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Parametric Study for Different Er3+/Yb3+ Fiber Samples Based on a Computer Model for Diode Pumped Fiber Laser

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Abstract: In this paper the Erbium-Ytterbium (Er^{3+}/Yb^{3+}) co-doped fiber laser pumped by a laser diode is simulated using the Optiwave software. The proposed model is introduced and was used to perform a parametric study on four different samples of Er^{3+}/Yb^{3+} fiber A, B, C, and D differ in their core diameters and their numerical apertures. The study was done in terms of fiber length, cutoff length, output mirror reflectivity, slope efficiency, and lasing threshold. The simulation results demonstrated that the optimum fiber length is 2 m, 0.5 m, 1.7 m, and 2.3 m for type A, B, C, and D respectively. The max achieved power is 3.15 w for type C at the optimum fiber length. The cut off length is 2.1m, 1.8m, 1.9m, and 2.4m for type A, B, C, and D respectively. Max. optical power of 3.15 w at 40 % reflectivity for type C fiber. Lowest lasing threshold level is 140 mw for type D. The highest slope efficiency is 73% for type C.

1. Introduction

Fiber laser uses optical fiber doped with rare-earth elements such as erbium, ytterbium, neodymium, and thulium as a gain medium. Fiber laser offers many advantage over other types, it can have active regions several kilometers long and can provide very high optical gain with high-quality optical beam. Fiber lasers are compact compared to rod or gas lasers of comparable power, also fiber lasers exhibit high vibrational stability and extended lifetime. The shape of an optical fiber laser reduces the thermal loading density and is good for heat-sinking. Optical fiber doped with Erbium Er^{3+} has been developed for use in lasers. These devices are of considerable importance since they operate in the third window for the optical fiber communications around 1550 nm. The Er^{3+} doped fiber is laser diode pumped around 810 nm. The operating wavelength of a laser diode is temperature dependent and the absorption of Er^{3+} in silica is spectrally narrow a shown in figure (1), fluctuations in temperature will lead to change in performance of the fiber laser. Another trouble with erbium, is that it is not particularly soluble in the primarily silica core of an optical fiber. Solubility is improved significantly by modifying this mold through the addition of alumina but this may makes the core with opaque crystalline characteristics. One solution for this problem is to sensitize the fiber by co-doping erbium Er^{3+} with ytterbium Yb^{3+}. Unlike erbium, ytterbium is highly soluble in optical fiber core with the result that single mode absorption figures as high as a thousand dBs per meter or greater may be achieved. The unique shape of the ytterbium absorption spectrum also offers significant advantages over erbium. Erbium typically needs wavelength-stabilized, thermo electrical cooled pump diodes, to lock the pump diode onto one or other of its narrow absorption peaks, whereas ytterbium provides a much flatter wide absorption wavelengths band around 940 nm as shown i n figure (1). This wide absorption band can enable the use of un-cooled pump lasers reducing

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costs and power consumption and enhancing overall system reliability. The addition of Ytterbium to an Erbium doped fiber increases the pump absorption by 2 orders of magnitude. This allows shorter fiber lasers to be constructed, which reduces the cavity round trip time and also the duration of the output of the Q-switched pulse [3]. Ytterbium on its own generates gain close to 1100 nm and must be co-doped with Erbium in order to shift this gain into the third telecoms window around 1550 nm. The recent development of diode arrays in 980 nm range radically improved the pumping schemes of the fiber lasers [4].

