Characteristic study of Erbium (Er), Ytterbium (Yb) and Er-Yb Co-doped Optical fiber amplifiers

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We analyze as to how an optical amplifier of different doping ions such as Erbium, ytterbium and Er-Yb co-doped, will respond when its parameters are varied, in terms of its output power in dB. The parameters include the Pump power, doping concentration and the signal power. The results demonstrate that EDFA requires half the amount of pump power than that required for YDFA and further Er-Yb amplifiers help extend EDFA from C-band (1530 – 1565) to L-band (1565nm-1625nm).

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Keywords: Erbium, Ytterbium, Er-Yb co-doped, Doping concentration, Pump and signal power

1. Introduction

One of the most important features that impose a limitation on the transmission distance in an optical communication is the signal loss. Electrical repeaters which require the optical-electrical conversion were employed to compensate for the power loss, but their installation seemed to be costly. Further to overcome these issues the optical amplifiers were introduced. We have done a study about EDFA, YDFA and EYDA. Silica doped with erbium ion can operate in the 1550nm range in which the attenuation of the silica fiber is minimum. When the EDFA is pumped at 1480nm then it is used as a booster amplifier owing to its higher quantum efficiency [1]. Apart from the drawbacks like the excited state absorption and concentration quenching associated with the EDFA, EDFA is the most widely used optical amplifier in the C-band. Further, YDFAs have a simple energy level structure and provides amplification over the wide range of 975nm to 1120nm [2]. YDFA does not suffer from effects like the excited state absorption and concentration quenching thus has a great potential. Its applications include free-space laser communications, and chirped-pulse amplification of ultra-short pulses [3]. Now, with increasing capacity of wavelength division multiplexing systems, the optical amplifiers are forced to supply with higher optical output. Higher optical output means that the system will subjected to non-linear effects like the four wave mixing(FWM) and the cross phase modulation(XPM). To achieve low non-linearity by not degrading the optical amplification efficiency the co-doped amplifiers were employed. The Co-doped amplifiers like the EYDFA use the mechanism of stimulated emission rather than spontaneous emission when compared to EDFA and YDFA. Application includes planar waveguide technologies using sputtered or ion-exchanged waveguides fabricated from high concentration rare-earth doped glasses [4].

2. Ytterbium doped fiber amplifier

In our paper we have kept one or two parameters constant at any instant and varied the other parameter to get the gain variation [5,6]. Initially, we took a YDFA amplifier of length 10m, excited state life time of 0.8 sec., core radius of 2.3μm, Yb ion density of 2.3μm and numerical aperture of 0.4. The input signal sweep ranged from 975nm-1120nm with pump wavelength of 1000nm. Now to study the dependency of gain or output power on the pump power, the pump power was varied between 100mW, 150mW and 200mW.

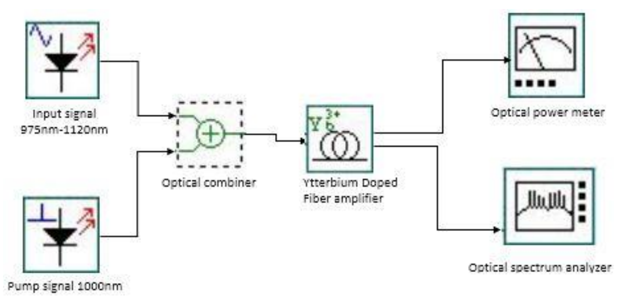

Fig. 1. Depicts the analysis setup with input signal, Pump signal, an optical connector for combining the two signals, YDF amplifier and measurement devises for recording the observation.

2.1 Pump power dependence of YDFA

Fig. 2 clearly depicts the output power dependency on input pump power. It can be seen that as the pump power is increased the gain also increases. The maximum gain value occurs at a particular wavelength of 1036nm, which is determined by the amplifier's parameter set. For the first increase in pump power , (i.e) from 100mW to 150mW the output gain is increased by about 13.5% and for the secong increase from 150mW to 200mW the gain increases by about 8% only. This indicates that, as the pump power is increased, the increase in gain reduces marginally and saturation is attained.

