Threshold Pump Power In L-Band EDFA

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Threshold Pump Power In L-Band EDFA

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Abstract *Recently, many types of optical amplifier have been designed using fiber optic which has doped by different types of rare earth ions, such as ion of erbium. Each types of rare earth amplifier has different operation region of the signal wavelength.[4]. In this paper we will discuss about threshold pump power value of L band EDFA which shows the minimum requirement of pump power where the amplification start to happen. In the process we solve population inversion coupled equation using fourth order the Runge-Kutta integration scheme .It is found that at different input signals the population inversion population will have different treshold pump powers.*

***Keywords**: Optical amplifier, Optic, Amplification, EDFA, Erbium, Rare earth, L-Band.*

1.INTRODUCTION

Optical communication is the communication system that using the fiber optic as a transmission medium. Information signal that will be sent has to be converted into light pulse signal before it is already be transmitted trough fiber optic[3]. The transmitter will produce the light that represent the information signal, and then in the receiver the light pulse will be converted back into its original signal of information.

After several kilometres along a fiber, the optical signal can become very weak because there are losses is about 0,22 dB/km. In the optical communication especially for telecommunication application, amplifier was very needed to support better quality of the transmission.

In the development, many types of optical amplifier has been designed using fiber optic which has doped by different types of rare earth ions, such as ion of erbium, ytterbium, neodymium, thulium, praseodymium, holmium etc. Each dopant with different types has different characteristic, and this will very influence the output of the amplified signal. Each types of rare earth amplifier has different operation region of the signal wavelength.[4] In this paper the author focused on L-Band EDFA.

L-band amplifiers will be essential enabling components for future lightwave communication systems operating in what has come to be called the fourth generation telecommunications window. For range 1570 nm to 1640 nm.

This paper the author will discuss about threshold pump power value which shows that the initial amplification will occur and also the signal output power with variations of pump power.

2. THEORITICAL BACKGROUND

In the following section, will be explained on Er^{3+} ion transition of energy levels $^4I_{13/2}$ to the energy levels $^4I_{15/2}$. capable of providing and strengthening the lasing wavelength of the signal at 1500 nm. Scheme of energy levels in Er^{3+} and the resulting of spectrum is shown in Fig.1

Erbium has a very long lifetime at the amplification transition. This fact occurs because the energy gap by erbium between level excited state ($^4I_{13/2}$) dan level ground state ($^4I_{15/2}$) is very large. Its lifetime value is estimated at 10 ms and varies depending on the composition of the main glass and erbium concentration

Characteristics of the atomic structure is necessary in the process of amplification. Transitions can occur because there is separation of the atomic energy levels Erbium configuration. Separation of energy levels in the Erbium ions depicted in Fig. 1. Each E^{r3+} energy levels associated with the wavelength region of light absorption and emission.[3] This means that photons with particular wavelengths are absorbed or emitted from a particular state associated with energy levels

The results of absorption measurements of the ion-doping erbium into the fiber and measured at room temperature is shown in Fig. 2.

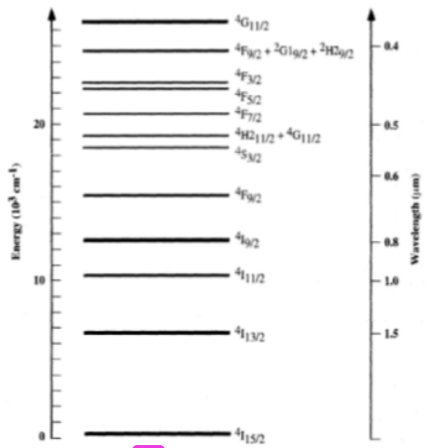

Fig. 1. Energy levels of Er^{3+} in glass host material [1]

The various peaks correspond to the transition between the ground state and the higher states. The two main pump regions at 1480nm and 980nm are seen to provide significant absorption to obtain better amplification of signal with 1,5µm wavelength. With more absorption means will be more ions are excited to the higher state, it means there is possibility more number of ions will be emitted.