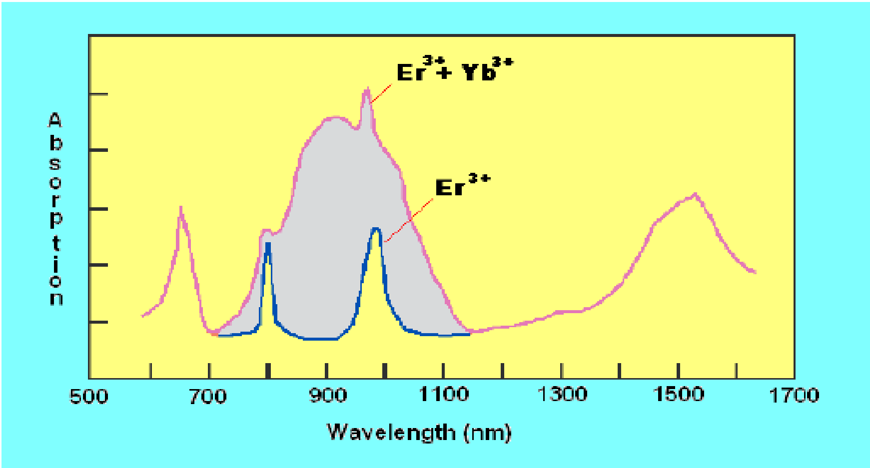

Figure (1) Erbium-Ytterbium (Er^{3+}/Yb^{3+}) absorption spectrum

2. Proposed Fiber Laser Setup

Fiber lasers technology has grown rapidly due to the rapid advances in high power diodes, diode-to-fiber coupling schemes and doped fiber design and fabrication. Erbium-Ytterbium (Er3+/Yb3+) co-doped fiber is an attractive active medium for the fiber lasers in which Ytterbium is co-doped with Erbium to produce a spectrum in third telecoms window around 1550nm which makes them suitable sources for long range applications. Rare-earth doped fibers offer a simple and performance-scalable way of amplifying low-power laser sources to high power while maintaining the optical parameters and beam quality. In addition to ultrashort pulse lasers, these also include Q-switched lasers and continuous sources. An average power of several kW range is possible. With their temporal dynamics, ultrashort laser pulses are of outstanding importance for various interdisciplinary applications that require high capacity such wavelength division multiplexed (WDM) systems [5]. Short pulse durations help to achieve high intensities, and non-linear optical processes can be particularly effectively operated to exploit new wavelength ranges. With the high quality of the generated structures, micromaterials processing also benefits from the use of ultrashort pulses. Fiber laser systems on the basis of ytterbium are excellently suited to generating and amplifying ultrashort laser pulses. The amplification bandwidth supports pulse durations of a few hundred femtoseconds. In addition, the use of special fibers with very large core diameters enables the amplification of the pulses to energies up to the milli joule range. The beam quality remains excellent. This is of key importance for many applications. Our proposed Erbium-Ytterbium Er^{3+}/Yb^{3+} co-doped fiber laser is shown in Figure (2). The pump source is a laser diode operating at 980 nm, the beam is collimated and then passed through an optical isolator to prevent back reflections from the fiber ends damaging the laser diode. The pump radiation is focused into the Er:Yb fiber through an input mirror, which is 98% reflecting at 1550 nm and 99% transmitting at 980 nm. A length of 0.1 m of Er:Yb fiber is suggested with an N.A. of 0.22. and the output mirror is 50% reflecting at 1550 nm.

