Contemporary Engineering Sciences, Vol. 5, 2012, no. 2, 75 – 83

Gain Improvement of Erbium –Ytterbium Waveguide Amplifier at Different Pump Configurations

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Abstract

The gain performance and noise figure of 3cm Erbium (Er^{3+}) (Ytterbium(Yb^{3+}) co-doped waveguide amplifiers (EYDWAs) is demonstrated at different pump configuration of 980nm pump wavelength. Taking into account background losses. The input pumping power is increased from 100 mW to 200mW for a small signal power of -30dB at the signal wavelength of 1535 nm.

Keywords: Erbium–Ytterbium co-doped waveguide amplifiers, EYDWAs, WDM, signal gain and noise figure.

1 INTRODUCTION

Over the past few decades, the huge expansion of telecommunication systems had led to development of many assorted optical components. In fiber optic communications, optical transmitters, fibers, fiber amplifiers, and optical receivers are routinely used. Hand in hand with increasing speed of data transmission, the importance of integrated photonic devices and circuits grows. the use of denes-wavelength-division multiplexing (DWDM) requires broad –band and code-transparent devices such as splitters, couplers. De- multiplexers, and waveguide amplifiers. In this concept, a loss less splitter for signal distribution into a number of outputs combined with an optical amplifier and a pump/signal de/multiplexer is highly desirable ,especially in the local area networks[1].many research groups have focused on the development of optical amplifiers operating at 1550nm[2],frequently based on erbium-doped glass–based waveguide amplifiers are appealing because of their potentialities to realize broad –band and inherently linear optical components compatible with current optical communication technology[3].Often ytterbium is used as a sensitizer for erbium since it has an absorption band that overlaps with the erbium 980 nm pump band, and the Ytterbium absorption cross section is much larger than the erbium absorption cross section at this wavelength ,By means of an efficient energy transfer from ytterbium to erbium the pump efficiency can be greatly increased [4,5].An obvious advantage of using Yb3+ sensitization is that it makes slection of pumping wavelength less critical because ytterbium ions exhibit not only a large absorption cross-section, but also a broad absorption band between 800nm and 1100nm[6]

In this paper, a simulation results have been presented at different pump configuration using 3cm of erbium –ytterbium waveguide.

2 MODEL THEORY

In this section, the basic equations of theoretical model background to those given in optisystem simulation program is introduced [3]. The propagation equations describe the power evolution of the propagating electromagnetic fields in the optical amplifier and are described as:

$$\frac{dP_{P\pm}}{dz} = \mp\gamma_P(z)P_{P\pm}(z) \mp \gamma_P P_{P\pm}(z) \qquad \text{.....…… (1)}$$

$$\frac{dP_S^i \pm (z, \nu_S^i)}{dz} = \mp[\gamma_{21}(z, \nu_S^{9i}) - \gamma_{12}(z.\nu_S^i)]P_s^I(z, \nu_S^i)$$
$$= \alpha_P P_S^i(Z, \nu_S^i),\ i = 1,........,\ WDM$$
$$\text{..…….. (2)}$$

$$dP^j{}_{ASE} \pm (z, \nu_j) = \pm[\gamma_{21}(z, \nu_j) - \gamma_{12}(z, \nu_j)]P^j{}_{ASE} \pm (z, \nu_s)$$
$$\pm mh\nu_j \Delta\nu_j \gamma_{21}(z, \nu_j) \pm \alpha_s P^j{}_{ASE} \pm (z, \nu_z),\ j = 1,......, M$$
$$\text{…..……. (3)}$$

To solve the power propagation equation, the boundary condition must be imposed as

$$P_{P^+}(0) = P_{P0}, P_{P^-}(L) = P_{PL} \qquad \text{..………. (4)}$$

$$P_{s+}^i(0) = P_{s0}(\nu_s^i) and P_{s-}^i(L, \nu_s^i) = P_{sL}(\nu_s^i), i = 1.......WDM$$
$$\text{…..……. (5)}$$

$$P_{ASE+}(0,\nu_z) = P_{ASE} - (l,\nu_j) = 0, j = 1,......M$$

…..…… (6)

Where L is the device length , $P_{s\pm}^{i}, P_{P\pm}, l,$ and $P_{ASE\pm}^{j}$ are the signals, pumps and ASE (Amplified Spontaneous Emission) longitudinal power distributions in the direction of propagation z,with the signs (+) and (-) meaning, respectively, the co-and counter propagation direction; α_s and α_p are the attenuation coefficients in the wavelengths for signal and pumping respectively. The index (i) in $P_{s\pm}^{i}$ refers to the -ith signal, centered in the frequency ν_s^i , of a total number of WDM signals that can propagate simultaneously within the amplifier, as in systems with Dense Wavelength Division Multiplex - DWDM. The ASE± spectrum is discretized in M intervals (slots) with spectral width $\Delta\nu_j$, centered in the frequencies ν_j , in such a way, $P_{ASE\pm}^{J}$ that (see equation 3) refers to the -jth spectral component of ASE±. Also in Equation 3, we have (m) as the total number of modes present in the waveguide, and (h) is the Planck0 constant.

