Investigation of Two Bidirectional C + L Band Fiber Amplifiers with Pumping Sharing and Wavelength Reused Mechanisms

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Abstract— Two types of bidirectional fiber amplifier are proposed and experimentally demonstrated, including EDFA and hybrid fiber amplifier in C + L band. A single-wavelength pump source is used to pump both the C band and L band fiber amplifiers. Using different pumping power and wavelength the average gains are about 10.72 dB for the hybrid fiber amplifiers and 15.4 dB for the EDFA, respectively, with a launched wavelength tunable signal power of −10 dBm. The average noise figures areabout 5.17 dB and 5.1 dB for the C band and L band EDFA, respectively.

1. INTRODUCTION

The rapid growth of data traffic in optical communications and optical networks demands extensive research into wideband optical amplifiers as the roles they play have become increasingly important. Both L and Erbium-doped fiber amplifier (EDFA) and Raman fiber amplifier operating in C + L band wavelength-division-multiplexing (WDM) systems are now a mature technology. So far, there are many methods to amplify the C + L band signals such as EDFA, Raman fiber amplifier (RFA) and semiconductor optical amplifier (SOA). For the C band, EDFA is a mature and widely used technology, owning to its higher gain and lower noise figure (NF) than other methods. RFA is a convenient method to amplify various wavebands, and it has even lower NF than that of EDFA [1]. We have studied theoretically both serial-type scheme and parallel-type hybrid amplifier scheme [2, 3]. Both dispersion compensation and power equalization are realized by adjusting the fiber Bragg grating (FBG) reflectivity and the pumping ratio. In addition, compared to the unidirectional EDFA, bidirectional EDFAs can not only reduce the complexity of the optical system, but also reduce the cost of transmission optical fiber. In this paper, we proposed and experimentally demonstrated two kinds of bidirectional fiber amplifiers. The amplification range covers both the C band and L band signals. We use a single wavelength pump laser diode for both the C band and L band. Moreover, we employ concept of residual pumping power reuse to optimize both the gain efficiency of C + L band signals.

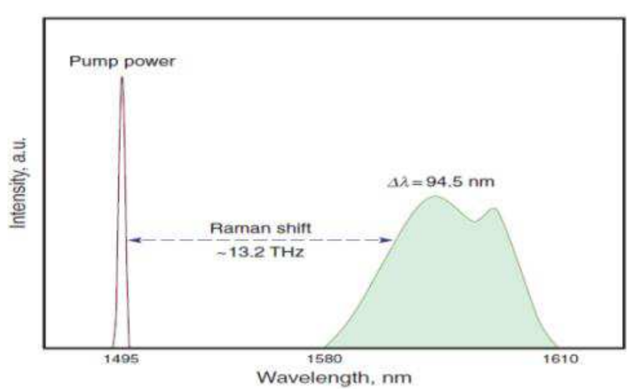

Figure 1: Pump-sharing to C-band EDFA and L-band RFA concept.

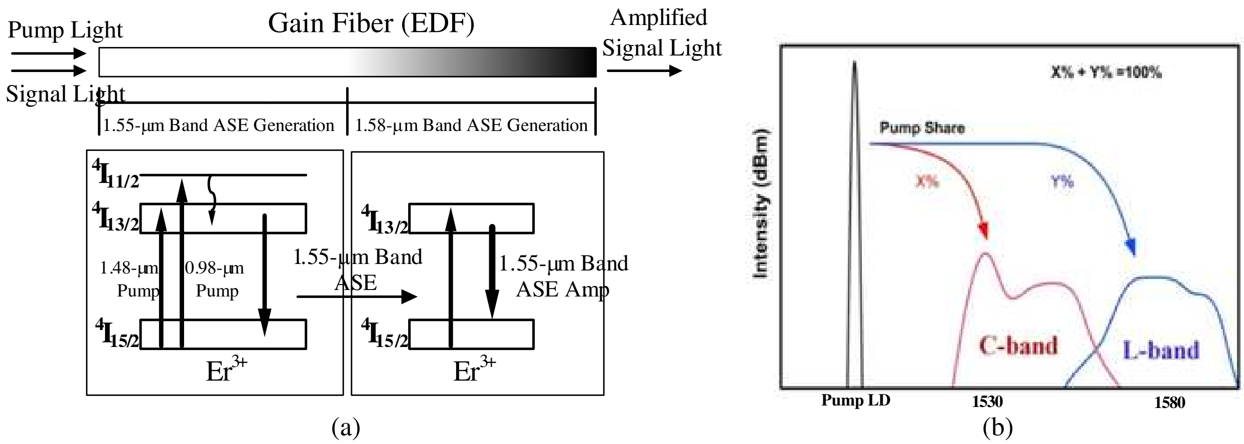

Figure 2: (a) Amplification mechanism of EDF [4], (b) distribution of pump power.

