Optimisation of Hybrid TDFA-Raman Amplifier in S-Band

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Abstract*- Thulium doped based amplifier(TDFA) is a main approach as an amplifying media in S-band for Wavelength division multiplexing(WDM) system. But, the TDFA do not provide an adequate gain and the gain is not flat in entire S-band. In this paper, the combination of TDFA with Raman amplifier has been used to flatten the gain in the S-band. Gain curves of Thulium doped based amplifier are solitary analysed, and TDFA length and Thulium doping concentration are optimised. Then by controlling the gain of Raman, overall gain of hybrid configuration is flattened. It was observed that equitably gain curve with 5 dB variation in S-band (1460-1500nm) is achieved, maximum gain of 31.1dB at 1470nm and least gain of 26.1dB at 1500nm was observed.*

Keywords*-* Thulium doped fibre amplifier [TDFA], Raman, Gain, Hybrid Amplifier, S-band.

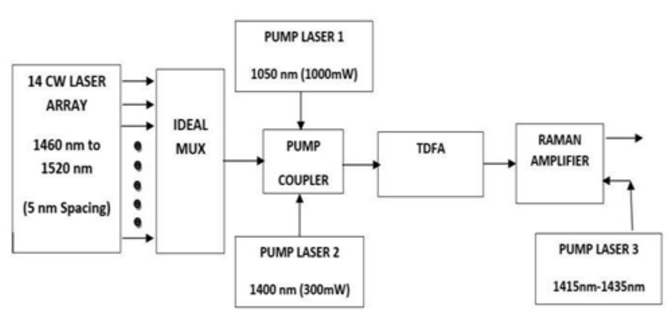
I. INTRODUCTION

Constructing hybrid amplifiers that combines various amplifiers with variable gain bandwidths is one of the effective ways to extend the optical amplifier's gain bandwidth. An increase in demand for the more transmission bandwidth is expected to go beyond that can be fulfilled with the current C and L band EDFA. Many of the solutions are available which can be adopted, one of them is to increase the transmission bandwidth, other is to increase the efficiency of usage of existing band. By extending the L-band via Raman amplification, the former one is achieved and proceeding to shorter wavelengths (1450nm-1520nm), commonly termed as S-band. Due to higher phonon energy in silica host [3], TDFA has low gain in S-band. On the other hand, fluoride based TDFA shows good gain even at low pump powers [5,8]. Silica based TDFA is advantageous over fluoride based because of easy splicing with standard single mode fibre made of silica. The major drawback associated with TDFA isits low gain and non-uniform curve [10]. To flatten Hybrid combination of Raman with TDFA is used to flatten the gain in Wide bandwidth hybrid configuration. In this paper, a silica based thulium doped fibre amplifier is used with Raman amplifier to achieve the gain flatness and high-gain hybrid amplifier has been optimised for several parameters which are TDFA length, doping concentrations and Raman Pump wavelength. In past, for TDFA many pumping schemes with single pump [12], dual pump [13] and triple pump [14] have been discussed. In this, dual pumping scheme with 1050nm and 1400nm for TDFA has been used [15].

The paper is organised as follows: Simulation steps are mentioned in section 2, methodology is discussed in section 3, results and discussions are presented in section 4, conclusion ad the future directions are given in section 5.

II. SIMULATION SETUP

The system has been simulated on Opti system 13.0 simulation tool to evaluate the gain curves of TDFA, Raman and hybrid amplifiers. Figure 1 shows the simulation setup which is used for the purpose of simulation. At the side of transmitter,14 continuous wave lasers having each of them -20 dB power, in a range of 1460nm to 1520 nm are placed with an equal spacing of 5nmwhich are further multiplexed together by an ideal multiplexer in wavelength domain.The hybrid configuration of TDFA-RAMAN is formed by cascading TDFA and RAMAN as showed Fig1 with 1000 Mw TDFA is pumped with copropagating 1050 nm pump and with 300mW power 1400nm pump.Whereas, RAMAN amplifier of length 20 km is pumped by counter propagating pump laser3 of 1000 Mw power whose wavelength is varied in the range of 1415nm to 1435 nm.