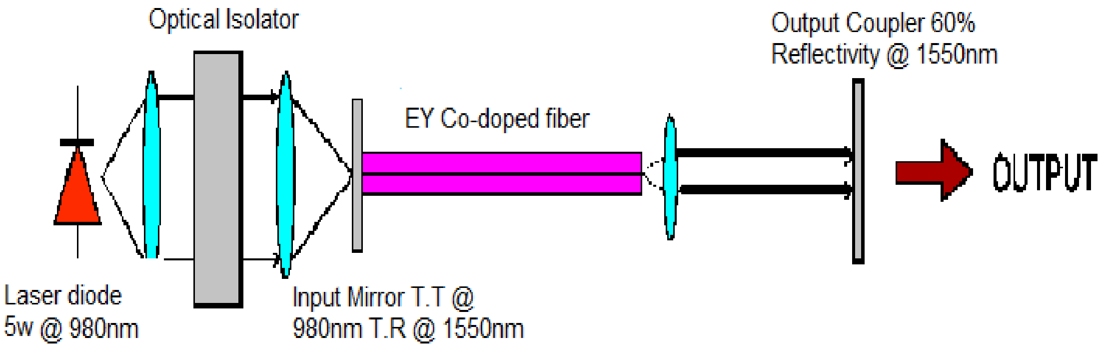

Figure (2) Erbium-Ytterbium Er^{3+}/Yb^{3+} co-doped fiber laser

3. Simulation Work

CAD tools allow creating, executing and analyzing complex experiments within one, easy to use, CAD driven platform. Comprehensive content can be designed, viewed and analyzed to reach the suitable design that should be implemented. OptiSystem allows optical component and system design engineers to determine the tradeoffs for Er^{3+}/Yb^{3+} co-doped fiber laser. Evaluate cost and performance by calculating how metrics such as minimum output power, maximum noise figure, maximum gain ripple, and minimum pump power depend on device specifications such as pump wavelength range, passive component losses, component costs and much more. The component library includes single or double-clad fibers, static and dynamic amplifiers. Fig. (3) Shows the simulation setup for Er^{3+}/Yb^{3+} co-doped fiber laser using OptiSystem software. Er^{3+}/Yb^{3+} fiber laser is pumped by a laser diode at 980 nm [1].

The pump source was swept to generate a continuous wave (CW) optical signal. The pump radiation was focused into the Er^{3+}/Yb^{3+} fiber through an input mirror which is a bidirectional reflector, with wavelength dependent reflection and insertion loss. Two optical delays were