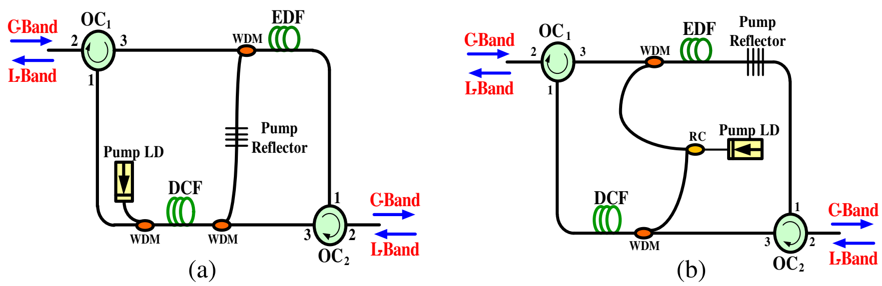

Figure 3: (a) The proposed C + L band hybrid amplifiers using a single-wavelength pump laser source, and (b) the proposed C + L band Erbium doped fiber amplifiers using a single-wavelength pump laser source.

2. THEORY

2.1. Raman

The Raman shift concept is illustrated in Fig. 1. For a pump source at 1495 nm for example, the corresponding gain peak can be described using the following equation [5]:

$$\Delta\lambda = -\lambda\frac{\Delta f}{f} = -\lambda^2\frac{\Delta f}{c} = 94.9\,\text{nm} \tag{1}$$

where $\Delta f = -13$ THz and $\Delta\lambda = 94.9$ nm are the total amount of detuning with respect to the pump frequency and wavelength, respectively. The maximum gain occurs at 1589.5 nm in the L-band region. The C-band EDFA can also use the same 1495 nm pump laser diode (LD). The gain is only a little smaller than that using 1480 nm.

2.2. EDFA

The amplified concept of EDFA using single wavelength pump LD in C + L band is illustrated in Fig. 2(a). First, the pump LD injected into the front-ends of EDF, the population inversion enables the EDF to absorb pump light and generate C band amplified spontaneous emission (ASE). After the pump light running out, C-band amplified spontaneous emission is absorbed by the rear end EDF again and generates L band ASE. Therefore, the length of EDF is key factor on generating L band ASE.

2.3. Pump Sharing

We use concept of pump sharing for gain equalization and saving cost. Fig. 2(b) depicts the pump sharing concept. We provide the $X\%$ and $Y\%$ of pump power for the C band and L bandfiber amplifier, respectively. $(X + Y = 100\%)$. we divide pump power by an optical ratio coupler (RC) and a pump reflector, respectively.

3. EXPERIMENTAL SETUP

3.1. Hybrid Fiber Amplifiers

Figure 3(a) shows the proposed bidirectional hybrid, C + L-band EDFA/RFA for WDM applications. The C-band EDFA is for the downstream signal amplification. In this case, the length and absorption coefficient of EDF are 3 m, 12.4 dB/m@979 nm and 18.79 dB/m@1531 nm, respectively. The L-band RFA for the upstream signal amplification consists of a dispersion compensating fiber (DCF). Here, the fiber loss, dispersion and dispersion slope for the DCF are 0.4 dB/km, -95 ps/nm/km and -0.62 ps/nm^2/km, respectively. The residual pump power was then routed to the C-band erbium-doped fiber (EDF) via a pair of WDM couplers. Since the residual pump power may still be too much for the EDFA, a ratio pump reflector was placed between the WDM pair to reflect part of the residual pump back to the L-band RFA for further pumping. The left hand side optical circulator (OC) is used to add the C-band signals to the EDFA as well as receive the L-band signals from the RFA. The right hand side OC is used to add the L-band signals to the RFA as well as receive the C-band signals from the EDFA. The signals for both bands have unidirectional paths thank to the inter-port isolation of the OCs. Note that the DCF plays a dual role as both the gain medium and dispersion compensator for the RFA.

3.2. EDFA

Figure 3(b) depicts the proposed bidirectional C + L band EDFAs for WDM application. The C band EDFA is for the downstream signal amplification at the upper path, and the L band EDFA is for the upstream signal amplified at the lower path. The C-band EDFA consists of a wavelength division multiplexer (WDM), EDF parameters are identical to the case in Fig. 3(a). The residual pumping power can be re-absorbed and reused by the EDF_1 after it loops back to the EDF_1 by the FBG-based pump reflector. The L-band EDFA is constructed by a WDM and 10 m-long EDF. The absorption coefficient of EDF_2 (RightWave^{TM} EDF LRL Reduced Length) is 10 dB/m@1480 nm and 33.5 dB/m@1530 nm. The pump power of 200 mW was used only one pump LD. We assign 60 mW of pumping power to C-band EDFA. The residual pumping power can be reabsorbed by C-band EDFA again.