Parameters which are used in TDFA are mentioned in table 1, length of the TDFA is varied in the range of 10m to

100m, doping concentration varied from 20×1024 m-3-60×1024 m-3

Parameters	Value(unit)	Parameters	Value (unit)
Length	10-50m	Ar30	1353.85s
Numerical Aperture	0.4	Ar31	138.46s
Core Radius	1.3μm	Ar32	46.153(1/s)
Doping radius	0.5μm	Ar50	581.4(1/s)
Thulium ion density	$20\times10^{24}m^{-3}$ -$60\times10^{24}m^{-3}$	Ar51	69.767(1/s)
Non-radiative lifetime1	0.00043s	Ar52	348.84(1/s)
Non-radiative lifetime 3	45.00000000000001e-006 s	Ar53	127.91(1/s)
Non-radiative lifetime 5	0.000784s	Ar54	34.883(1/s)
Ar10	285.7s		

III. METHODOLOGY

Formerly,TDFA is simulated for varied length from 10m to 50m, after realising the results 30m TDFA length was found most suitable. In the next step, again TDFA is simulated for varied doping concentration from 20 ppm to 60ppm. By analysing the results, 30ppm concentration was found most favourable. At the last, wavelength of pump3 has been varied 1415nm to 1445nm to flatten the entire gain of hybrid amplifier.

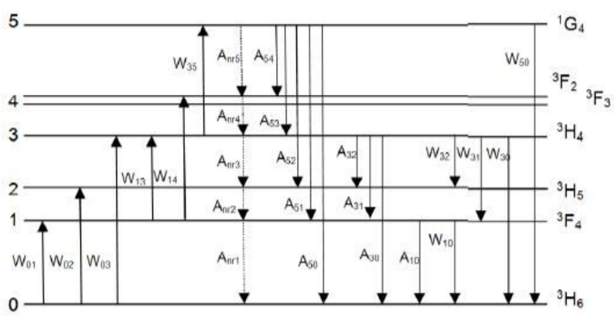


Fig. 2: Energy level diagram of Thulium [10]

Figure 2 shows the complete energy level diagram of Thulium ions [10], level $^3H_6$,$^3H_4$,$^3H_5$,$^3H_4$,$^1G_4$ entitled as level 0,1,2,3,5 respectively. The rate equation can be written as:

$$\frac{dN1}{dt} = N0.(W01 + W02) - N1.(W10+W13+W14+Anr1+A10) + N3.(W31+W32+Anr3+A32) + N5.(A51+A52)$$

$$\frac{dN3}{dt} = N0.(W03) + N1.(W13 + W14) - N3.(W35 + W32 + W \ldots + A54 + A53)$$

$$\frac{dN5}{dt} = N0.(W05) + N3.(W35) - N5.(W50 + Anr5 + A54 + A \ldots$$

And, $N_t = N_0+N_1+N_3+N5$

Where, N_0, N_1, N_2, N_3,N_5, N_t are the population density of $^3H_6$,$^3F_4$,$^3H_4$,$^1G_4$. W_{ij} is the stimulated absorption and emission rates from I level to J. Whereas, A_{ij} and Anrj are the radiative and non-radiative decayrates respectively.

IV. RESULTS AND DISCUSSIONS

Firstly, for varied fibre length and doping concentrations gain of TDFAhas been obtained. Figure 3 shows gain of TDFA amplifier module (doping concentration=20ppm), particularly for varied length from 10m to 50m. From the figure it is seen that as the TDFA length increases, gain for the lower wavelengths also get increased, when TDFA length is increased from 10m to 40m maximum gain increases abruptly whereas, after 40m TDFA length maximum gain increases very faintly.

