S+L Dual Band Silica Based EDFA Enabling Seamless Upgrade from C-band to S+C+L Triple Band System

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Abstract: We propose S+L dual-band silica-based EDFA, enabling seamless upgrade from C-band to S+C+L triband transmission system. We achieve ~20dB gain, ~6dB NF with this 3-stage EDFA and 1500nm-1600nm gain bandwidth when combined with C-band EDFA. © 2024 The Authors

1. Introduction

The development of wavelength multiplexed pumping for distributed Raman amplification enables us to utilize over 100nm of optical fiber bandwidth for high bit rate WDM transmission [1]. 100nm gain bandwidth EDFA was also proposed using EDF's inherent wide gain bandwidth [2], but it was not productized due to the reliability of its Fluoride glass host. And the limited bandwidth of current Silica based EDFAs prohibits the use of the full bandwidth. Thus, widening the gain bandwidth of the Silica based rare earth doped fiber amplifiers is imperative to realize the full benefits of the available bandwidth of optical fibers. C-band and L-band EDFAs have been in widespread use and gain bandwidths of each one has been extensively investigated to cover wider bandwidth towards the 100nm [3, 4]. However, the development of discrete S-band amplifier can be a more effective way for bandwidth upgrade with existing C-band EDFAs and L-band EDFAs. There are multiple technologies proposed for S-band including Thulium doped fiber amplifier (TDFA), and nonlinear based fiber amplifier such as discrete Raman amplifier or optical parametric amplifier (OPA), however, S-band silica based EDFA is the easiest upgrade from existing C- and L-band transmission, because there is no operational difference. In early 2000, S-band Silica based EDFA was proposed by accumulating small gain by cascading EDF stages with ASE removal in C- and L-band between each stage [5-7]. This approach using Silica based EDF with 980nm pumps is the most practical from the viewpoint of reliability and power consumption. But at that time, EDF parameters were not well optimized for other bands like S-band and L-band compared to C-band, and so, the amplifier needed 5 stages or more to accumulate enough gain. Recent development of extended C band EDF, which is expanding its gain bandwidth, also has transparent (gain) bandwidth in S-band and optimized gain at 1500nm reaches up to 10dB/stage depending on its design. It is possible to realize a S-band EDFA with more than 20dB gain with fewer stages. This simple configuration may enable new band utilization. The extended C band EDF also has transparent (gain) bandwidth in L-band. If ASE removal filter after each stage only attenuates C-band, this EDFA can also have L-band gain. So, this S+L dual band EDFA can be utilized to seamlessly upgrade from C-band only system to S+C+L triple band system with over 100nm bandwidth by combining with C-band EDFA as shown in Fig. 1.

In this paper, we investigate the new Silica based EDF with different ASE rejection filters to realize S-band EDFA, and S+L dual band EDFA to make seamless upgrade from C-band only transmission system to S+C+L-bands transmission system covering over 100nm bandwidth.

2. Principle

Fig. 2 shows the calculated wavelength dependence of the gain for different lengths of extended C band EDF using the OFS Optics OASiX optical amplifier simulator with 980 nm pump. It is found that high inversion rate is obtained with a shorter EDF length, and gain is obtained in a wide wavelength range.

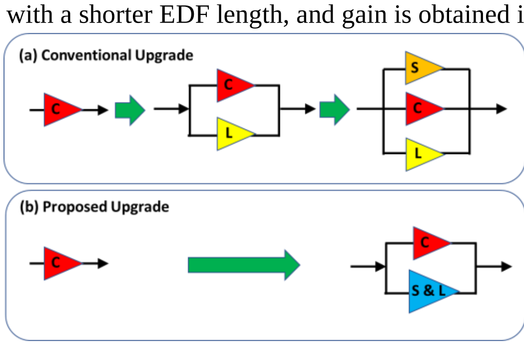

Fig. 1 (a) Conventional band upgrade, (b) Proposed upgrade

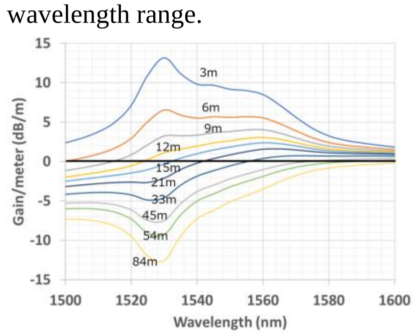

Fig. 2 Calculated wavelength dependence of gain per EDF length (in meters)

In general, the C-band EDFA can select a length at which a flat gain can be obtained in the C-band (in this case, 6m), and the L-band similarly can select 21m to obtain a flat gain in L-band. To obtain gain in the S-band, it is better to use a shorter fiber length of 3m, where a gain of more than 10 dB is expected, although with some gain tilt. A gain of more than 20 dB is possible by cascading multiple stages, but the ASE generated in the C-band must be removed to avoid waste of pump energy in C-band. In addition, on the long wavelength side, there is gain which can be used for L-band just like the S-band. If the ASE can be removed from the C-band only, an amplifier that provides gain in both the S-band and the L-band simultaneously can be realized.