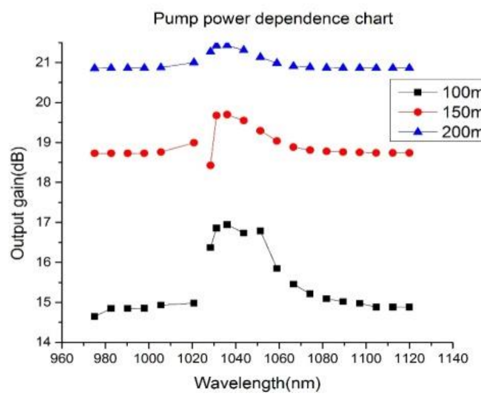

Fig. 2. Gain variations with pump power for YDFA.

2.2 Doping concentration dependence of YDFA

Fig. 3 depicts the dependence of output power on the Yb ions doping concentration. It is observed that when the doping concentration is about 1xe^25 the output power varies with maxima and minima. Now, upon decreasing the doping the concentration to 1xe^23 the shows almost a constant gain throughout the wavelength range thus attaining gain flattening, further the gain attained is also marginally increased. This result establishes the idea that the doping concentration and the output power are inversely proportional.

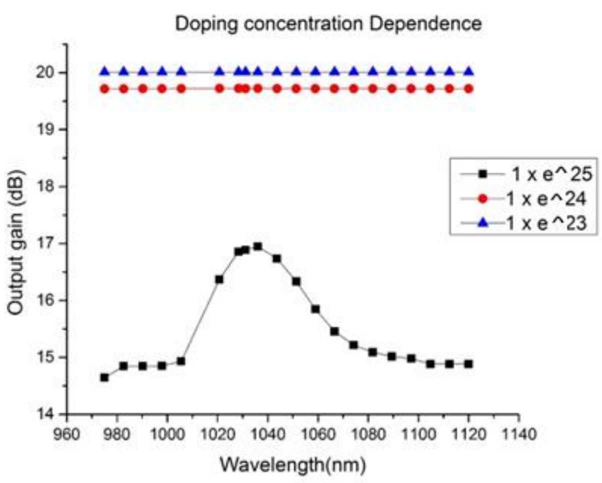

Fig. 3. Gain variations with doping concentration for YDFA.

2.3 Signal power dependence of YDFA

Fig. 4 shows several plots of output gain with varying signal power. It can be seen that as the signal power increases the output gain increases with a low margin for every step. Further for a 1000% increase from 10mW to 100mW the output gain increases only by 22%. On the other hand, the output gain appears to be flattened for the signal power of 100mW. Therefore to attain gain flattening, very high signal power is a prerequisite which is not feasible, since energy supplied is more than the energy transmitted. For applications where there are no bandwidth constraints such as short haul transmissions signal power can be varied to alter the output gain.

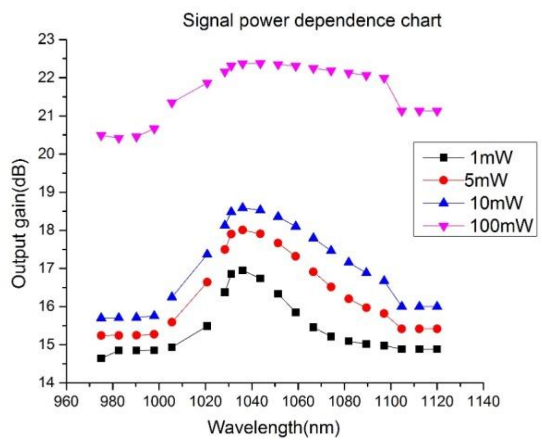

Fig. 4. Gain variations with signal power for YDFA.

3. Erbium Doped Fiber Amplifier

In our paper we have considered the EDFA of length 10m, Er ions with metastable life time of 10ms, core radius of 2.2μm, Er doping radius of 2.2μm, initally Er ion density of 1×e^25 and numerical aperture of 0.24. We have taken a lossless ideal amplifier which responds only to parameter variations. The input signal sweep is ranged between 1530nm-1565nm of the C-band. The pump power wavelength is to about 980 nm which is suffiecient to achieve the required population inversion. Fig. 5 shows the EDFA analysis setup used.

