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Gain and Noise figure analysis of L-band EDFA

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Abstract— Gain of L-band EDFA has been analyzed. The effect of change in the length of doped fiber and the use of various pumps on EDFA has been examined. EDFA exhibits a maximum gain of 16.80 dB at 188.2 THz at 980 nm pump (length of doped fiber = 150m, pump power = 100 mw) and a maximum gain of 20.53 dB at 191 THz at 1480 nm pump (length of doped fiber = 150m, pump power = 100 mw).The overall noise figure is round 4 dB for both 980 nm and 1480 nm pump. Gain of L- band EDFA increases with the length of the fiber and noise figure also increases with increase in length of fiber keeping pump power constant.

Keywords- *EDFA(Erbium doped fiber amplifier), L-band, Gain, Noise figure, Amplified spontaneous emission (ASE)*

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I. INTRODUCTION

When an optical signal passes through the optical fiber for long distances, the signal gets attenuated over a certain distance. So in order to compensate the attenuation of the signal, optical amplifiers come into existence. Optical amplifiers, operate solely in the optical domain with no interconversion of photons to electrons[1]. Therefore, instead of using regenerative repeaters, optical amplifiers are placed at regular intervals to provide the amplification of optical signal. EDFA is the most commonly used optical amplifier because of its low cost, high gain, low noise figure, polarization insensitivity. Till now, the C- band (1520-1560 nm) of EDFA has been utilized .The increase in data traffic causes the operating band to be extended from C- band to S- band (1460-1510nm) and L- band (1570-1610nm).Because of practical purposes, L- band EDFAs have obtained more interest in terms of gain and noise figure[2].

L- band amplifiers can be constructed by using Erbium doped fiber amplifiers, provided that the Erbium is operated at low inversion level, to shift the gain spectrum to L- band. Thus, the gain per unit length is small, the length of doped fiber has to be long enough in order to achieve the reasonable gain.

II. PRINCIPLE OF OPERATION OF EDFA

EDFA is based on the principle similar to that of laser i.e. amplification of the signal via the feedback.

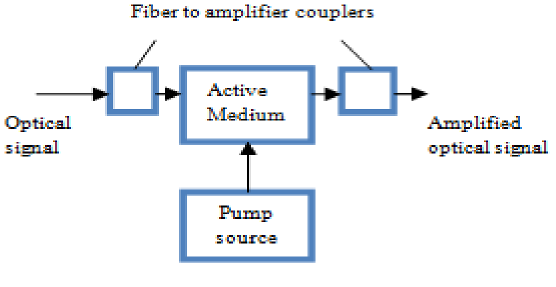

Figure 1. Block diagram of EDFA

The optical signal of appropriate wavelength is passed through the active medium via fiber to amplifier couplers. In the active medium, it undergoes stimulated emissions which result in the amplification of optical signal and amplified signal is available at the output via fiber to amplifier couplers. The power from pump source is transferred to the signal when it passes through the active medium.

III. ENERGY LEVEL DIAGRAM OF EDFA

The optical fiber can be doped with rare earth elements such as Erbium, Neodymium, Praseodymium, Ytterbium and the host material of optical fiber can be silica, bismuth, fluoride. Amplification can be achieved by stimulated emission of photons from the doped fiber. The energy level diagram of EDFA has three levels-ground , metastable, excited state. The metastable state acts as lasing level where electrons await stimulated emission to undergo amplification. Two types of pumps are mostly used-980 nm and 1480 nm pump.980 nm pump provides better gain and better noise figure whereas 1480 nm pump has better optical conversion efficiency[3]. So, 980 nm pump is preferred. The pumped electrons to excited state undergo a non radiative decay to upper level of metastable state. From the upper level of metastable state, it decays to lower level of metastable state where it awaits for stimulated emissions. When the optical fiber is excited by suitable pump source, two types of emissions are there- one is spontaneous emission which is highly incoherent and occurs naturally and other is stimulated emission which is highly coherent.

Stimulated emission has much more importance in optical fibers. Spontaneous emission contributes to noise and cannot be totally eliminated but can be reduced.

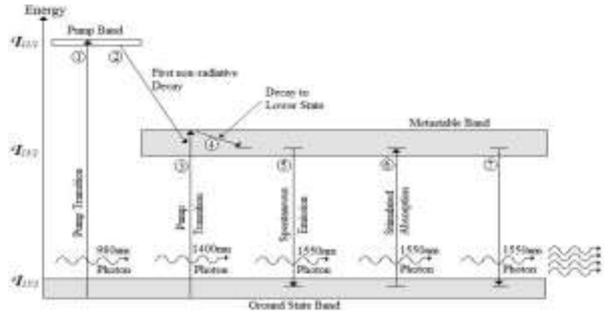

Figure 2. Energy level diagram of EDFA

IV. GAIN ANALYSIS OF EDFA SYSTEM

EDFA is a lumped amplifier and is modeled as three level system-ground, metastable and excited level.

$$G \max(L, \lambda p, \lambda s) = \exp[L \frac{rp(\lambda p) - r(\lambda s)}{1 + rp(\lambda p)}]$$

where L (L_{amp}, Γ , σ_{se}, λ_s,N_T) varies with signal wavelength, L_{amp} is the physical length of amplifier which is constant, Γ is the signal to core overlap, $r_{p=}$ σ_{pa}/σ_{pe} (pump absorption/ pump emission) is cross section ratio of pump and r = σ_{sa}/σ_{se} (signal absorption/signal emission) is cross section ratio of signal[4].

