Optimization of TDFA length, pump power, pump wavelength inhybrid TDFA-RAMAN wideband amplifieryielding flat gain inS-band

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Abstract:For S- Band WDM systems a wideband optical amplifier is desirable,Silica based Thulium doped fiber amplifier (TDFA) is a main amplifier media in S-band.But it has limitations of low gain and less gain flatnessin wide bandwidth.In this paper, TDFA-RAMAN amplifier in hybrid configuration has been used to flatten the gain in S-band. The gain curves for the TDFA-RAMAN configuration are evaluated and are optimized to achieveflat overall gain. The gain of hybrid configuration is flattened by controlling the gain ofRaman amplifier by precisely pumping.

Keywords: TDFA, RAMAN, Gain, Hybrid amplifier

1. Introduction

C-Band WDM systemsare very popular due to the availability of good amplifiers like EDFA and Hybrid amplifiers (RAMAN-EDFA, RAMAN-SOA)[1, 2].In S –band (1460nm-1520nm) Thulium doped fiber amplifier (TDFA) is the main amplifier. Silica based TDFA has limitation of low gain in S-band due to high phonon energy in silica host[3,4] on the other hand Fluoride based TDFA amplifier provideshigh gain even at low pump powers [5-8]. But Silica based TDFA has many advantages over Fluoride based TDFA like ease of splicing,nontoxic nature, easy manufacturing[9]. Main limitation of silica TDFA is low gain and non-uniform gain curve [10]. In this paper, RAMAN amplifier has be used with TDFA in hybrid amplifier configuration to achieve wideband gain flatness. The Hybrid amplifier has been optimized for TDFA length, pump wavelengths, and pump powers of pump laser 1 and pump laser 3 as shown in simulation setup.For TDFA there are single pump [11], dual pump [12], and triple pump [13] pumping schemes. Figure.1 shows the energy level diagram of thulium doped fiber amplifier, 1400nm pump excites electrons from ground level to N_1 level. Second pump around 1050nm excites electrons from ground level to N_2, but the life time of electrons at N_2 is very low so the electrons gets transferred to N_1 level by non-radiative transition.From N_1 level the electrons gets excited to N_3 level directly by 1400nm pump,with pump around 1050nm the electrons are excited firstly to N_5level but due to low life time at N_5 they get shifted to N3 level. Due to long lifetime of electrons at N3level population inversion takes place and by stimulated emission from N3 level to N1 level the gain is provided in the S-band (1460-1500nm).

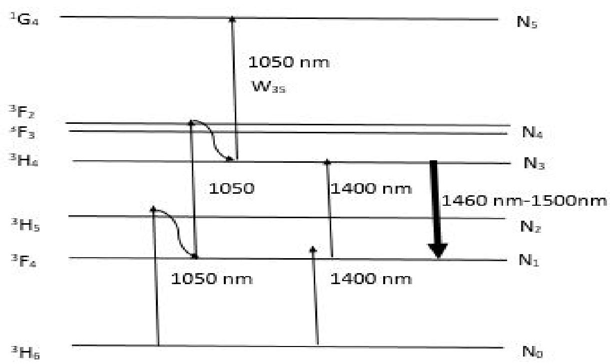


Figure.1: Energy level diagram of Thulium doped fiber amplifier

In this paper dual pumping scheme for TDFA with 1052.42nm (optimized) and 1400nm (fixed) pumping has been used. Gain of Raman amplifier is pump dependent, this effect has been used to flatten the gain of hybrid amplifier by controlling gain of Raman amplifier.