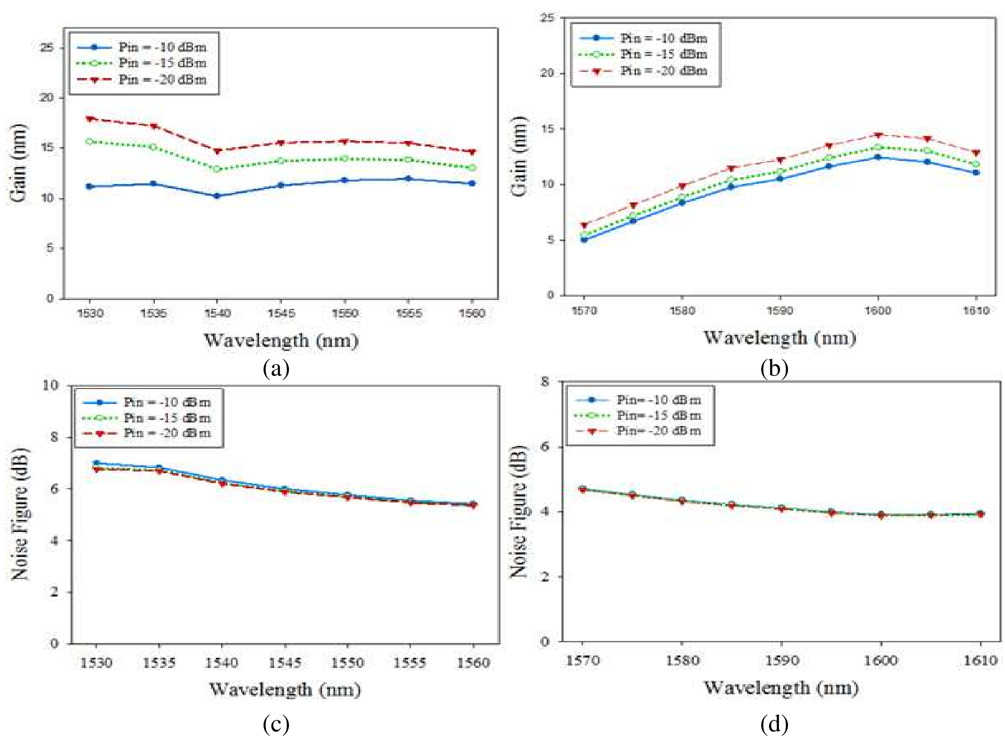

Figure 4: Measured gain and NF profiles using a tunable laser source, respectively, for (a) C-band EDFA gain, (b) L-band RFA gain, (c) C-band EDFA NF, (d) L-band RFA NF.