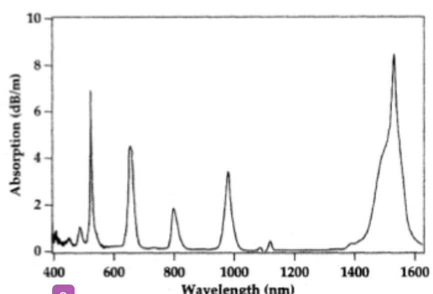

Fig. 2. Absorption spectrum of an Er^{3+} doped silica fiber [1]

If the population number in ground state is more than the population in the upper state, the incoming signal will be interact more with the population in the ground state, therefore there will be more absorption than stimulated emission. The stimulated emission rate can exceed the absorption only when $N_2 > N_1$.[4] This condition is referred as population inversion. This condition means there are more number of ions has excited to higher state, and then it will interact with the signal photons and will be emitted as the stimulated emission [1].

The population in each state will be changed by the absorption and emission cross section also spontaneous emission. The equations for population rate change in three-level atomic system can be formulated [1] as:

$$\frac{dN_1}{dt} = \Gamma_{21} N_2 - (N_1 - N_3)\, \sigma_p \phi_p + (N_2 - N_1)\, \sigma_s \phi_s \quad (1)$$

$$\frac{dN_2}{dt} = -\Gamma_{21} N_2 - (N_2 - N_1)\, \sigma_s \phi_s + \Gamma_{32} N_3 \quad (2)$$

$$\frac{dN_3}{dt} = -\Gamma_{32} N_3 - (N_3 - N_1)\, \sigma_p \phi_p \quad (3)$$

Where:

ϕ_p is flux intensity of incoming light at a frequency corresponding to the transition level 1 to level 3, or the flux intensity of the pump light, or photon flux input pump.

σ_p is pump absorbtion cross section (m^2).

ϕ_s is flux intensity of incoming light at a frequency corresponding to the transition level 1 to level 2, the flux intensity of the signal light, or photon flux input signal.

σ_s is signal emission cross section (m^2).

Γ_{32} is spontaneous transition rate from level 3 to level 2, or the probability of transition from level 3 to level 2.

Γ_{21} is spontaneous transition rate from level 2 to level 1, or the probability of transition from level 2 to level 1.

In a state of steady-state, the derivative with respect to time for all the problems on each level will be equal to zero.

$$\frac{dN_1}{dt} = \frac{dN_2}{dt} = \frac{dN_3}{dt} = 0 \quad (4)$$

And total population of N is:

$$N = N_1 + N_2 + N_3 \quad (5)$$

Population of erbium ions at level 3 can be determined from equation (3) and shown in the equation below:

$$N_3 = \frac{1}{1 + \Gamma_{32} / \phi_p \sigma_p} N_1 \quad (6)$$

Using Eq.(5) that substituted in Eq.(6) we obtain:

$$N_2 = \frac{(\phi_p \sigma_p / \Gamma_{32}) + \phi_s \sigma_s}{\Gamma_{21} + \phi_s \sigma_s} N_1 \quad (7)$$

Pump Power Threshold

The threshold pump power of an optically pumped laser is the value of the pump power for which the laser threshold is just reached. If Γ_{32} has a large value (decay occurs rapidly from level 3 to level 2) compared with a pump rated at level 3 (σ_p ϕ_p), then the value of N_3 is close to zero. This allows for most existing populations in energy levels 1 and 2. The value of the population in N_2 obtained by substituting the equation (7) into the equation (2):[2]

$$N_2 - N_1 = \frac{\phi_p\sigma_p - \Gamma_{21}}{\Gamma_{21} + 2\phi_s\sigma_s + \phi_p\sigma_p} N \quad (8)$$

Eq. (8) shows the state in population inversion, and amplification at the transition level 2 to level 1 (assuming no lossless), where $N_1 \geq N_2$. Threshold value of amplification the case for $N_1 = N_2$, and generates a statement like in equation (9) for pumping the necessary flux.[5]

$$\phi_{th} = \frac{\Gamma_{21}}{\sigma_p} = \frac{1}{\tau_{21}\sigma_p} = \frac{1}{\tau_2\sigma_p} \quad (9)$$

where:
ϕ_{th} = pump flux threshold

3. RESULTS AND DISCUSSIONS

The result of population rate change is to shows the number of population on each state as a function of time, that describe the population inversion process inside EDFA.[5] This simulation is based on the two-level atomic system theory, there are population density in state1 (as ground state), and state2 (as the upper state). The population moved from state1 to state2 because the existing pump power with the value that higher than the threshold power.

Fig. 3 shows the relation between the fractional population inversion or $(N_2-N_1)/N$ with the pump power with the different input signal power respectively -20 dBm (0.010 mW), -15 dBm (0.032 mW), -10 dBm (0.100 mW) and -5 dBm (0.316 mW) with a constant wavelength of 1570,4 nm.