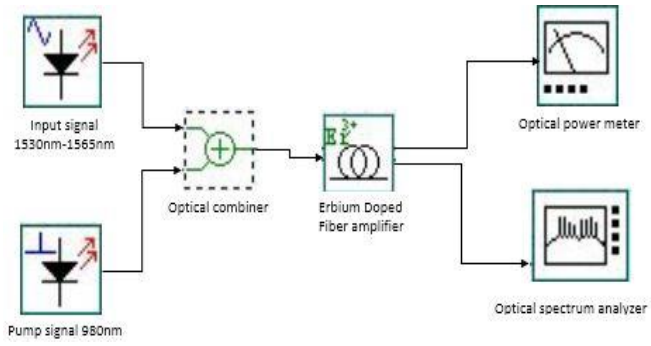

Fig. 5. EDFA analysis setup.

3.1 Pump power dependence of EDFA

Fig. 6 represent the variation of the EDFA output power with the varying pump power. The EDFA exprementally proves to provide the most stable gain flattened amplifer compared to the YDFA. It can be observed from the graph that the gain appers to almost constant for the entire ampplification range. Further, increasing the pump power increases the output gain accordingly. Also, the gain flattening character of EDFA is observed at all the pump power supplied indicating that manipulating the required output gain for a specific application is achievable in EDFA.

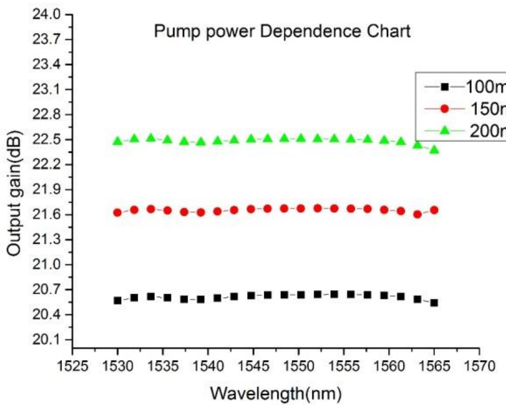

Fig. 6. Gain variations with pump power for EDFA.

3.2 Doping concentration dependence of EDFA

Fig. 7 depicts the output gain of EDFA's dependence on the doping concentration. The graph clearly indicates that the doping concentration and the output gain are inversely proportional. When the doping concentration is to about 1×e^25 the gain varies with maxima and minima making the amplifier prone to instability and noise. Further, upon decreasing the doping concentration to 1×e^23 the output gain is almost flattened and the gain is reduced by 3% only.

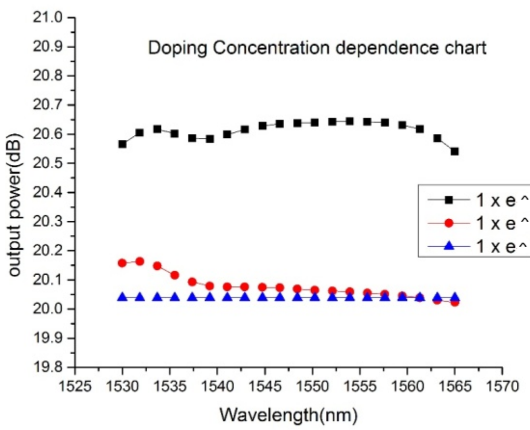

Fig. 7. Gain variations with doping concentration for EDFA.

3.3 Signal power dependence of EDFA

Fig. 8 can be used to observe the signal power dependence. The graph shows output gain values for drastically ranged signal power values. Signal power of 1mW is observed to the most optimal value owing to the constant gain throughout the wavelength range. When the signal power is increased or decreased the output gain is found to have instability with maxima and minima. For a 1000% increase in signal power from 10mW to 100mW the output gain increases by just 46% approximately. Thus altering the output gain using the signal power is not an energy efficient solution.