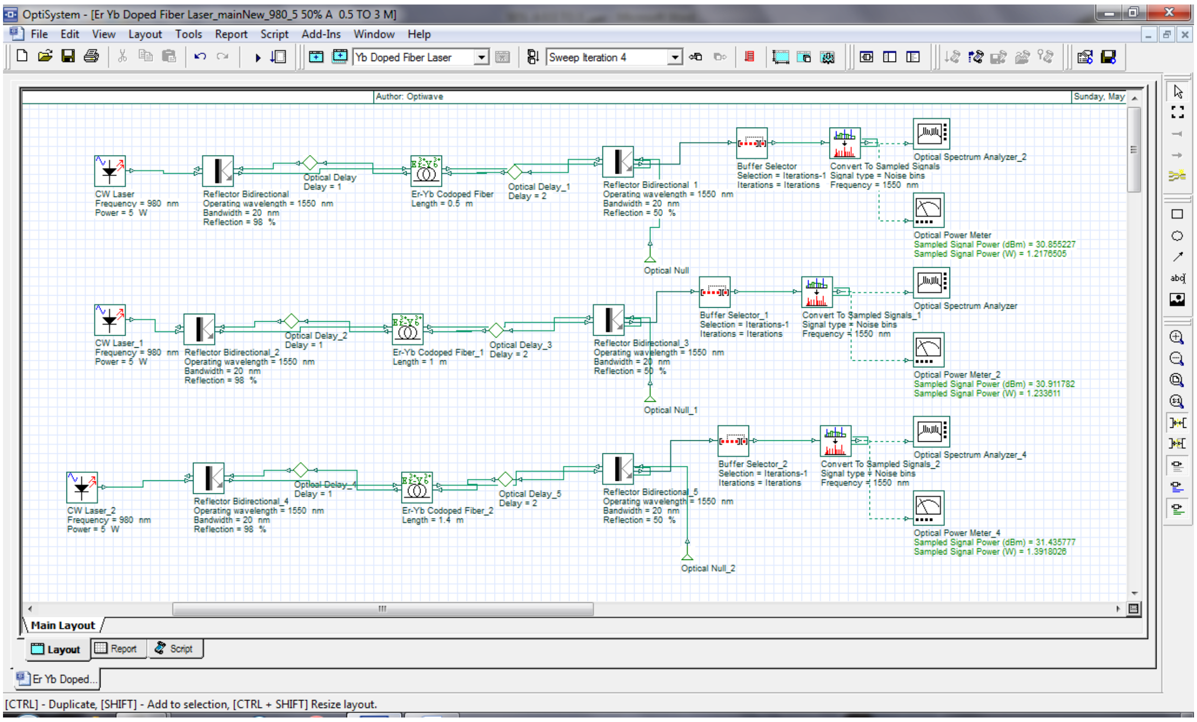

Figure (3) OptiSystem simulation setup

used in the setup to generate optical signal delay to enable the simulation. A suitable length of Er^{3+}/Yb^{3+} fiber was used, Er^{3+}/Yb^{3+} codoped fiber component simulates a bidirectional Erbium-Ytterbium codoped fiber, it solves numerically the rate and propagation equations for the steady-state case and can take into account nonlinear phase changes by propagating the signal using the nonlinear Schrödinger equation. Buffer selector was used to allow the selection of one of the signals from the input buffer. Convert to sampled signals was used to convert parameterized signals or noise bins into sampled signals. Measuring tools such as optical spectrum analyzer and optical power meter were used to monitor the results.

The proposed model was used to compare various fiber types A, B, C, and D with parameters shown in Table (1).

Table (1) Fiber types under test

TYPE	N.A	Core diameter (μm)	Cladding diameter (μm)	E_r ion density	Y_b ion density
A(E_rY_b)	**0.22**	**5**	**124.7**	**2.54E+43**	**3.20E+26**
B(E_rY_b)	**0.2**	**31.6**	**124.7**	**2.54E+43**	**3.20E+26**
C(E_rY_b)	**0.24**	**19.3**	**124.7**	**2.54E+43**	**3.20E+26**
D(E_rY_b)	**0.14**	**4.8**	**124.7**	**2.54E+43**	**3.20E+26**

3.1 Output Optical Power vs. Fiber Length

The above setup shown in Fig. (3) was used to examine the optical power vs. fiber length. The fiber length was swept from 0.5 to 2.4 m and the optical power was recorded. Type A fiber shows max. optical power of 1.68 w at 2 m fiber length, Type B fiber shows max. optical power of 2.6 w at 0.5 m fiber length, Type C fiber shows max. optical power of 3.15 w at 1.7 m fiber length, and Type D fiber shows max. optical power of 1.4 w at 2.3 m fiber length. The cut off fiber length was found to be 2.1 m, 1.8 m, 1.9 m, 1nd 2.4 m for type A, B, C, and D respectively. Table (2) and figure (4) summarize the above results.

Table (2) Output optical power vs. fiber length

L (m)	Output optical power (w)			
	TYPE A	TYPE B	TYPE C	TYPE D
0.5	1.213	2.608	2.775	0.969
1	1.243	2.186	2.899	1.13
1.7	1.42	1.366	3.150	1.139
1.8	1.5	0	2.599	1.16
1.9	1.497	0	0	1.19
2	1.685	0	0	1.236
2.1	0	0	0	1.247
2.2	0	0	0	1.312
2.3	0	0	0	1.403
2.4	0	0	0	0
L_{cutoff} (m)	2.1	1.8	1.9	2.4