At this model nine relevant energy levels considered (four levels due to the presence of the Erbium ions, two due to the Ytterbium dopant, and three due to the formation of Erbium paired-induced ions)[3]. Rij 's and Wij 's are the pump and signal stimulated rates, and the Aij 's are the nonradioactive rate from level i to j. A21 is the fluorescent rate. C_{up} and C_3 are the homogeneous upconversion coefficients. C_{14} and C_{16} are the cross-relaxation coefficients. Figure (1)also shows the population densities of the three possible states of an excited pair ($\overline{N_{0p}}$ (no ions excited), $\overline{N_{1p}}$ (one ion excited), $\overline{N_{2p}}$ and (two ions excited), due to the PIQ effect.

In figure (1)for the 980nm-pumping region, we have representations of the $4I_{15/2}$, $4I_{13/2}$, $4I_{11/2}$, and $4I_{9/2}$ energy levels (due to the Erbium dopant), with corresponding population densities of $\overline{N_i}$ (i=1,4) , respectively. The $4F_{7/2}$ and $4F_{5/2}$ energy levels are also shown, with population densities $\overline{N_i}$ (i=5,6) , due to the Ytterbium dopant. The populations of the three possible states of an excited ion $(\overline{N_{0p}}, \overline{N_{1p}}, \overline{N_{2p}})$ are also shown. τ_{21} is the fast non radiative up conversion lifetime[3].

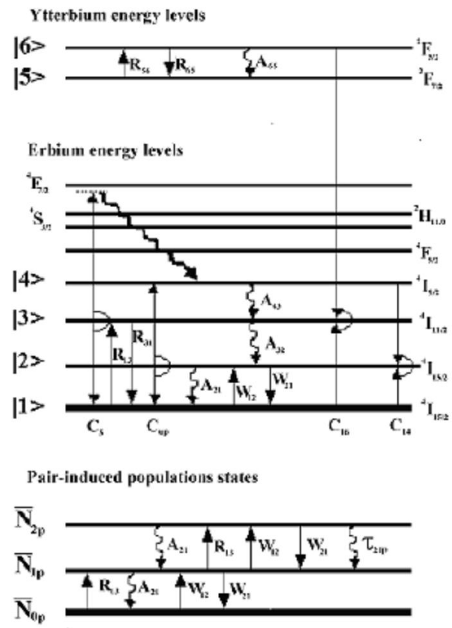

Figure (1) Coupled Er^{+3}/Yb^{+3} system, pumped in 980nm region

3 MODEL SIMULATIONS AND DISCUSSION

A nine- level numerical model of Er-Yb-co-doped active waveguide was formulated to fit the measured gain and to analyze the amplifier performance. the model incorporates the Er-Yb rate and propagation equations to calculate the pump and signal evolution along the waveguide. It takes into account the losses, due to the introduction of Erbium in the material by diffusion or by another implantation method, at the signal and pump wavelength. Backscattering is a typical effect observed in this case.
The simulation made for optimum waveguide length 3cm, at pump wavelength of 980nm and 1532nm signal wave length.

Table (1) shows the other parameter's that have been used in the simulation.

Table (1): EYWAs parameters

Parameter	Symbol	Value	Unit
Er^{3+} abs. cross section @ 980nm	σ_{13}	1.35×10^{-26}	m^2
Er^{3+} abs. cross section@1532nm	σ_{12}	3.54×10^{-27}	m^2
Er^{3+} emis. cross section@1532nm	σ_{21}	4.8×10^{-25}	m^2
Yb^{3+} abs.cross section @980nm	σ_{56}	1.4×10^{-26}	m^2
Yb^{3+} emis.cross section @980nm	σ_{65}	3.35×10^{-25}	m^2
Er^{3+} metastable life time	τ_{Er}	11	ms
Yb^{3+} metastable life time	τ_{Yb}	1.3	ms
signal input power	PS	-30	dBm
Signal wavelength	λs	1532	nm
Pump wavelength	λp	980	nm
Up-conversion coefficient	Cup	1×10^{-24}	m^3/s
Scattering loss@980nm	α_p	29.3	dB/m
Scattering loss @1550nm	α_s	37.3	dB/m

Figure (2) shows the gain at 1532nm as a function of ytterbium concentration for increasing erbium concentration .the input signal power is -30dBm , and the waveguide is co directionally pumped with 200mW ,the ytterbium concentration is swept from(1×10^{26} to 2×10^{28}) atoms/m^3 . The strong decrease of the gain if the ytterbium concentration is increased occurs because Ytterbium clusters may form, which means there won't be any energy transference to the Erbium ions, the pump energy will be wasted and is completely absorbed before it reaches the end of the waveguide leading to absorption of the signal.

