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High Output Power Er^{3+}/Yb^{3+} Co-doped Optical Amplifiers Pumped by Diode-Pumped Nd^{3+} Lasers

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Introduction:

As the erbium-doped optical fiber amplifier has gained acceptance in the telecommunications industry, the majority of attention has focussed on the choice of the semiconductor pump source, especially with regards to lifetime and power scalability. High output power erbium optical amplifiers have been demonstrated with both 980 and 1480 nm pump diodes. However there are serious questions regarding power scalability once more than two pump diodes are required. A +22.3 dBm output power amplifier has been reported using four 1480 nm pump diodes[1]. This configuration however required the use of polarization preserving diode pigtails and bulk polarization combining optics, which had a high insertion loss and introduced non-negligible reflections in the amplifier system.

We have recently demonstrated an efficient Er/Yb energy transfer system in a phosphorus-doped silica fiber[2]. This allows us to pump on the long-wavelength edge of the broad Yb^{3+} absorption with diode-pumped Nd^{3+} lasers (DPL's). The advantages of using a DPL as a pump source are the use of mature, efficient, and high-power AlGaAs diode laser arrays, the high output beam quality, and the power scaling advantage. The DPL is an efficient brightness converter and has allowed us to couple powers in excess of 1 Watt into single-mode fiber. Unlike direct diode excitation, this approach is arbitrarily scalable in power with increasing non-diffraction limited pump array or bar size.

The 1.06 micron absorption in Yb^{3+} and the energy transfer to Er^{3+} is shown schematically in Figure 1. Success with this pumping scheme relies on obtaining efficient energy transfer, a process that is strongly dependant on glass host[3]. In particular, overall transfer efficiency depends on the probability of back transfer. Since back transfer can only take place from the $^4I_{11/2}$ level of Er^{3+} we require a short lifetime for the $^4I_{11/2}$ state. As this lifetime is governed by non-radiative decay, glasses with a high phonon energy such as phosphate, are sought. We have demonstrated initial $Yb^{3+} \rightarrow Er^{3+}$ transfer efficiencies of up to 90% in a phosphorus doped silica fiber. The overall 1.06→1.54 μm optical conversion efficiency in a power amplifier is 38% with respect to absorbed power.

Experimental:

The Er/Yb co-doped fibers are fabricated by the solution doping process. A phosphosilicate frit is deposited, via the conventional MCVD process, at a temperature to insure complete oxidation and diffusion, without fusion to a glass. An aqueous solution of high purity rare-earth and aluminum chlorides is diffused into the frit, with the resulting fiber ion concentration being proportional to solution concentration. The phosphosilicate frit is heated in the presence of Cl_2 and O_2 to remove the solvent. The frit is sintered to a glass, trapping the dopant ions. The preform collapse and fiber drawing are then done in the conventional fashion.

The amplifier is shown schematically in figure 2. We used a diode-pumped (3 Watt AlGaAs diode array) Nd^{3+}:YLF laser as the pump source, with a dual line output at 1047/1053 nm, pigtailed to one port of a 1050/1540 WDM coupler. The pump power coupled into the WDM single-mode fiber was 1 Watt and was counter-propagated with respect to the signal. The input and output to the WDM couplers were preceded by polarization insensitive isolators. The input and output SMF-28 fiber was connected by ST/PC connectors. All power and gain values quoted are system values, those measured at the input and output connectors.

System Performance:

An output power versus system gain plot is shown in Figure 3 for a 1535 nm input signal. A maximum power of +24.6 dBm (290 mW) has been obtained for a +4 dBm input signal at 1535 nm. A maximum small signal gain of 51 dB has been obtained with a 1535 nm input signal. It can be seen that at an output power of +20 dBm, the gain is only compressed to 47 dB.

In order to test the power scaling of this co-doped amplifier, we pumped with a flashlamp-pumped CW Nd:YAG laser in the counter propagating direction while pumping in the co-propagating direction with a Nd:YLF DPL. We have observed up to +27 dBm of output power for just under 1500 mW of coupled pump power, as shown in Figure 4. The input signal was +2 dBm at 1542 nm. From the single DPL result of Figure 2, it can be seen that by the use of two Nd:YLF DPL's in a bi-directional pumping configuration, +27 dBm of output power could be readily obtained in a diode-based system. Such ultra-high output power optical amplifiers, although Argon-ion Ti:sapphire pumped, have already been used in systems experiments such as the demonstration of how a single tranmitter unit could service 39.5 million users[4]. The system noise figure of the Er/Yb amplifier is shown in Figure 5, at each of 40 CATV channel frequencies. The average value of the noise figure was found to be 3.5 dB, indicating a high degree of inversion. When corrected for input coupling losses, a quantum-limited noise figure of 3 dB is obtained.

Conclusion:

A high output power Er/Yb co-doped optical amplifier has been demonstrated using a diode-pumped Nd:YLF laser as the pump source. Small signal gains of up to 51 dB and output saturation powers of +24.6 dBm have been demonstrated when pumped with a single DPL. The diode-pumped Nd^{3+}:YLF laser pump source has allowed the use of high power, reliable AlGaAs diode laser arrays. As demonstrated, this approach is readily scalable in power with pump array size.