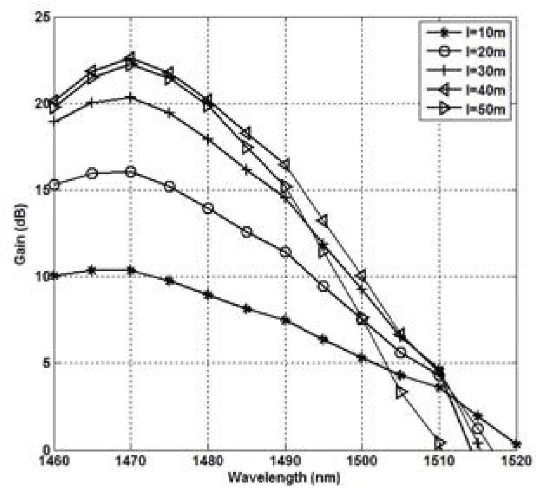


Fig.3: Gain vs wavelength for varied TDFA Length

Table 2 shows the gain at 1470nm and 1510nm for varied TDFA length 10m to 50m. Ratio of gain at 1470nm to 1510nm gives a measure of gain flatness. Lesser ratio gives an adequate means of gain flatness, whereas higher ratio level will cause a problem for the gain flattening. For the lower gain ratio,

TABLE 2: RATIO OF TDFA GAIN AT 1470nm TO 1510nm FOR VARIED FIBER LENGTH

TDFA Length (m)	A (Gain at 1470nm)	B (Gain at 1510nm)	Ratio A/B
10	10.33	3.62	2.85
20	16.02	4.28	3.74
30	20.35	4.67	4.35
40	22.66	4.46	5.08
50	22.24	0.43	51.72

TDFA provides a maximum gain which is low. Therefore, TDFA of 30m length is chosen at which gain around 20dB has been observed.For a particular value of TDFA length doping concentration of Thulium is varied from 20ppm to 60ppm. Figure 4 shows a plot of gain vs wavelength for the varied doping concentration from 20ppm to 60ppm for the TDFA length of 30m. It is clearly depicted from the graph that the TDFA gain is quite sensitive to the corresponding doping concentration. At 1470nm gain gets increased with the increase in doping concentration respectively, this was very similar to the gain with the TDFA length as shown in figure 3.

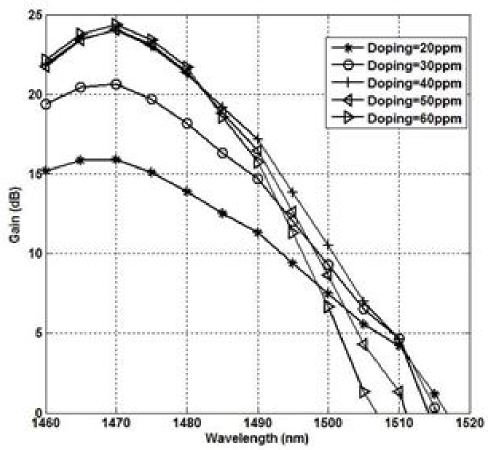


Fig.4. Gain vs. wavelength for varied doping concentration for fixed TDFA length of 30m

TABLE 3: RATIO OF TDFA GAIN AT 1470nm TO 1510nm FOR VARIED THULIUM DOPING

Thulium doping (ppm)	A (Gain at 1470nm)	B (Gain at 1510nm)	Ratio A/B
20	15.9	4.23	3.75
30	20.35	4.65	4.37
40	24.00	4.62	5.19
50	24.05	1.33	18.08
60	24.39	2.30	10.6

From the table 3, 30ppm doping concentration is selected. Since doping concentration at 20ppm is very low and hence it is not suitable, for the doping between 40ppm and 50ppm variation of gain is quite large and thus it would be difficult to flatten the gain at 30ppm.