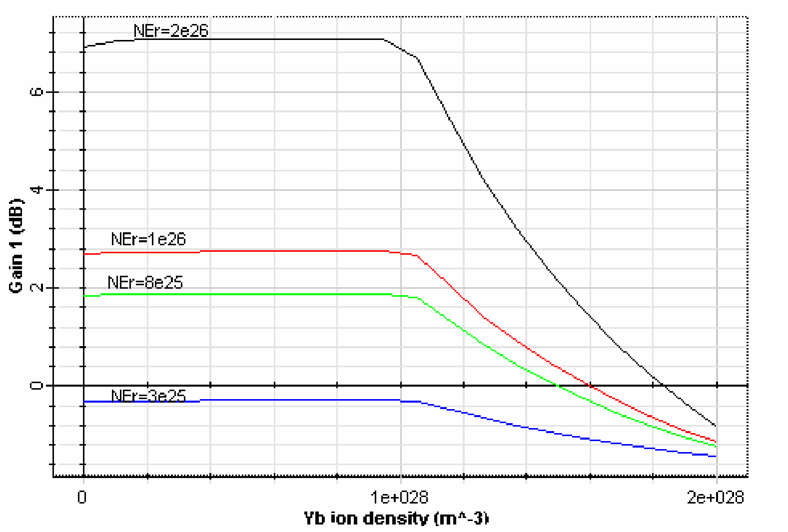

Figure (2) gain as a function of ytterbium concentration, back directional pumping with200mW.

Figure (3) is similar to figure (2) expect that bidirectional pumping is used. the total power is kept 200mW by lunching 100mW in each direction, since the waveguide is pumped from both directions the curve saturate above a certain ytterbium concentration.

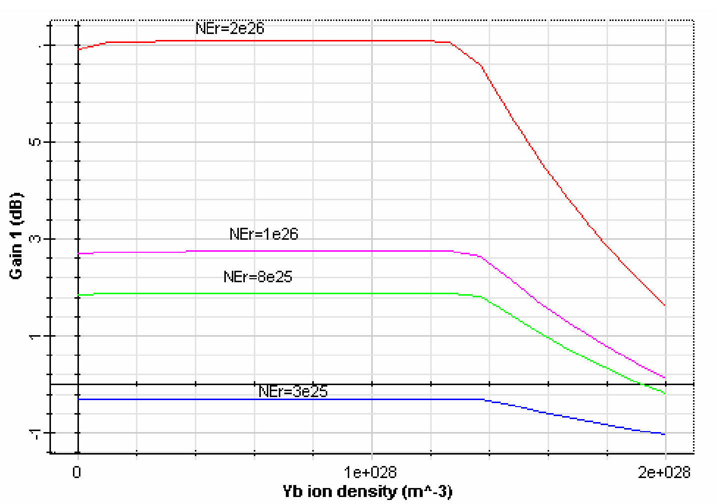

Figure (3) Gain as a function of ytterbium ion concentration, bidirectional pumping with 100mW in each direction

Figure (4-a) shows the gain as a function of the total pump power for the two pumping schemes and Yb concentration of 0 and 1×10^{27} ions/m^3.the erbium concentration is 6×10^{26} ions/m^3.,we see ,that without Ytterbium codoping the gain is not fully saturated at 100mW ,while the gain is saturate at less than 20mW with ytterbium concentration.

A higher gain can be obtained if ytterbium codoping is used since a higher inversion can be obtained with the more efficient pumping provided by the ytterbium codoping.

