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Simulation and Computer Modeling of a Diode pumped Erbium-Ytterbium (Er^{3+}/Yb^{3+}) Co-doped Fiber Laser

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Abstract:

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 (Er^{3+}/Yb^{3+}) 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. In this paper the Er^{3+}/Yb^{3+} fiber laser pumped by a laser diode at 980 nm is simulated using the Optiwave software. The pump source was swept from 1.25 to 5 w to extract the slope efficiency. The pump radiation was focused into the Er^{3+}/Yb^{3+} fiber through an input mirror, which was 98% reflecting at 1550 nm and 99% transmitting at 980 nm. A length of 0.1 m of Er^{3+}/Yb^{3+} fiber was used with an N.A. of 0.22, Er^{3+} ion density of 25.4 x 10^{24} m^{-3}, and Yb^{3+} ion density of 320 x 10^{24} m^{-3}. The output mirror was 50% reflecting at 1550 nm. Then the length of the fiber was swept from 1m to 5m in order to obtain optimized fiber length. The simulation results demonstrated that a laser output power of 0.8 W was obtained at 1550 nm for a launched power of 2 W with a slope efficiency of 40% and a lasing threshold of 0.4 W of launched pump power. The results also showed that the optimized fiber length was achieved at 2 m which is in a good agreement with the published similar experimental schemes.

1- Introduction:

Fiber laser is an acronym for the laser that uses the optical fiber as active gain medium, the used optical fiber doped with rare-earth elements such as erbium, ytterbium, neodymium, and thulium. 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 waveguiding further safeguards against thermal distortion of the lasing field even at high powers. For these reasons, fiber lasers can be power-scaled without the reduction of efficiency and brightness that are common problems for conventional "bulk" lasers [1]. 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 singlemode 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 in figure (1). This wide absorption band can enable the use of un-cooled pump lasers reducing 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 [2]. 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 [3].

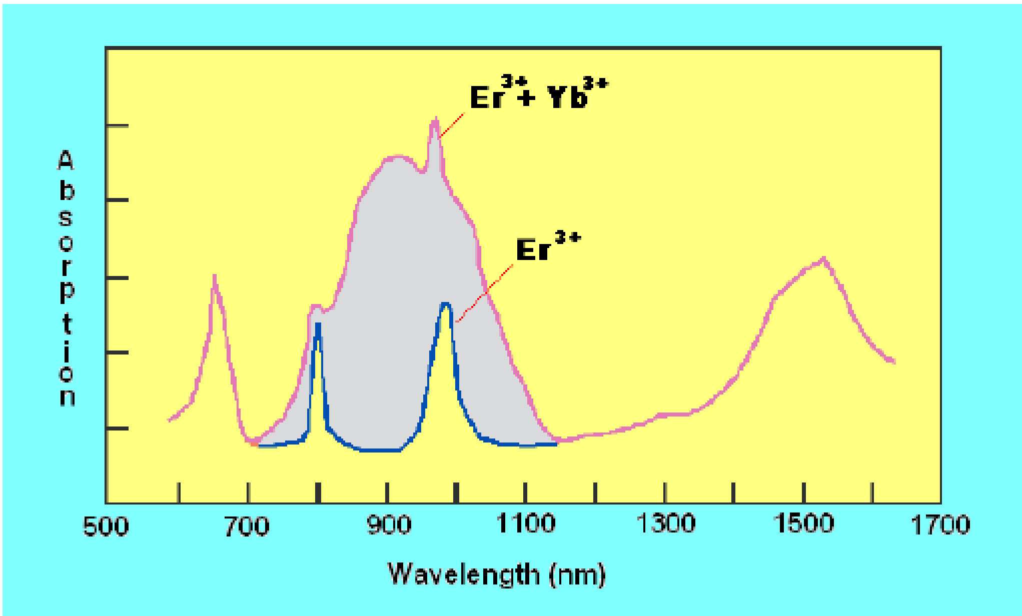

Figure (1) Erbium-Ytterbium (Er^{3+}/Yb^{3+}) absorption spectrum

2- Proposed fiber laser setup:

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 [4]. 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 millijoule 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.