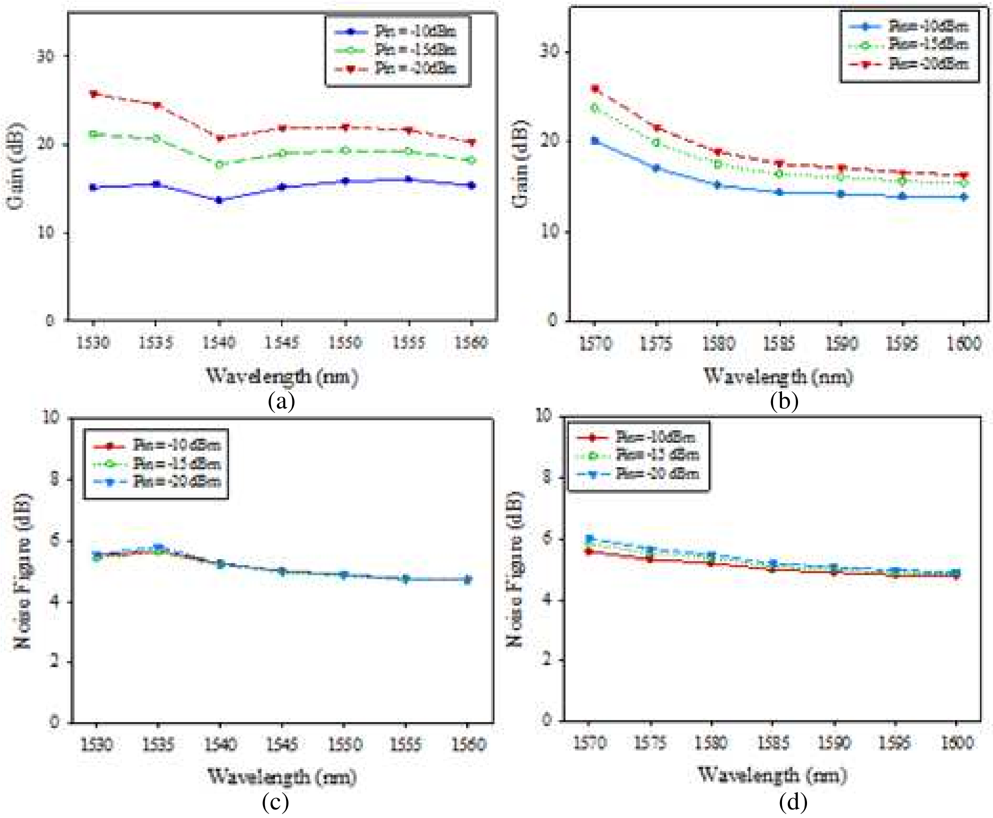

Figure 5: Measured gain and NF profiles using a tunable laser source, respectively, for (a) C-band EDFA gain, (b) L-band EDFA gain, (c) C-band EDFA NF, (d) L-band EDFA NF.

4. RESULTS AND DISCUSSION

Three input power conditions of −20/−15/−10 dBm were set for each channel into the C + L band fiber amplifier. Seven WDM channels were measured step by step, in 5 nm spacing, from 1530–1560 nm for the C-band signals. Similarly, seven WDM channels were measured step by step, in 5 nm spacing from 1570–1610 nm for the L-band signals.

4.1. Hybrid Fiber Amplifier

Figures 4(a) and 4(b) show the gain profiles of the EDFA and RFA, respectively, for different launched power (P_{in}) levels. The average gains are 11.35 dB for the C-band EDFA and 10.08 dB for the longer band of L-band RFA, respectively, for −10 dBm launched power for each channel. The power variation between C- and L-bands could be further smaller if the pump reflector have precisely controlled at 43% in reflectance. Figs. 4(c) and Fig. 4(d) show the NF characteristics of the EDFA and RFA, respectively, for different launched power levels (P_{in}). The average NF is 6.13 dB for the C-band EDFA and 4.20 dB for the L-band RFA, respectively.

4.2. EDFA

Figures 5(a) and (b) show the gain profiles of the C-band and L band EDFAs, respectively, for different launched powers (P_{in}). For −10 dBm launched power, the average gains are 15.25 dB for the C band EDFA and 15.54 dB for the L band EDFA, respectively. Figs. 5(c) and (d) show the noise figure (NF) characteristics of the C band and L band EDFAs, respectively, for different launched power levels (P_{in}). The average NFs are 5.11 dB for the C band EDFA and 5.08 dB for the L band EDFA, respectively.

5. CONCLUSION

Two C + L band amplifiers, either hybrid EDFA/RFA or EDFA were experimentally investigated and demonstrated. A single-wavelength pump source was shared between the C-band and L-band fiber amplifier. Gain equalization between these two bands can be further improved by adjusting the pump reflector reflectivity. In hybrid EDFA/RFA. Using 550 mW pump power at 1495 nm and a launched signal power of −10 dBm, the average gains were 11.35 dB for the EDFA and 10.08 dB for the RFA, respectively. The average NFs were 6.13 dB for the EDFA and 4.20 dB for the RFA, respectively. In C + L band EDFA, with −10 dBm signal power, the average gains were 15.25 dB for the C-band EDFA and 15.54 dB for the L-band EDFA. The average NFs were 5.11 dB for the C-band EDFA and 5.08 dB for the L-band EDFA, respectively.

ACKNOWLEDGMENT

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REFERENCES

1. Zhou, X., C. Lu, P. Shum, and T. H. Cheng, "A simplified model and optimal design of a multiwavelength backward-pumped fiber raman amplifier," *IEEE Photon. Technol. Lett.*, Vol. 13, No. 9, 945–947, 2001.
2. Liaw, S.-K. and Y.-S. Huang, "C + L-band hybrid amplifier using FBGs for dispersion compensation and power equalisation," *Electron. Lett.*, Vol. 44, No. 14, 844–845, 2008.
3. Liaw, S.-K., L. Dou, A. Xu, and Y.-S. Huang, "Optimally gain-flattened and dispersion-managed C + L-band hybrid amplifier using a single-wavelength pump laser," *Opt. Commun.*, Vol. 282, No. 20, 4087–4090, 2009.
4. Ono, H. and M. Yamada, "1.58-μm band gain-flattened Erbium-Doped fiber amplifiers for WDM transmission systems," *Journal of Light. Tech.*, Vol. 17, No. 3, 490–496, 1999.
5. Hecht, J., *Understanding Fiber Optics*, Upper Saddle River, Pearson Prentice Hall, New Jersey, 2006.