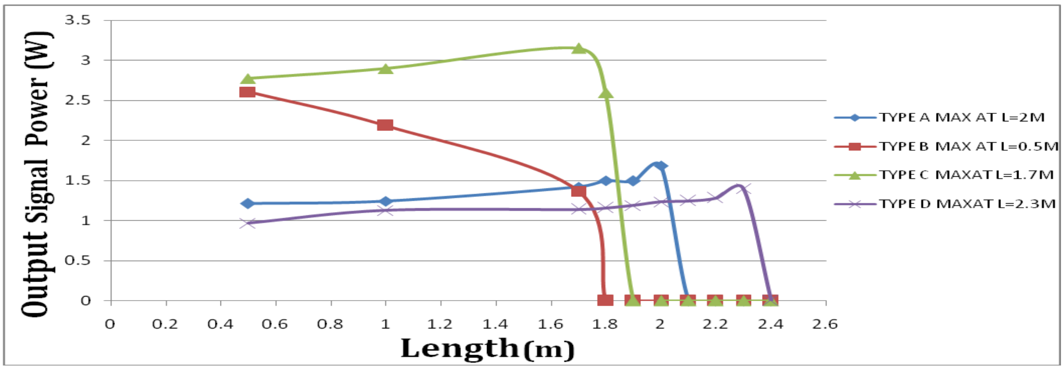

Figure (4) Output optical power vs. fiber length

3.2 Output Optical Power vs. Reflectivity

The mirror reflectivity was swept from 10 to 80% and the optical power was recorded. Type A fiber shows max. Optical power of 1.68 w at 50 % reflectivity, type B fiber shows max. optical power of 2.6 w at 50 % reflectivity, Type C fiber shows max. optical power of 3.15 w at 40 % reflectivity, and Type D fiber shows max. optical power of 1.4 w at 60 % reflectivity. Table (3) and figure (5) summarize the above results.

Table (3) Output optical power vs. mirror reflectivity

R%	TYPE A	TYPE B	TYPE C	TYPE D
10	0.728	1.856	1.881	0.589
20	0.813	2.1	2.33	0.812
30	0.966	2.178	2.704	0.962
40	1.149	2.2	3.15	1.062
50	1.685	2.608	2.908	1.103
60	1.265	2.103	2.899	1.403
70	1.185	1.83	2.71	1.072
80	1.05	1.49	2.246	0.901