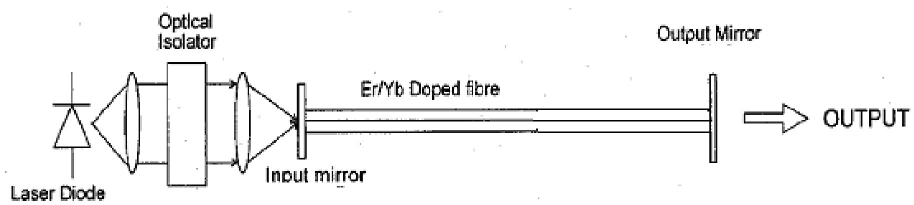

Figure (2) Erbium-Ytterbium Er^{3+}/Yb^{3+} co-doped fiber laser

3- <u>Simulation work:</u>

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. The pump source was swept from 1.25 to 5 w. CW laser generates 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. The mirror was 98% reflecting at 1550 nm and 99% transmitting at 980 nm. Two optical delays were used in the setup to generate optical signal delay to enable the simulation. A length of 0.1 m of Er^{3+}/Yb^{3+} fiber was used with an N.A. of 0.22, Er^{3+} ion density of 25.4 x 10^{24} m^{-3}, and Yb^{3+} ion density of 320 x 10^{24} m^{-3}. 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. The output mirror was 50% reflecting at 1550 nm. 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.

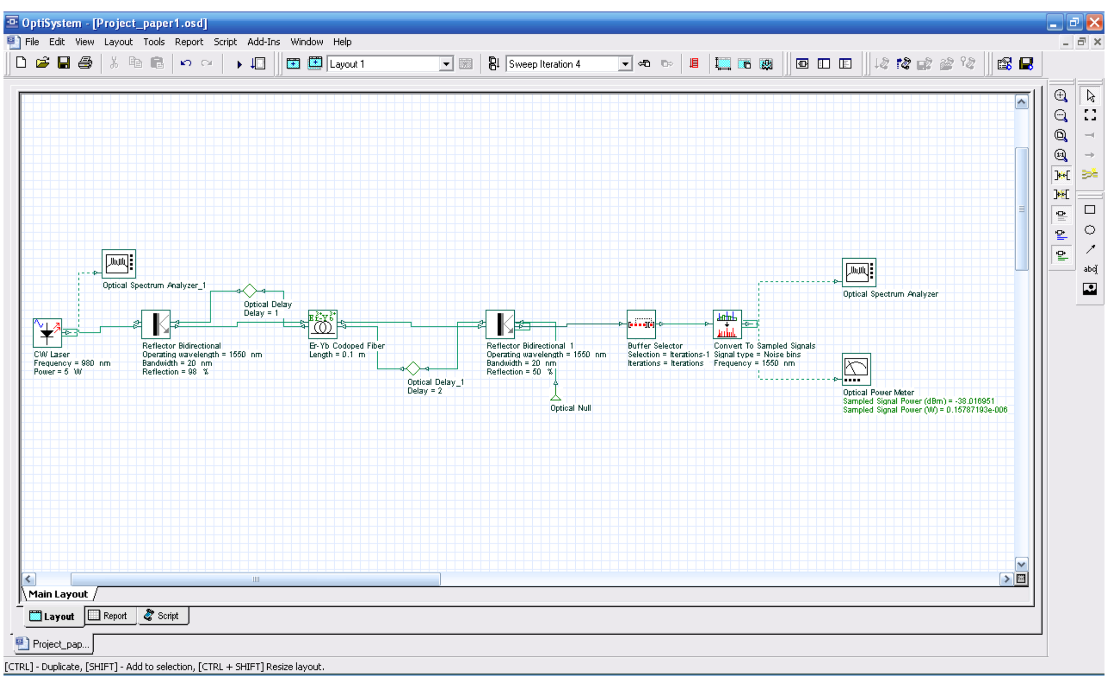

Figure (3) OptiSystem simulation setup for Er^{3+}/Yb^{3+} co-doped fiber laser

Another simulation setup for Er^{3+}/Yb^{3+} co-doped fiber laser is shown in Figure (4) in which the length of the fiber was swept from 1m to 5m in order to obtain optimized fiber length.