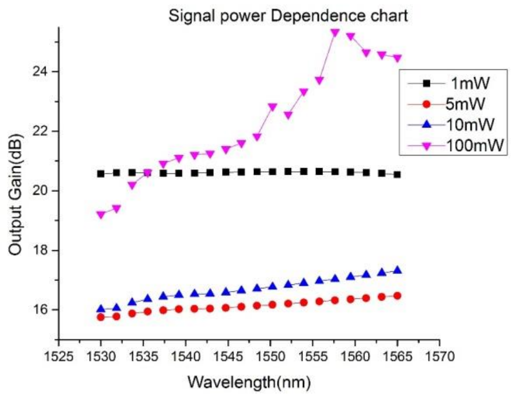

Fig. 8 Gain variations with signal power for EDFA.

4. EYDF amplifier

In our paper we have optimized the EYDF parameters for efficient utilization of the entire bandwidth [7,8,9,10]. The parameters include Input Power of 0.02mW, Input Power Wavelength of 1530nm, Pump power of 200mW, Pump power Wavelength of 980nm, Er density of 2× 10^26/meter cube, Yb density of 2×10^27/meter cube, Er-Yb Waveguide Length of 2 meters. Fig. 9 shows the EYDF setup used for analysis.

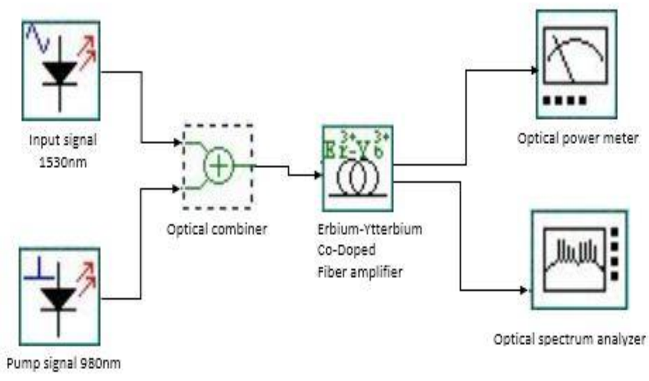

Fig. 9. EYDF analysis setup.

4.1 Optimization of Er ion doping concentration

For the EYDF we used only single valued input signal wavelength for optimization of specific parameters. Fig. 10 shows that for a specific optimized wavelength of 1530nm several values for the Er ion density against the output gain was plotted. The gain was found to be maximum when the Er ion density was 2×10^26/meter cube. Thus for maximum gain, the optimized value of Er ion density is 2 × 10^26/meter cube.

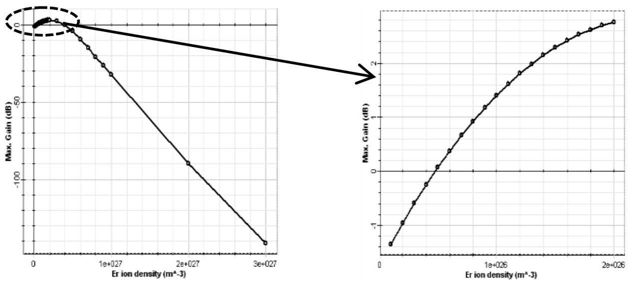

Fig. 10. Interpretation of the Gain vs. Er ion density graph for obtaining the optimized density value.

4.2 Optimization of EYDF waveguide length

Fig. 11 illustrates the results graphed for the optimization of the length of the Waveguide. It can be observed that the gain of the EYDF drops drastically at 1m and the gain maxima is attained well before that. Now upon further decimation of the length for optimized value it is found that the maximum gain occurs at the optimized length of 0.2m. The optimized parameter values of YDFA, EDFA and EYDFA are shown in Table 1.

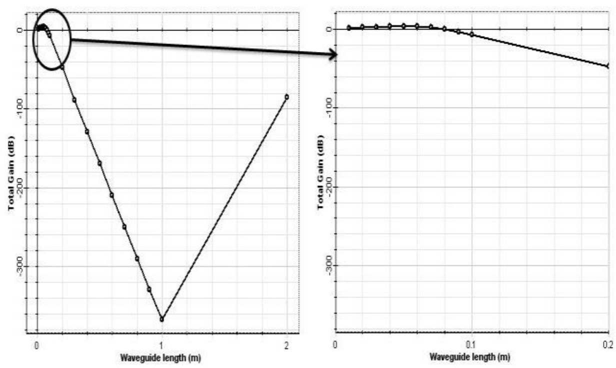

Fig. 11. Interpretation of Gain vs. Waveguide length for obtaining the optimized wavegiude length.