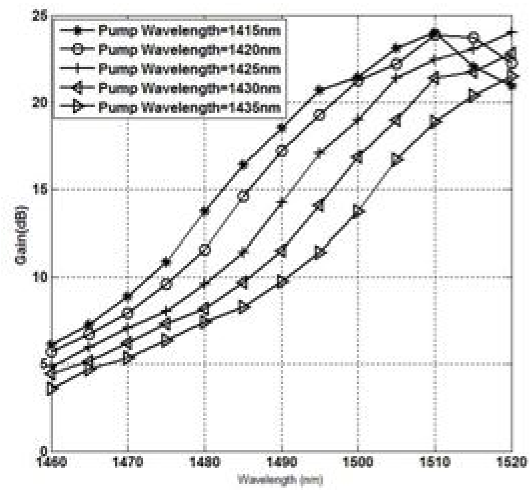


Fig.5. Gain vs. wavelength of Raman Amplifier for varied pumping wavelength

Figure 5 shows the gain of Raman amplifier which is plotted for varied wavelength of pump 3. It was seen from the figure that with the increase in pump wavelength, the maximum gain at mid values of wavelength decreases which leads to gain flatness.

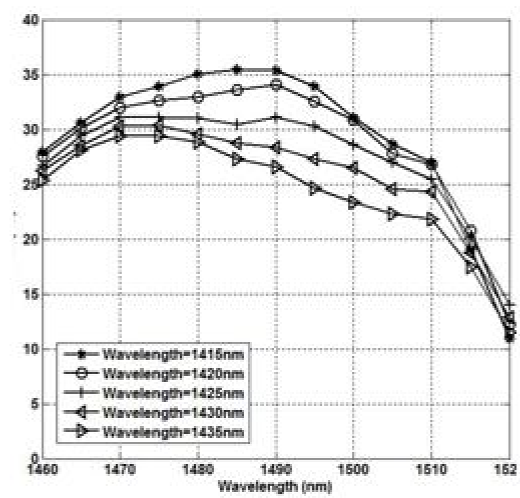


Fig 6 Gain vs wavelength for the hybrid Raman and TDFA configuration

In figure 6 gain curves are shown for the Raman and RDFA configuration for varied propagating pump wavelength. Using 1415nm pumping at 1490nm wavelength, a maximum gain of 35dB has been observed, also at this pumping gain varies in the region of 1465nm to 1500nm is 30.5dB to 35.2dB, also the gain variation is very low of around 2dB in 1470nm to 1495nm. At 1420nm the pumping gain is almost similar to the gain at 1415nm but the gain was less, with this pumping gain of approx. 3dB was observed in 1465nm to 1500nm and the maximum gain observed was 34.05dB at

1490nm. Most of the flat curves has been observed at 1425nm pumping with the gain variation of 5dB in 1460nm to 1505nm pumping. In this region maximum gain is 31.1dB at 1470nm and lowest gain is 26.1nm at 1500nm.Whereas,in the 1430nm pumping case the gain variation (Approximately 4 dB) from 26.46 to 30.34dB.In the region 1460 to 1500nm has been observed. With the 1435 nm pumping the gain decreases at higher wavelengths, the gain in the region1460nm 1490nm ranges from lowest 25.39dB at 1460nm to highest 29.42 dB at 1470nm in this region gain variation of approximately 4 dB has been observed. From all of the above observations it has been concluded that the most absolute pumping to achieve a flat gain in the large bandwidth is 1425nm.

V. CONCLUSION

In this paper, gain flatness is examined for the hybrid configuration of Raman-TDFA, by making use of co-propagating 1050nm to 1400nm pumps to TDFA by varying of counter propagating pump wavelength to the Raman amplifier. Formerly TDFA fibre length was varied from 10m to 100m and by observing the gain curves TDFA length 30m has been chosen since at this point it provides a maximum gain of around 20dB. At lower wavelengths TDFA shows a low maximum gain whereas at higher wavelengths at higher distances ratio of maximum to minimum gain in 1460nm to 1510nm is quite large which makes it difficult to flatten the gain. Then Raman amplifier was used in a cascading way to flatten the overall gain of TDFA-Raman hybrid configuration. Gain variations of Raman amplifier is evaluated by varying the counter propagating pump which in turns changes the overall gain of hybrid amplifier. It was observed that by providing 1425nm counter propagating pump to Raman amplifier best gain flatness is achieved in hybrid amplifier. In this case with the gain variation of 5 dB in 1460nm to1505nm region, maximum gain of 31.1dB at 1470nm and lowest gain of 26.1dB at 1500nm was observed.

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