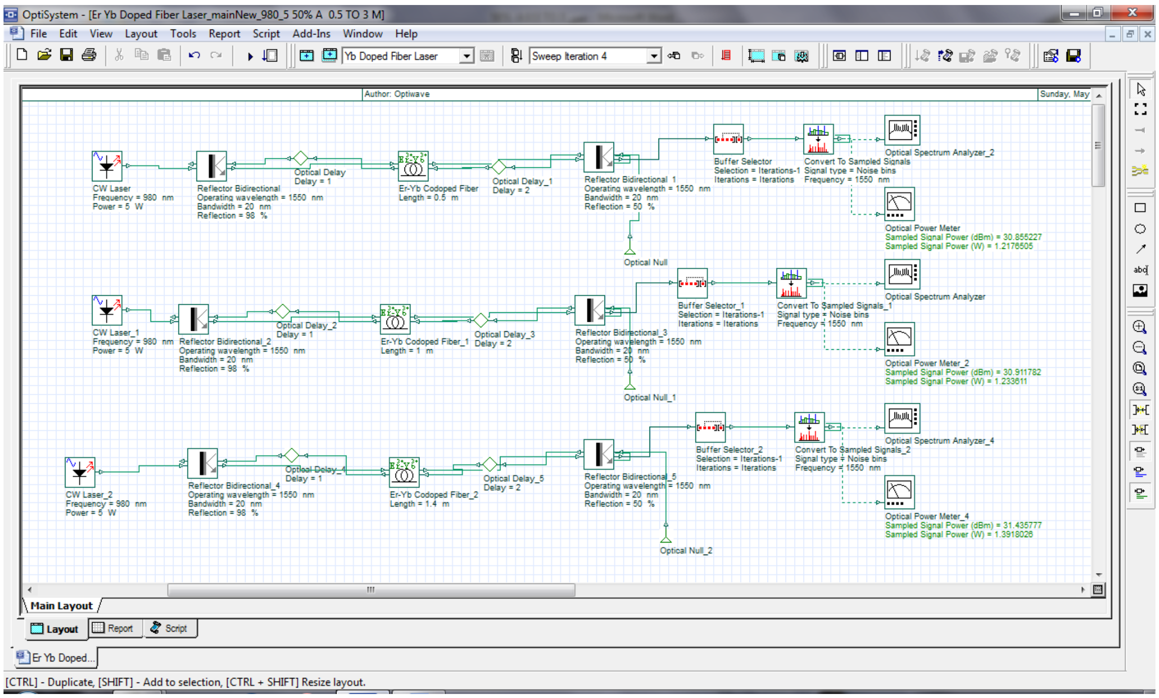

Figure (4) OptiSystem simulation setup for different fiber lengths

4- Results Analysis:

Figure (5) shows the simulation results, it illustrates the laser output vs. the pumping power (slope efficiency). A CW power of 0.8 W at 1550 nm is demonstrated for a launched power of 2 W with a slope efficiency of 40%. A CW lasing threshold of 0.4 W of launched pump power was achieved. Figure (6) shows the spectrum of the generated laser signal at 1550 nm using the built in Optisim spectrum analyzer. Fig. (7) Shows the simulation results for laser output vs. the pumping power for different fiber lengths. The results indicated that the length of 2 m gives the best slope efficiency. Beyond this length, the performance starts to degrade.

