OFC '91 PD7-1

High-Power Sensitized Erbium Optical Fiber Amplifier

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Introduction:

Much of the recent discussion regarding the systems deployment of erbium-doped fiber optical amplifiers has focussed on the pump source. Ideally, when choosing which pump band to use, one desires high efficiency, quantum limited noise performance, and the availability of a long-lived semiconductor based pump source. Initial experiments focussed on the 800 nm pump band of erbium due to its coincidence with commercially-available high-power AlGaAs diode lasers. Unfortunately, the presence of a strong excited state absorption (ESA) in this pump band severely limits the gain performance and degrades the amplifier noise figure. The pump wavelengths of 980 and 1480 nm have their advantages and disadvantages with regards to gain efficiency, amplifier noise figure and overall system advantages. However, there still remain questions with regard to pump laser reliability at both of these wavelengths.

We describe here the operation of the first sensitized erbium (Er^{3+}/Yb^{3+}) optical amplifier using a diode-pumped Nd^{3+} laser (DPL) as the pump source at 1064 nm. This approach indirectly utilizes highly non-diffraction limited high-power AlGaAs diode laser arrays and is easily power scalable, a notable advantage for a power optical amplifier. This pumping scheme operates without any noticeable ESA and exhibits a near quantum-limited noise figure. Previous work has focussed on the use of frequency-doubled DPL's at 532 nm as a pump source for erbium fiber amplifiers[1]. In terms of overall efficiency, the utilization of the Nd^{3+} DPL fundamental as the pump source is a significant improvement and avoids the operational complexities of the nonlinear frequency-doubling process.

Fiber Host Spectroscopy:

The relevant energy levels of Er^{3+} and Yb^{3+} are shown in figure 1. Of critical importance is the Yb^{3+} - Er^{3+} transfer step, the efficiency of which depends strongly on the glass host. We have measured the initial energy transfer efficiency in a standard SiO_2/GeO_2 MCVD type fibre to be 5%. For fibers made from bulk phosphate glass this efficiency is 85%, principally due to the reduced probability of back transfer (Er^{3+} - Yb^{3+}) for this host[2]. An efficient Nd^{3+} intracavity-pumped bulk Er glass laser has been demonstrated with this same co-doped Er/Yb phosphate glass[3].

Although fibers made from phosphate glass show good efficiency, MCVD silica based fibre would allow direct splicing into the amplifier system, thereby minimizing coupling losses and reflections. We have found that when small amounts of P_2O_5 are incorporated into SiO_2/Al_2O_3 MCVD fiber, the spectroscopy of the Er^{3+} ion is significantly altered (figure 2) so that it mimics the phosphate. Such silica based fiber shows considerably improved transfer efficiency. However, the doping levels for this system have not yet been optimized so that the results presented here are based on an Er(0.5 wt %)/Yb (12 wt %) doped phosphate glass fiber fabricated by the rod-in tube method.

System Performance:

The pump source was a diode-pumped Nd^{3+} laser (ALC-350) pigtailed to one port of a 980/1535 WDM coupler (Gould). The input and output to the doped fiber were preceded by polarization-insensitive isolators (Gould). Connection between the silica and phosphate fiber was made by active alignment. Reflections due to the index mismatch at the phosphate/silica fiber interface were minimized by use of an intermediate index gel or angled fiber ends. We estimate the input loss to be at least 4 dB whilst the output loss is approximately 4.5 dB, primarily due to the coupler-amplifier fiber mismatch as well as the silica-phosphate coupling process. Also included are the isolator and WDM coupler (not optimized for a 1064 pump wavelength) losses. Figure 3 shows the small signal gain plot of this amplifier. Figure 4 shows the power amplifier plot. Both figures show the total system value as well as the active fiber internal gain, correcting for the aforementioned losses. The noise figure of this amplifier has been measured to be as low as 3.5 dB, near the quantum limit of 3 dB. This is consistent with independent measurements that show the inversion parameter to be essentially unity.

Conclusion:

An erbium optical amplifier based on indirect pumping through a sensitizer (Yb^{3+}) has been demonstrated for the first time. Small signal gains of up to 42 dB and output saturation powers (3 dB gain compression) of +14.5 dBm have been demonstrated. The use of a diode-pumped Nd^{3+}:YAG laser as a pump source has allowed the use of high-power, reliable AlGaAs diode laser arrays. This approach is readily scalable in power with pump array size, an advantage for a power optical amplifier. Significant enhancement in system performance is expected with improvements in the Er/Yb co-doped fiber.

Acknowledgements:
We gratefully acknowledge the technical assistance of Bill Humer and Allan Wallenberg of Amoco Technology as well as K. Jedrzejewski and M. Takahara currently visiting the University of Southampton.

References:

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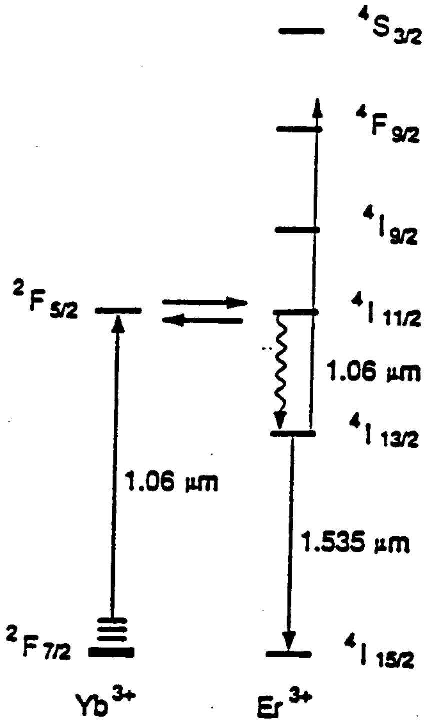

Figure 1: Energy level diagram showing the relevant levels involved in the Er/Yb energy transfer.