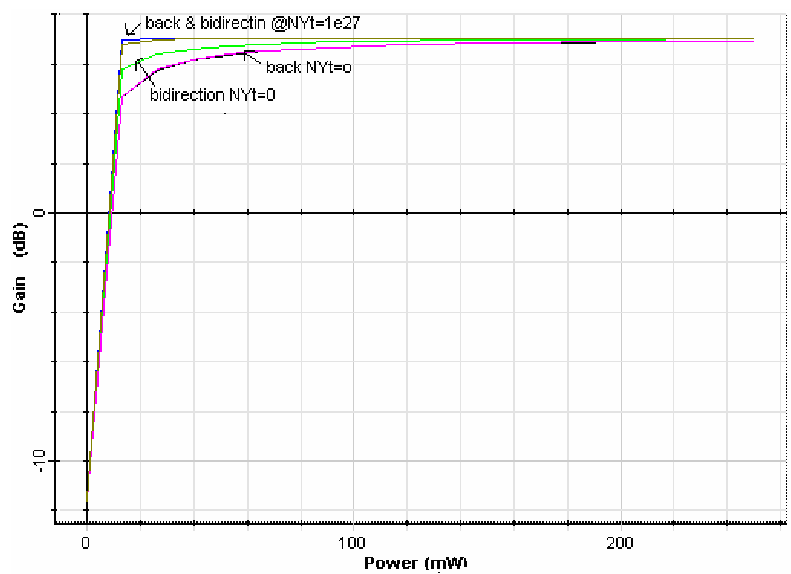

Figure (4-a) gain as a function of pump power

It is also seen in Figure (4-b) that the noise figure decreases faster as a function of pump power for the amplifier codoped with ytterbium when the pump power is the same.

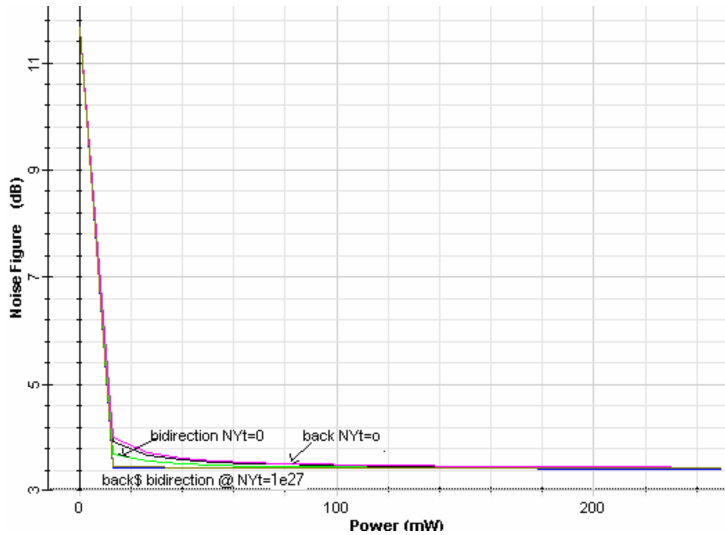

Figure (4-b) Noise figure as a function of pump power with backward and bidirectional pumping

Another important characteristic of optical amplifiers is the amplifier gain dependence on the signal input power, referred to as saturation behavior. The dependence has always a decreasing character. figure (5 and 6) shows saturation behavior for different pump configuration at (0 and 1×10^{27} ions/m^3)ytterbium concentration .the pump power is fixed at 100mW for 1535nm signal wavelength .the signal gains is higher for the amplifiers doped with ytterbium and bidirectional pumped ,this is due to input signal re amplification in the waveguide. However, as the input signal power is increased further the amplifier's gain decreases, this is owed to input signal saturation and can be compensated by increasing the amplifier's pump power.

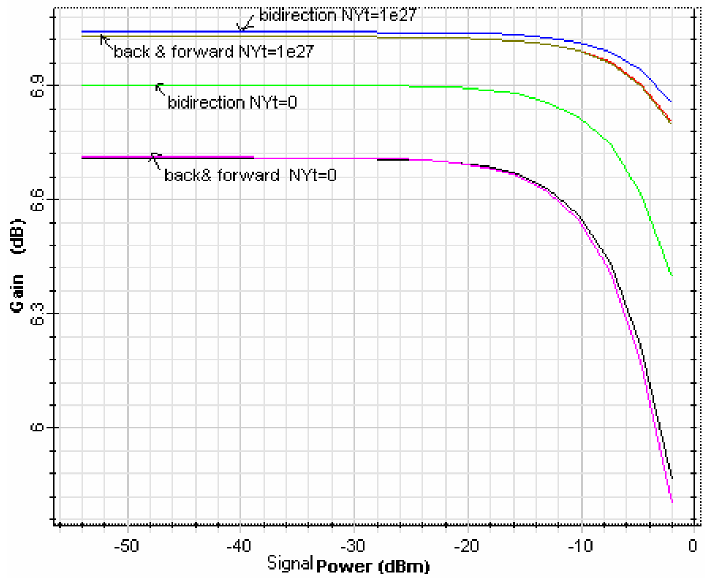

Figure (5) Gain as a function of signal power at different Yb-concentration and pump power configurations

4 CONCLUSIONS

Based on the result of the model simulation were used to estimate the effect of codoping with ytterbium at different pumping configuration for 3cm long amplifier ,it was shown that the gain saturate more above a certain Yb-concentration for bidirectional pumping than backward pumping. Also it is seen that the pump power can be used much more efficiently in an ytterbium codoped amplifier than an amplifier without ytterbium, and the gain of bidirectional pumping amplifier is higher than the amplifier which pumped with unidirectional pumping.

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