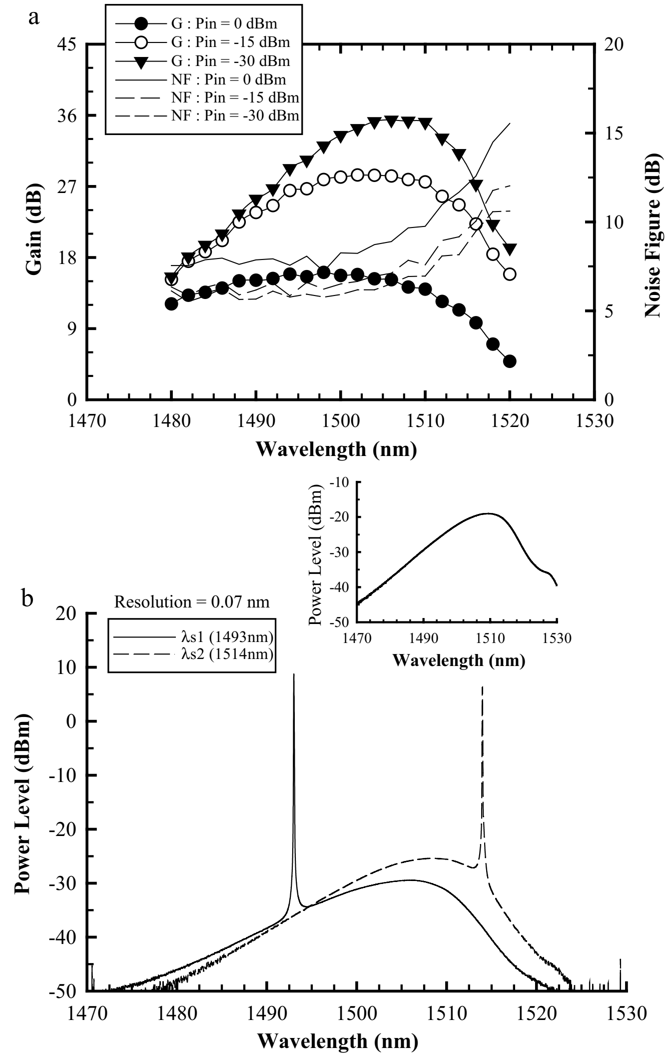

Fig. 2. (a) Optical gain spectra and noise figure of the S band EDFA module over the operation range from 1480 to 1520 nm when the input signal power Pin $= 0, -15$, and -30 dBm, respectively. (b) Two lasing wavelengths, 1493 nm (λ_{s1}) and 1514 nm (λ_{s2}), of the proposed setup with forward optical feedback while the output ratio of C_2 is 80%, and the insert is S band ASE spectrum without optical feedback.