Fig. 3 as the solution of the Eq.(1) and Eq.(2), shows that the number of population in ground state will be excited to the upper state.

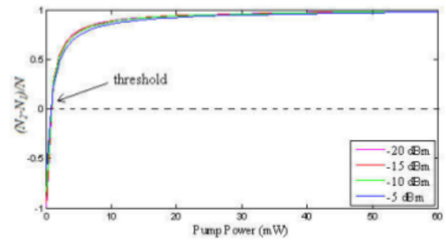

Fig. 3. Fractional inversion population characteristics against power pump with different signal power

This is occurred by the decreasing of the number of population in state1. But as the opposite, the population number of state2 is added, by the movement of some population from state1. The figure shows that all of the population from ground state can be excited to the upper state when use the 980nm pumping wavelength.

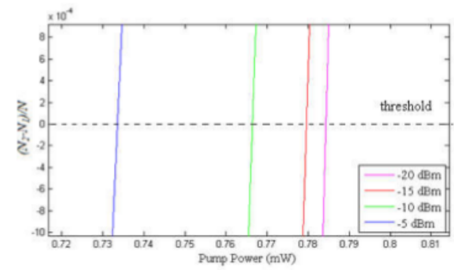

Fig. 4. Threshold value for different signal power

Fig. 4 shows that the threshold value occurs at a signal power of about 0,7844 mW for -20 dBm, and 0,7336 mW for -5 dBm, it shows at the Table 1. We will see that we get higher fractional population inversion if we using the higher signal input power. Threshold value is a value which shows that the initial amplification will occur, and also showed that the number of erbium ions at level 2 equals to the number of erbium ions at level 1. We define the pump power that required getting the zero fractional population inversion as the threshold pump power as plotted.[2]

Table 1. Threshold pump power

Signal Power	Pump Power at Threshold
-20 dBm	0,7844 mW
-15 dBm	0,7797 mW
-10 dBm	0,7664 mW
-5 dBm	0,7336 mW

The value of a population inversion indicates that the ions at the level of the ground state displaced all the excited state level. Increases linearly with pump power giving increase caused population inversion value increased exponentially at a certain pump power limit, and then approached saturation to increase the pump power is higher. Perfect population inversion occurs when the number of erbium ions in state1 = 0 ($N_1 = 0$), so that $N_2 = N$.

Signal Output Power To Signal Input Power

Purpose of this section is to evaluate the signal output power characteristic to the input signal power from the variation of pump power with the constant length. Measurements and calculations obtained at a wavelength of a predetermined input signal is 1570,4 nm

This figure below show the signal output power to the input signal power from the variation of pump power with the constant length. The variation of the signal input power respectively 60 mW, 50 mW, 40 mW, and 30 mW with 30 meters amplifier length. The signal output power characteristic results are shown in the figure below.

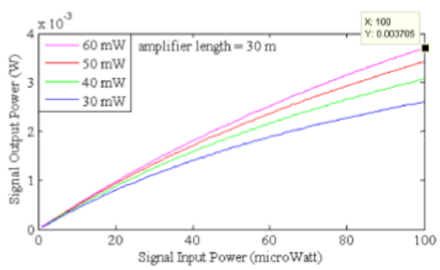

Fig. 5. signal output power characteristic of EDFA, variations of pump power

Fig, 5 we can see the relation between signal output power and signal input power. It shows that if we using more signal input power we will get higher signal output power. This can happen because there is more number of photons that excited to the upper state if we give more pump power.

And for variant input pump power, we will see that we get higher signal output power if we using the higher pump power. In this simulation, we use the 980 nm pump power.

From the figure, can see when the fiber length 30 meters, we get 3,705 mW signal output power for the 100 µW input pump power. we can see that the higher and the best signal output power is reach if we using 30 meters optical amplifier with 100 mW input pump power and with the small pump power is about 60 mW.

4. CONCLUSION

Based on the simulation and analysis. We can conclude that:

All of the population from ground state can be excited to the upper state when use the 980nm pumping wavelength

The threshold value occurs at a signal power of about 0,7844 mW for -20 dBm, 0,7797 mW for -15 dBm, 0,7664 mW for -10 dBm 0,7336 mW for -5 dBm. We will see that we get higher fractional population inversion if we using the higher signal input power.

We get higher signal output power if using more signal input, more length, more pump power. The best signal output power is reach if we using 30 meters optical amplifier with 100 mW input pump power and with the small pump power is about 60 mW.

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