The population inversion is achieved with the help of power from the pump source. A large number of electrons are there in metastable state awaiting the stimulated emissions to go from metastable level to ground level. As input power increases, a large number of electrons undergo stimulated emissions resulting in amplified output signal. As this process continues, the population inversion goes on depleting as more and more electrons decays to ground level from excited level. So, due to insufficient number of excited electrons, gain starts decreasing at high input powers. Thus, gain is highest at low input powers and starts decreasing as input power increases.

V. ANALYSIS OF EDFA SYSTEM

VPI Photonics simulation software is used to analyze the L-band EDFA system. A single stage WDM source of emission frequency 184 THz, channel spacing of 200 GHz with input signal power of 0.01 mw is used. 50 channels are transmitted from WDM source. It is forward pumped system using 100 mw power at 980 nm pump and 1480nm pump respectively. The amplifier is excited by WDM combination TESTSETAMPLIFIER modules used around the whole amplifier system. Isolator is used to prevent the back propagation of the signals which causes the reflections resulting in unstability of the whole system.

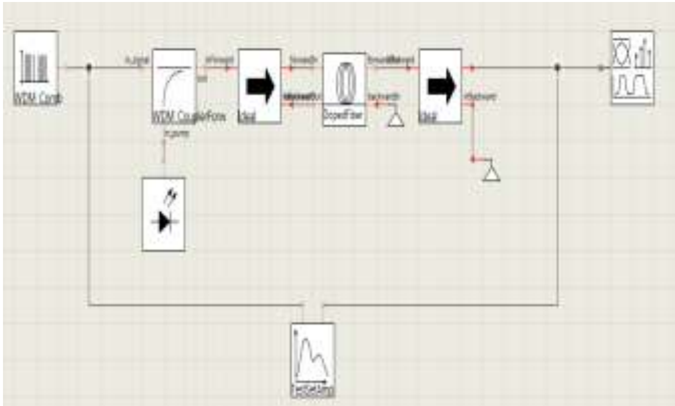

Figure 3. EDFA system

The fiber's operation can be divided into two distinct regions.When pumped with 980nm pump, the first 12m of fiber has an inversion of greater than 50% (length of doped fiber=150m).This amplifies the signal spectrum and produces a large amount of ASE noise.The remaining length of fiber has an inversion of less than 50%.This means it will absorb the ASE generated by first stage and uses this energy to amplify the signal spectrum.

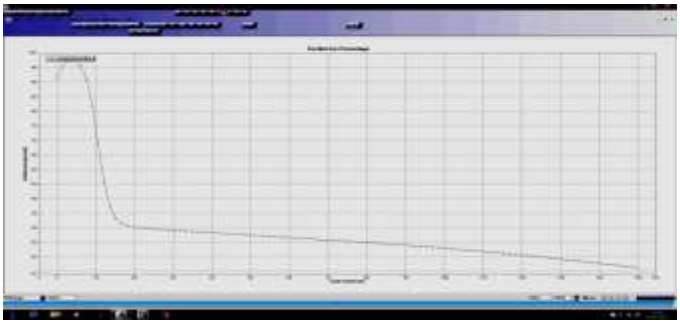

Figure 4. Inversion level with ASE included at 980nm pump

The amplifier has a gain of above 16 dB and a noise figure of round 4 dB over the range of 186-190 THz at pump 980nm when length of doped fiber is 150m.