2. Simulation setup

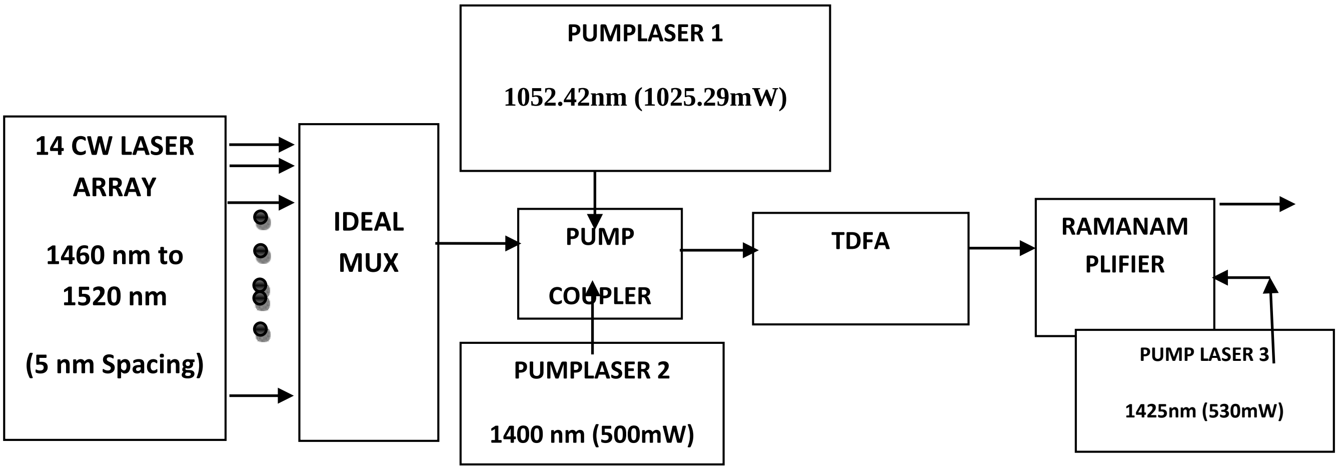


Figure.2: Simulation setup used to measure gain and noise figure

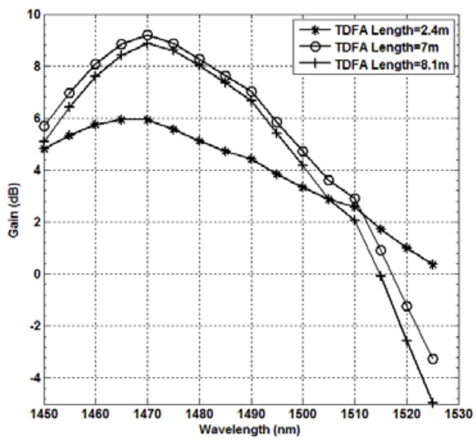
Gain and noise figure of the hybrid configuration of TDFA-RAMAN has been calculated by simulating the system in Optisystem 13.0 tool. The simulation setup has been shown in figure 2, at the transmitter 14 continuous wave lasers each with -20 dB power, ranging from 1460 nm to 1520 nm have been used with equal spacing of 5 nm. The spectrum from the transmitter lasers has been multiplexed together in wavelength domain by an ideal multiplexer. After the multiplexer theTDFA-RAMAN Hybrid amplifier configuration is formed in cascade. Using the multiple parameter optimization, the wavelength and power of pump laser 1 has been optimized, the optimized values of wavelength and pump power for pump laser1 are 1052.42nm and 1025.29mW respectively. Wavelength and power of pump laser 2 has been fixed to be 1400nm and 500mw respectively. The pumps are coupled together with the multiplexed input stream and is launched to the TDFA module in co propagating configuration. After the TDFA, Raman amplifier of 20 km length is placed which is pumped by counter propagating pump laser 3 whose wavelength and power is optimized to be 1425nm and 530mW.Parameters used for the TDFA are listed in the table.1

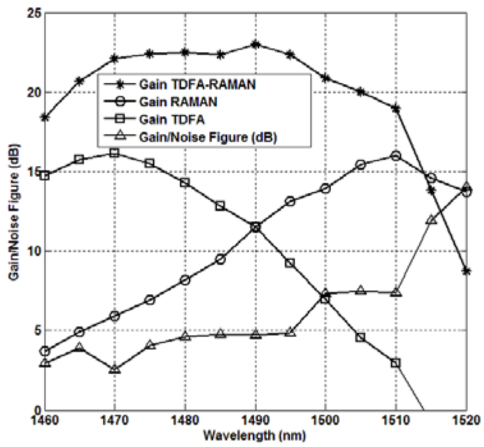
Table: 1 TDFA parameters used in simulation

Parameter	Value (Unit)	Parameter	Value (Unit)
Length	12.638m (Optimized)	Ar30	1353.85s
Numerical Aperture	0.3	Ar31	138.46s
Core radius	1.3μm	Ar32	46.153(1/s)
Doping radius	1.0 μm	Ar50	581.4(1/s)
Thulium ion density	$20x10^{24}$ m^{-3}	Ar51	69.767(1/s)
Non-radiative lifetime 1	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		

3. Results and discussion

Figure 3(a) displays the gain curves of the TDFA amplifier as presented by P. Peterka et.al [10] with 1064nm with 1000mW pumping, the TDFA concentration in this case is 15.5ppm from the figure it is clear that the gain less than 10 dB has been obtained from the TDFA even at 1000mW pump.