3. Experimental setup

Fig. 3 shows a 3-stage configuration of S-band and S + L dual band EDFAs. The 1st stage has 980nm pump laser for forward pumping with 1W and the second stage after an ASE rejection filter has 980nm pump laser for backward pumping with 1W. The 3rd stage has 1480nm pump laser for backward pumping with 1.5W. OFS's HP-19 EDFs, which have 19dB/m peak absorption, are used for all stages. EDF lengths are 2.5m, 3m, and 5m for the 1st, 2nd, and 3rd stages, respectively, to maximize the gain.

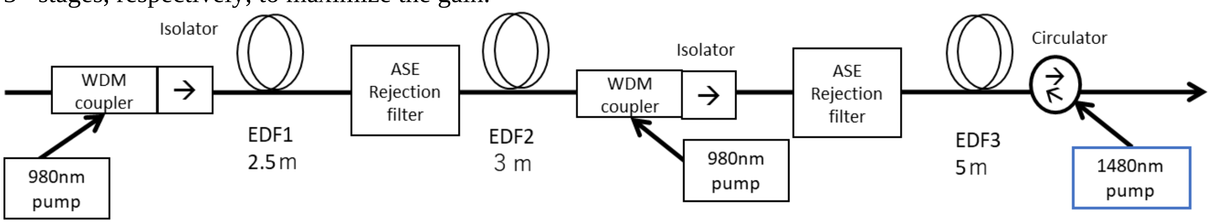

Fig. 3 Configuration of the proposed EDFA

4. S-band EDFA

First, we employ C-and L-band rejection filter shown in Fig. 4 to characterize S-band amplification. The filter has transparent window in S-band and increases its attenuation towards C-band. This filter also has large attenuation in L-band of more than 30dB. Fig. 5 shows the measured and simulated gain and noise figure (NF) of the proposed S-band EDFA with -30dBm single CW channel. Simulation results calculated with OASiX show good agreement with measured results. There is a gain tilt of about 0.8dB/nm. However, it can be easily flattened using an optimized gain flattening filter because NF is almost flat around 4 to 6 dB across the gain bandwidth. Dip of gain around 1520nm is due to higher attenuation of the non-optimized rejection filter (please refer to the shoulder of loss curve around 1520nm in Fig.4). The gain decreases beyond 1526nm due to higher loss of the rejection filter as designed. The 20dB gain bandwidth of this S-band EDFA is 28nm from 1500nm to 1528nm. Further gain bandwidth expansion may be possible with larger number of stages.

Fig. 6 shows signal input power dependence on signal output power for 1499.71nm, 1513.34nm, and 1523.92nm. Signals on 1513.34nm and 1523.92nm are saturated around 20dBm/channel, but at 1499.71nm the output power is not saturated with 1dBm/channel signal power due to smaller gain of 20dB. 1523.92nm signal has relatively high gain of around 50dB with -30dBm small signal and reaches 20dBm saturated output power with -20dBm input signal power. Then this S-band EDFA's linear operation range could be less than -20dBm input signal power. In addition, higher gain (like gain around 1524nm) is also achievable by cascading more EDF stages with appropriate rejection filters.