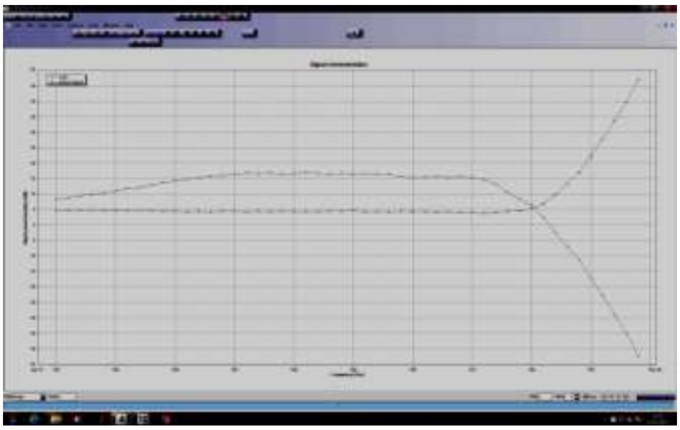

Figure 5.Gain and noise figure analysis of EDFA at 980nm pump

TABLE I. Gain and noise figure at 980nm pump

S.NO.	FREQUENCY (THz)	GAIN (dB)	NOISE FIGURE (dB)
1.	186	14.21711095	4.5023980
2.	186.2	14.82850412	4.2657725
3.	186.4	15.2267805	4.4257864
4.	186.6	15.82683957	4.2802631
5.	186.8	16.07724083	4.4155160
6.	187	16.23272601	4.5071660
7.	187.2	16.67863511	4.2188410
8.	187.4	16.65259086	4.4243932
9.	187.6	16.71638277	4.2614739
10.	187.8	16.34186232	4.4709864
11.	188	16.63909408	4.3547870
12.	188.2	16.80971026	4.3413040
13.	188.4	16.65435086	4.3689937
14.	188.6	16.51863098	4.4104687
15.	188.8	16.59161947	4.4537239
16.	189	16.4804538	4.6467694
17.	189.2	16.5761611	4.2776797
18.	189.4	16.3422439	4.2975871
19.	189.6	16.3007866	4.2000815

S.NO.	FREQUENCY (THz)	GAIN (dB)	NOISE FIGURE (dB)
1.	186	15.55892829	4.5203515
2.	186.2	16.23220604	4.2903755
3.	186.4	16.68650466	4.4667400
4.	186.6	17.35939263	4.3229876
5.	186.8	17.67984468	4.4654963
6.	187	17.89472525	4.5708361
7.	187.2	18.41453262	4.2822858
8.	187.4	18.44940974	4.4954691
9.	187.6	18.58618271	4.3342491
10.	187.8	18.28895961	4.5512150
11.	188	18.66564997	4.4442374
12.	188.2	18.92442226	4.4363529
13.	188.4	18.85503752	4.4733142
14.	188.6	18.81196901	4.5201720
15.	188.8	18.98380392	4.5820929
16.	189	18.99271331	4.7811450
17.	189.2	19.21204321	4.4141141
18.	189.4	19.10880751	4.4518746
19.	189.6	19.22402333	4.2000815

When pumped with 1480 nm,the first 21m of fiber has an inversion of greater than 50% keeping the length of doped fiber constant i.e. 150m.As larger length has an inversion >50% so gain obtained with 1480nm pump is higher than obtained with 980 nm pump.

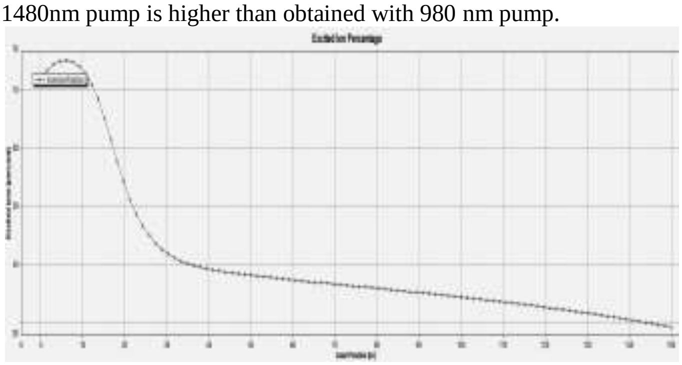

Figure 6.Inversion level with ASE included at 1480nm pump

The amplifier has a reasonable gain of above 18 dB and overall noise figure of round 4 dB over the range of 186-190 THz at pump 1480 nm when length of doped fiber is 150 m.

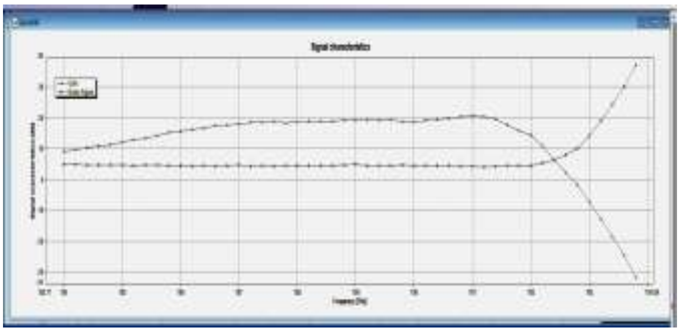

Figure 7.Gain and noise figure analysis of EDFA at 1480nm pump

Table II. Gain and noise figure of EDFA at 1480nm pump

VI. CONCLUSION

L-band EDFA exhibits a maximum gain for 1480nm pump as compared to 980nm pump for same length of doped fiber and the overall noise figure is 4dB approx. for both 980nm and 1480nm pump. For obtaining maximum gain, the length of doped fiber has to be increased in case of L operating band and noise figure also increases due to increased length of doped fiber. So,the disadvantage of L-band EDFA is that noise figure gets increased.

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