References:

1.) H. Takenaka, H. Okuno, M. Fujita, Y. Odagiri, Y. Sunohara, and I. Mito, Proc. Second Topical Meeting on Optical Amplifiers and Their Applications, p. 254. Paper FD2, Snowmass, Colorado 1991.

2.) J.E. Townsend, K.P. Jedrezewski, W.L. Barnes, and S.G. Grubb, Elect. Lett., Vol. 27(21), 1958 1991.

3.) V.P. Gapontsev et. al., Opt. Comm. 46, 226 1983.

4.) A.M. Hill et. al., Elect. Lett., 26 1882 1990.

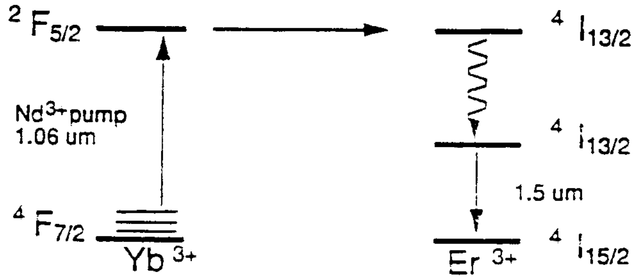

Figure 1: Energy level diagram for the $Yb^{3+} \rightarrow Er^{3+}$ energy transfer process.

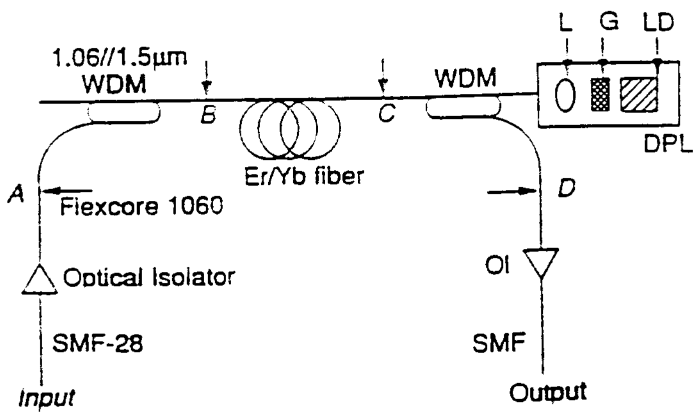

Figure 2: Er/Yb Optical Amplifier schematic.

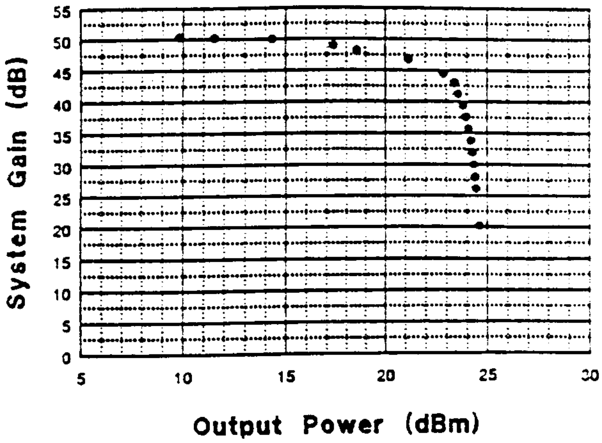

Figure 3: Output power versus gain plot for a single DPL-pumped optical amplifier.

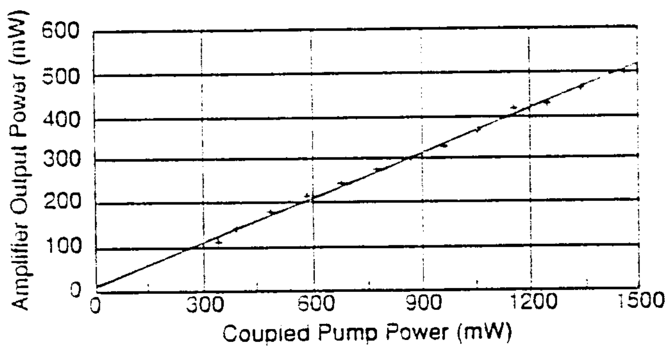

Figure 4: Optical amplifier output power versus pump power for a bi-directionally pumped unit.

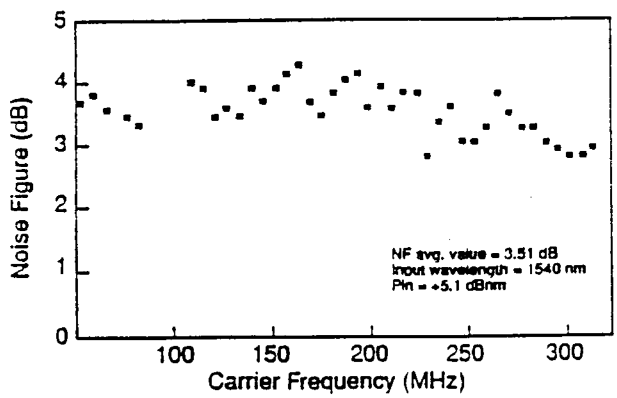

Figure 5: Amplifier system noise figure versus carrier frequency.