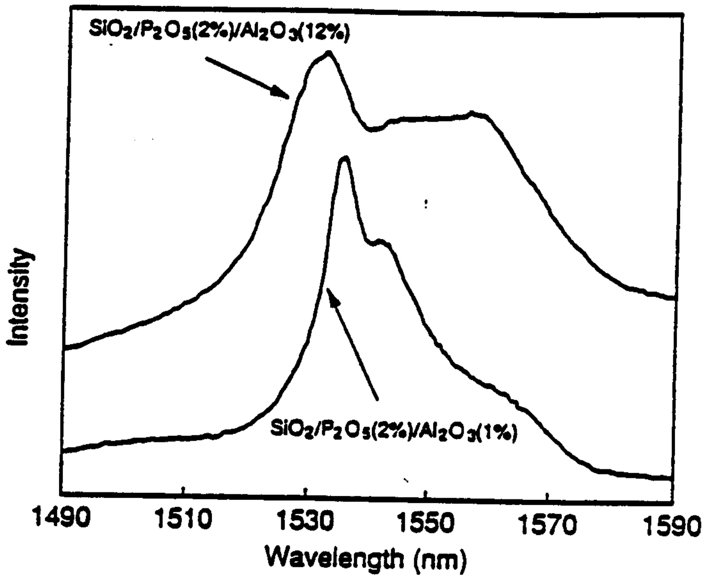

Figure 2: Er^{3+} fluorescence emission for two different Er/Yb co-doped MCVD fibers (a) SiO_2/P_2O_2 (2 mole %)/Al_2O_3 (12 mole %) host ; (b) SiO_2/P_2O_5 (2 mole %)/Al_2O_3 (1 mole %) host.

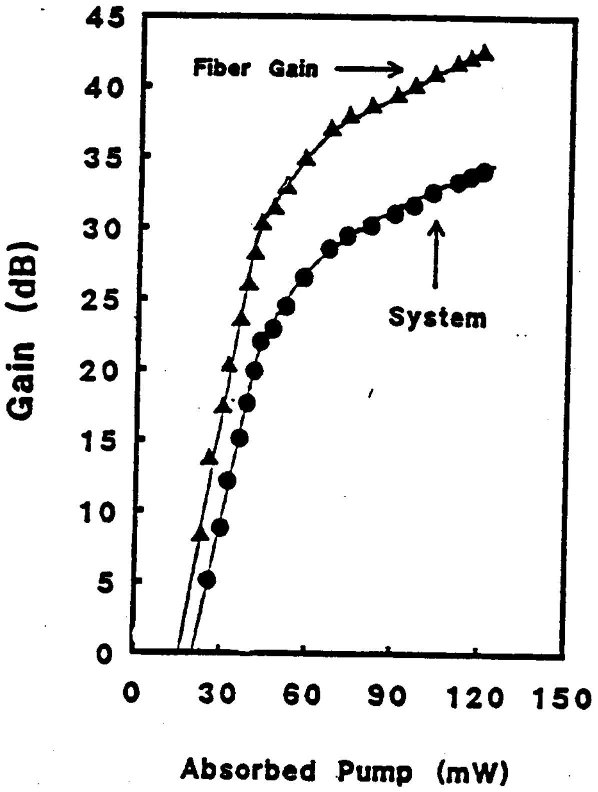

Figure 3: Small signal gain plot for the Er/Yb phosphate optical amplifier both corrected and uncorrected for system losses.

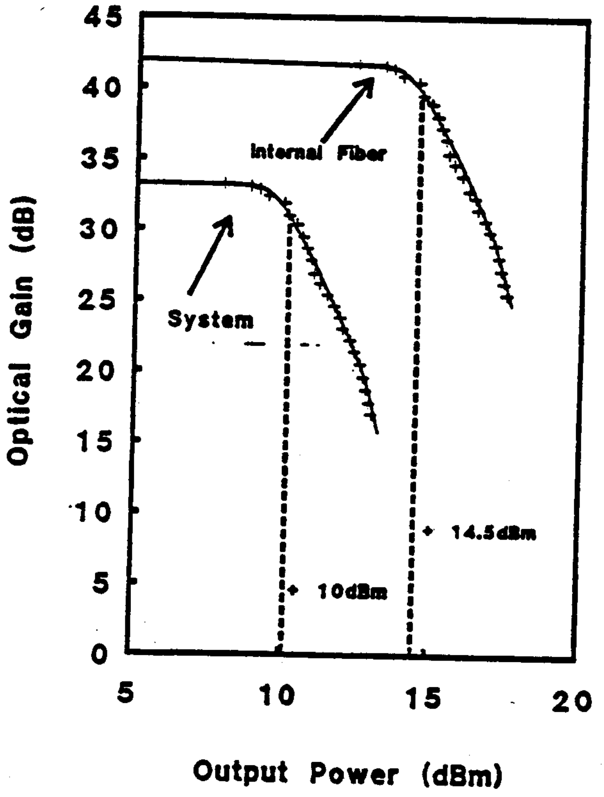

Figure 4: Power amplifier plot for the Er/Yb phosphate optical amplifier both corrected and uncorrected for system losses.