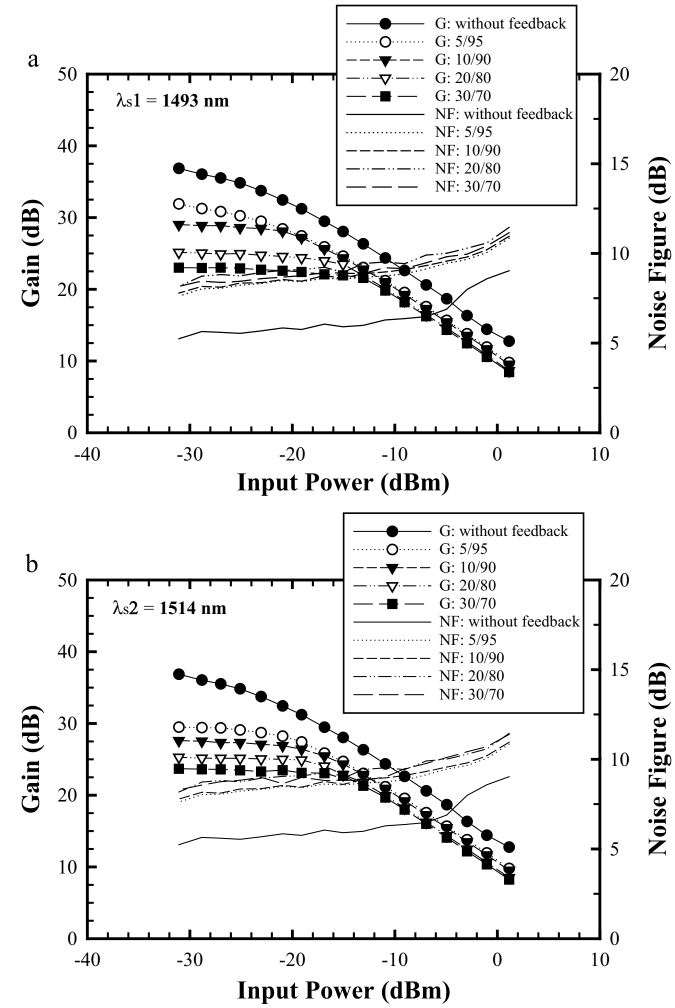

Fig. 3. Measured gain and noise figure characteristics versus the different power level of the input signal at 1510 nm while the saturated tone at (a) 1493 nm or (b) 1514 nm, and the output ratios of C_2 are 95%, 90%, 80%, and 70%, respectively.

at the 1530 nm peak, which limits the length of the population inversion. Introduction of a progressively sharper long wavelength cutoff filter suppresses the gain in the C and L bands, so that the S band region can exhibit increasing gain, as ASE from the 1530-nm peak does not grow and limit the population inversion. Final result is a complete suppression of the longer wavelength gain, resulting in a usable high net gain in the S band. Performance equivalent to typical C band EDFAs is obtained with a nominally longer fiber. The S band EDF integrates depressed cladding design and distributive filtering enhanced function for this amplifier, therefore, the quantitative analysis of Rayleigh scattering contribution is quite complicated and still needs further study. Fig. 2(a) shows the optical spectra of gain and noise figure for this S band amplifier module over an operation range from 1480 to 1520 nm when the input signal power sets at Pin $= 0, -15$, and -30 dBm, and the saturated output power at 1498 nm can be up to 16.1 dBm for inoput power of 0 dBm, but the noise figure is 7.2 dB as seen in Fig. 2(a). The FFP filter is an all-fiber device having a widely tunable range, low insertion loss of <0.5 dB, low polarization-dependent loss (PDL) of $\sim$ 0.1 dB, the free-spectral range (FSR) of 44.5 nm, the inesse of 200, and the 3-dB bandwidth of 0.4 nm. This FFP filter is placed into the intercavity to select a lasing wavelength ranging from 1493 to 1514 nm when the external voltage (<12 V) is applied on the piezoelectric transducer (PZT) of the FFP filter. Fig. 2(b) shows the lasing powers of two different wavelengths [resolution has also been shown in Fig. 2(b)], 1493 nm (λ_{s1}) and 1514 nm (λ_{s2}, for this proposed setup with forward optical feedback while the output ratio of C_2 is 80%, and the insert is S band ASE spectrum without optical feedback.

Fig. 3(a) and (b) shows the measured gain and noise figure characteristics versus the different power level of input signal at 1510 nm while the lasing wavelength at 1493 and 1514 nm, and the output ratios of C_2 are 95%, 90%, 80%, and 70%. Because some components placed at the signal input end have higher losses in S band and the splice point of S band EDF and WDM coupler possesses higher loss, the noise figure of this S band EDFA module will be slightly degraded. Therefore, compared with the C and L bands gain-clamped EDFAs [2]–[4], the noise