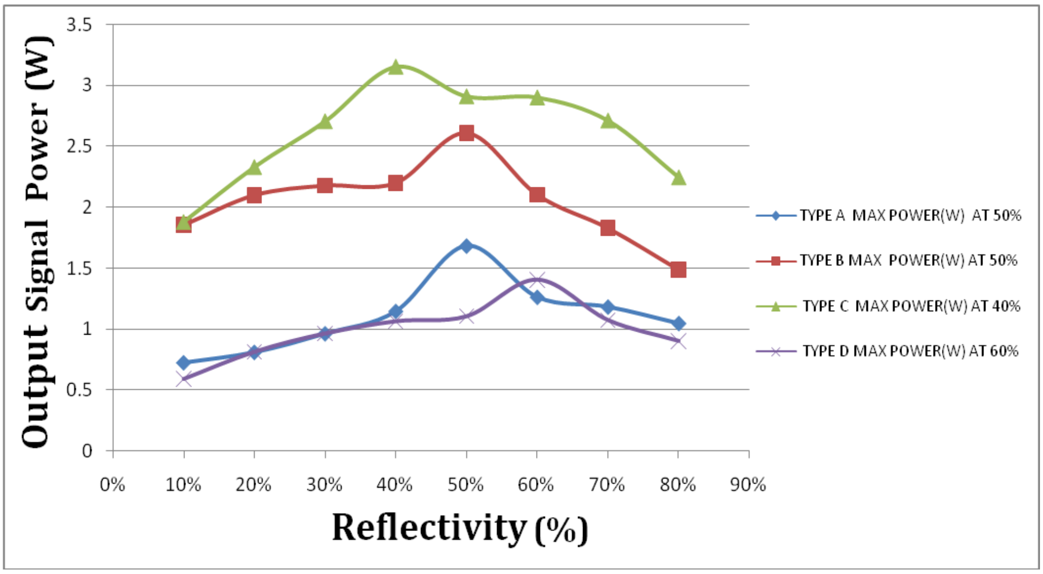

Figure (5) Output optical power vs. mirror reflectivity

3.3 Output Optical Power vs. Input Power (Slope Efficiency)

The input power was swept from 0.2 to 5 w and the output optical power was recorded. Type A fiber shows slope efficiency of 31% with a lasing threshold level of 160 mw, Type B fiber shows slope efficiency of 61% % with a lasing threshold level of 1250 mw, Type C fiber shows max. a slope efficiency of 73% % with a lasing threshold level of 600 mw, and Type D fiber shows slope efficiency of 25% % with a lasing threshold level of 140 mw. Table (4) and figure (6) summarize the above results.

Table (4) Output optical power vs. Input power

I/P POWER	TYPE A S.E= 31%	TYPE B S.E= 61%	TYPE C S.E= 73%	TYPE D S.E= 25%
0.05	5.4E-13	2.3E-17	5.1E-13	0.00000053
0.1	6.3E-10	5.4E-13	8.7E-12	0.0006
0.2	9.99084E-06	4E-12	3.5E-09	0.100962
0.5	0.221364572	2.71097E-09	1.94373E-06	0.25831
1.25	0.613159584	0.000359	0.20472	0.502106312
2.5	1.027962769	0.906262515	0.835850202	0.830840993
3.75	1.397687521	1.809812621	2.033590855	1.123355476
5	**1.685584318**	**2.608633421**	**3.150530007**	**1.403710447**
$P_{LTS.(mw)}$	**160**	**1250**	**500**	**140**

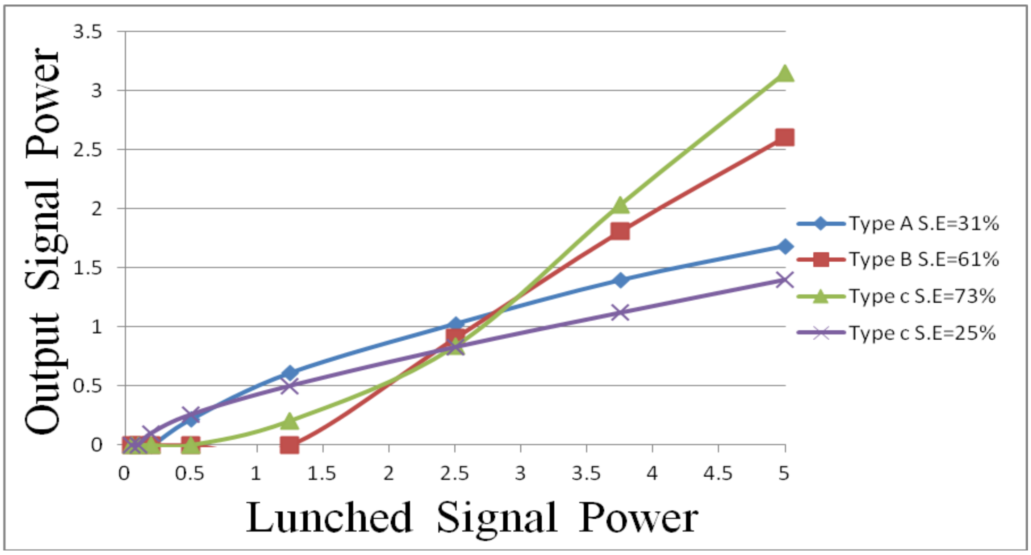

Figure (6) Output optical power vs. Input power

4. Conclusions

Er^{3+}/Yb^{3+} fiber laser pumped by a laser diode at 980 nm was simulated using the Optiwave software. Laser signal at 1550 nm was generated; the system was used to evaluate the performance of four different samples of Er^{3+}/Yb^{3+} fiber A, B, C, and D differs in their core diameters and their numerical apertures. The simulation results showed the optimum fiber length of each type, also the max achieved power, the cut off length, the lasing threshold level and the slope efficiency for each type was identified.

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