5- 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 achieved slope efficiency of 40% and the threshold level was 0.4 w. Using the simulation, the optimized fiber length was found to be 2 m beyond this length the laser output starts o degrade.

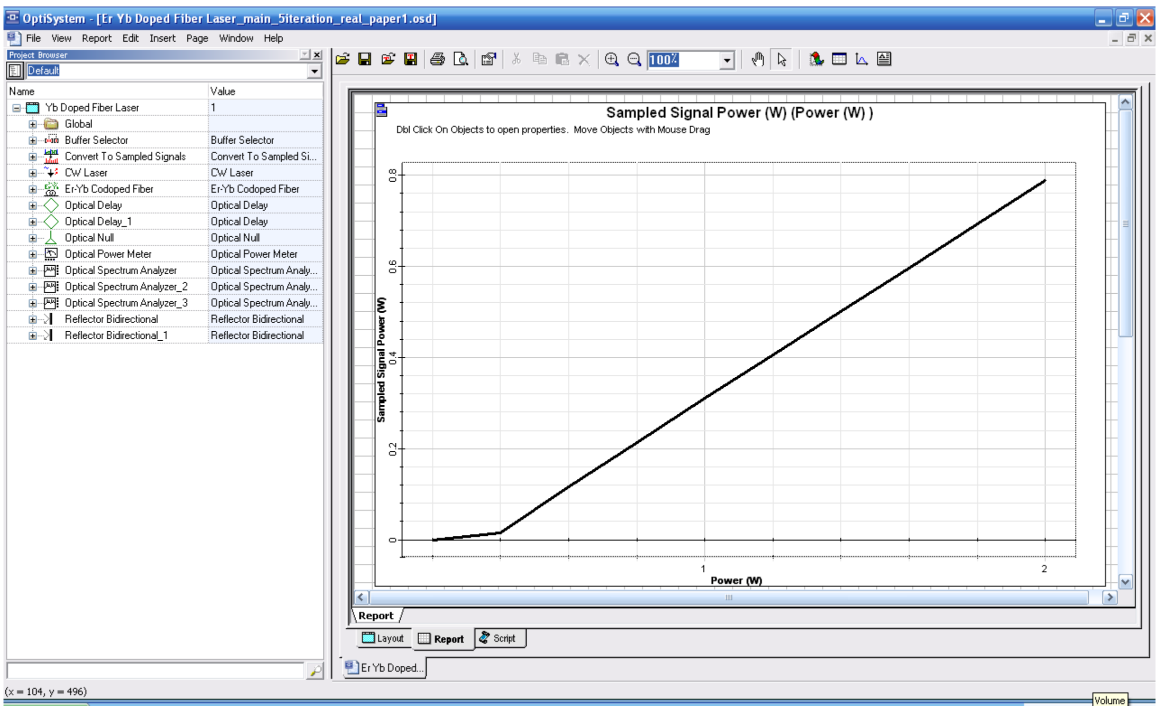