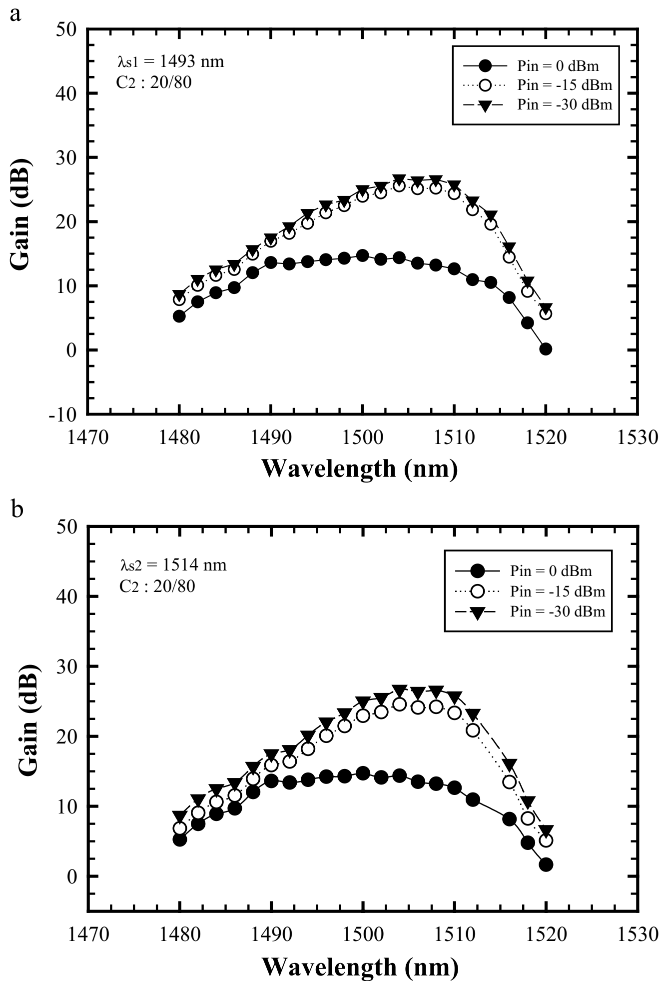

Fig. 4. Gain spectra of a S band gain-clamped EDFA module with an optical feedback injection and C_2 of 80% output ratio at the input signal-power Pin $= 0, -15$, and -30 dBm over the operation range from 1480 to 1520 nm whenthe lasing wavelength is (a) λ_{s1}, or (b) λ_{s2}

figure of an S band gain-clamped amplifier was also slightly higher than that of them. The gain clamping effect is observed when the output ratio of C_2 is not larger than 90% and 95% for lasing wavelength at 1493 and 1514 nm, respectively. By using C_2 of 70% output ratio, the gain can be kept constant at the input power of -15 dBm at the expense of around 5.3-dB gain and 2.8-dB noise figure degradations for the lasing wavelength at 1493 and 1514 nm. The noise figure of $\sim$2.8 dB impairment observed in Fig. 3(a) is mainly induced by the gain saturation of the lasing power and the insertion loss of optical coupler (C_1) at the signal input end for optical feedback configuration. As a result, a dynamic range of input signal from -30 dBm to -15 dBm and the gain of $>$23 dB are retrieved for the optical feedback scheme no matter the lasing wavelength is 1493 or 1514 nm.

Fig. 4(a) and (b) indicates the gain spectra of the gain-clamped amplifier module with C_2 of 80% output ratio at the input signal-power Pin $=$ 0, -15, and -30 dBm over the operation range from 1480 to 1520 nm form the lasing wavelengths λ_{s1} and λ_{s2}, respectively. Furthermore, the maximum gains at 1504 nm are 23.9 and 26.7 dB at the input power of -30 dBm, and the maximum gain variations are less then 1.2 and 2.4 dB over the operating wavelength range and 15 dB (-30 to -15 dBm) input dynamic range for the lasing wavelengths at λ_{s1} and λ_{s2}, respectively.

III. Conclusion

We have proposed and experimentally demonstrated an S band gain-clamped amplifier by using an optical feedback method. A dynamic range of input signal from -30 to -15 dBm and the gain of $>$23 dB over an operation range from 1480 to 1520 nm are retrieved. 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. This S band gain-clamped amplifier is very useful to the future S band applications.

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