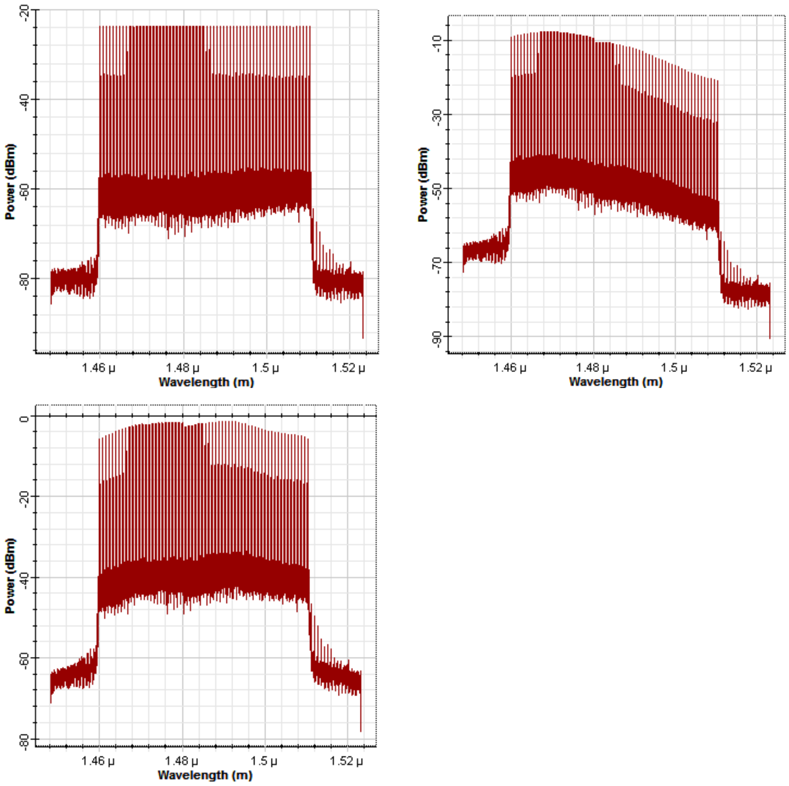




(a) (b)

Figure 3(a): Gain of TDFA with 1064nm pump [10], 3(b): Gain and Noise Figure curves TDFA, RAMAN and TDFA RAMAN hybrid configuration

Figure 3(b) shows the gain of optimized TDFA, Raman amplifier and TDFA-Raman hybrid configuration. The gain of TDFA alone is 15dB at the1460nm, Maximum value of TDFA gain is 16.16dB which has been observed at 1470nm. At higher wavelengths the gain of TDFA decreases linearly. At 1510nm gain of TDFA reduces to 2.96 dBand at 1520 the gain of TDFA is negative which is not shown in the figure. Due to carefully placing the pumps, Raman amplifier on the other hand yields low gain at lower wavelengths and its gain increaseslinearlyup to 1510nm.At 1460 nm the gain of RAMAN amplifier is 3.71 dB and at 1510nm maximum gain of 16dB has been obtained. The target was to achieve overall flat gain.The gain curve of TDFA-RAMAN hybrid configuration shown that the gain provided by hybrid configuration is much more flat than the individual amplifiers. In the region from 1460nm to 1510nm the gain variation is less than 4.5dB.At 1460nm and 1510nm overall gain obtained is 18.44dB and 18.98dB respectively. The maximum 22.9dB gain has been achieved at 1490nm. In entire bandwidth ranging from 1460nm to 1510nm the gain variation is approximately4.5dB. To show the gain flattening 100 channels starting from 1460nm with spacing of 0.8nm with -20 dB input power multiplexed together and were amplified by the TDFA and Raman modules. Figure 4(a), 4(b) and 4(c) show input spectrum, Spectrum after TDFA alone and spectrum after TDFA-Raman hybrid configuration



(a) (b)
(c)

Figure.4: (a) Input Spectrum (b) Spectrum after Thulium doped fiber amplifier (c) Spectrum after TDFA-Raman Amplifier

From the figure 4 (b) the gain variation of TDFA for various wavelengths has been observed, the signal with lower wavelengths experiences more gain and signals at higher wavelengths are getting low gain. Figure 4(b)on other hand shows relatively less gain variation, this is achieved by optimizing pump parameters and TDFA parameters in RAMAN-TDFA hybrid configuration.

4. Conclusion

In this paper the gain of hybrid TDFA-Raman amplifier has been optimized the optimized parameters are TDFA fiber length,wavelength and power of pump 1 and pump3. The optimized values of wavelength and power for pump 1 comes out to be 1052.42nm and 1025.29mW respectively. Wavelength and power of pump laser 2 has been fixed to be 1400nm and 500mw respectively. For the counter propagating pump laser 3, wavelength and power is optimized to be 1425nm and 530mW. At these optimized parameters the gain curves of TDFA, RAMAN and TDFA-Raman Hybrid configuration has been evaluated and plotted. With the hybrid configuration of TDFA-RAMAN gain flatness has been achieved to a large extent. In the region from 1460nm to 1510nm the gain variation obtained is less than 4.5dB. At 1460nm and 1510nm overall gain obtained is 18.44dB and 18.98dB respectively. The maximum gain value of 22.9dB has been achieved at 1490nm. The gain variation is approximately 4.5 dB in entire bandwidth ranging from 1460nm to 1510nm,which is quite low with respect toindividual TDFA and Raman amplifier.

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