Table 1. Optimized parameter value.

PARAMETER	YDFA	EDFA	EYDFA
Input Power	1mW	1mW	0.02mW
Amplifier length	10 m	10 m	2m
Pump wavelength	1000nm	980nm	980nm
Pump Power	100mW	100mW	200mW
Er Ion density	NA	1xe+23	2xe+26
Yb ion density	1xe+25	NA	2xe+27

4.3 Optimization of Yr ion concentration, Pump power and signal power

Fig. 12, Fig. 13 and Fig. 14 illustrates the Graphs plotted for the optimization of the Yb ion density, the Pump power and the signal input power respectively. Similar to the other two techniques the values were further decimated to get the exact optimized values at which the output gain is maximum is each individual case. Following this procedure the optimized values for the Yb ion density, pump power and the signal power were found to be Yb density of 2x 10^27/meter cube, Pump power of 200mW and signal power was 0.02mW respectively.

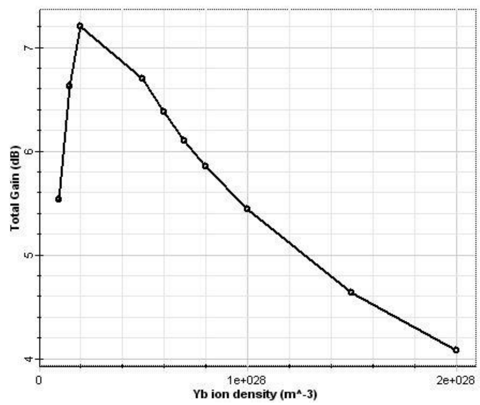

Fig. 12. Gain dependence on Yr ion concentration for EYDF amplifier.

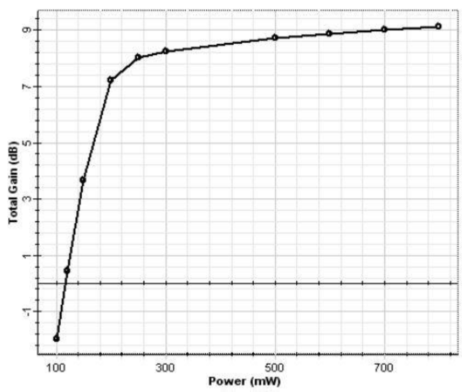

Fig. 13. Gain dependence on Pump power for EYDFamplifier.

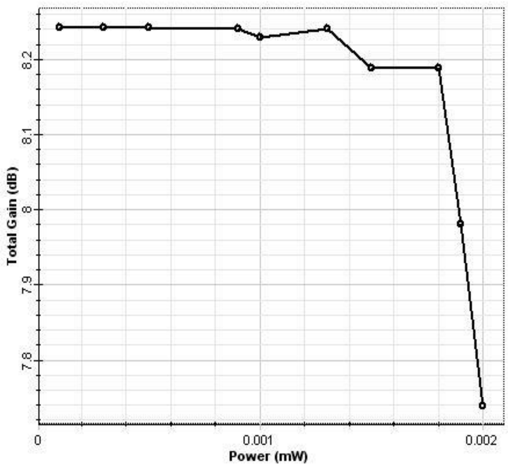

Fig. 14. Gain dependence on signal power for EYDF amplifier.

5. Conclusions

The results we have optimized denote that the EYDF is the best amplifier among EDFA and YDFA owing to its vast bandwidth handling capability and extending the efficiency of EDFA from C-band to L-band .Moreover the input power required for EYDFA is small as we use small length waveguide which makes the system more compact. Also EYDFA finds huge application in integrated photonic circuit comparative to EDFA and YDFA in efficient amplification with small waveguide length.

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