Figure (5) shows the simulation results

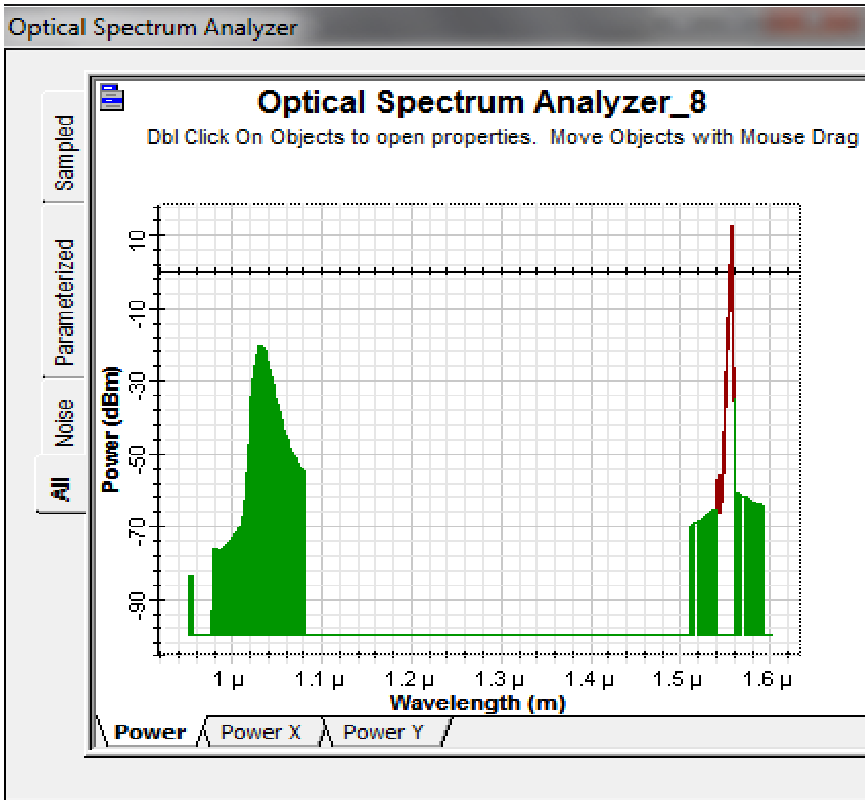

Figure (6) Generated laser signal at 1550 nm using

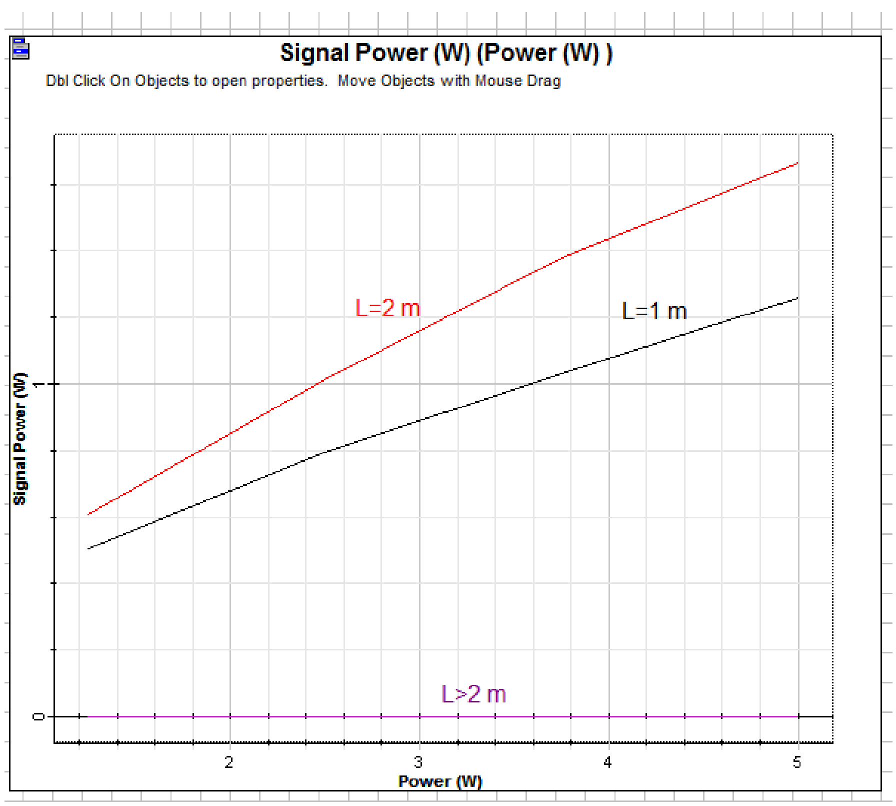

Fig. (7) Simulation results for laser output for different fiber lengths

6- References:

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