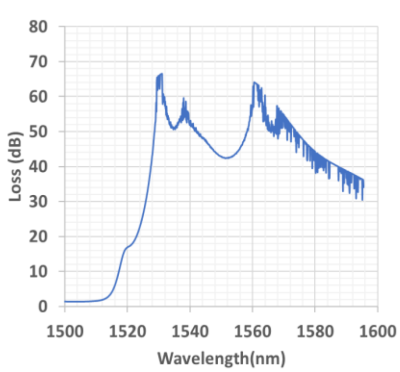

Fig. 4 Loss curve of C- & L- band rejection filter

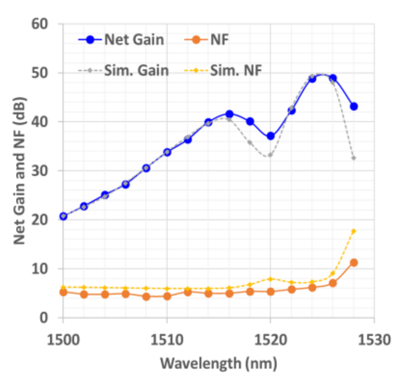

Fig. 5 Net Gain and NF of S-band EDFA

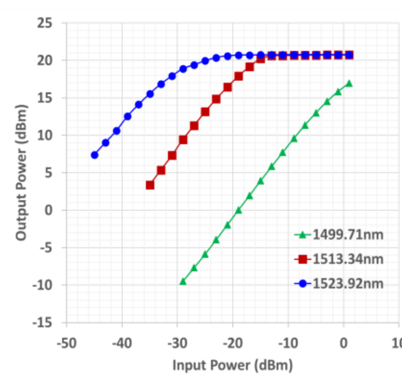

Fig. 6 Input dependence on amplified power

5. S+L dual band EDFA

Second, we employ C-band only rejection filter to get S- and L-bands simultaneous amplification. Fig. 7 shows C-band only rejection filter for S+L dual band amplification. Fig. 8 shows gain and NF of the proposed amplifier. We observed signal gain from 1496nm to 1526nm (30nm) and 1564nm to 1610nm (46nm) with more than 10dB gain. Gain tilt of 0.8dB/nm in S-band and -0.7dB/nm in L-band is observed. But as NF is relatively flat around 6dB across the gain bandwidth, an optimized gain flattening filter can be used to enable S- and L-band WDM signal transmission. Fig. 9 shows input power dependence on amplified signal power. Behavior of inner wavelengths (1569.93nm and 1523.92nm) are similar and saturate around 20dBm at smaller input power of less than -20dBm. Middle wavelengths (1584.92nm and 1513.34nm) also show similar behavior and saturate around 20dBm. Outer wavelengths (1599.92nm and 1499.71nm) do not saturate due to lower gain.

The saturated power at 1523.92nm is ~2dB lower in S+L dual band EDFA compared to S-band EDFA due to energy waste in the L-band. In case of 1499.71nm, which is not saturated, gain of S-band EDFA is 3.7dB higher than that of S+L band EDFA. This difference can be compensated by one additional stage.

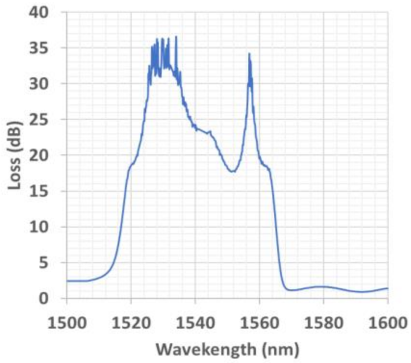

Fig. 7 Loss curve of C-band rejection filter

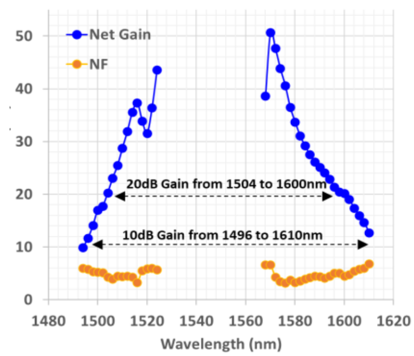

Fig. 8 Net Gain and NF of S+L dual band EDFA

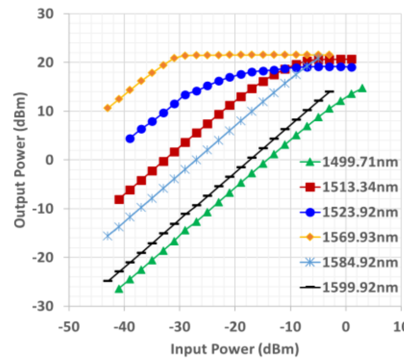

Fig. 9 Input dependence on amplified power

6. Conclusion

We proposed and characterized the performance of S-band EDFA and S + L dual band EDFA using the S-band and L-band side slopes of silica-based EDF's gain spectrum. The S-band EDFA has a 20dB gain bandwidth of >28nm from 1500nm to 1528nm. The S + L dual band EDFA has ~76nm bandwidth (S-band: 30nm from 1496nm to 1526nm, L-band: 40nm from 1564nm to 1610nm) with >10dB gain. We envision that such S+L dual band EDFA can enable seamless upgrade from C-band only to S+C+L triple band transmission with more than 100nm bandwidth using only Silica based EDFAs.

7. Acknowledgement

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