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# $Er^{3+}/Yb^{3+}$ co-doped power amplifier pumped by a 1W diode array.

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## Abstract.

We report the first $Er^{3+}/Yb^{3+}$ co-doped fibre power amplifier pumped by a 962nm diode array via an inner-cladding waveguide. The device exhibits a small signal gain of 24dB and a saturated output power of +17dBm.

## Summary.

The sensitisation of erbium-doped fibres with ytterbium is well established as a technique for increasing the choice of pump wavelengths for the erbium system[1]. The $Yb^{3+}$ ions exhibit strong absorbtion centred at 980nm and can be pumped by wavelengths from 750nm-1070nm, whereupon energy transfer occurs to excite the erbium ions. The approach has led to the development of high-power fibre lasers and amplifiers in the 1.55$\mu$m band pumped indirectly by laser-diode arrays operating in the 800nm band. These devices used a tandem-pumping scheme in which the diode-array pumps an intermediate laser operating at around 1.06$\mu$m, eg a miniature $Nd^{3+}$:YAG laser[2] or a double-clad $Nd^{3+}$ fibre laser[3], which in turn pumps the $Er^{3+}/Yb^{3+}$ fibre laser or amplifier.

While the tandem-pumping approach is a convenient route to high-power amplifiers, the use of an intermediate laser reduces device compactness and optical efficiency. A power amplifier in which the intermediate laser is eliminated by directly pumping an $Er^{3+}Yb^{3+}$ co-doped double-clad fibre with a 962nm diode-array source is reported here.

Efficient absorption of pump light from a low-brightness multistripe diode by a single-mode doped fibre core can be efficiently achieved by the use of a double-clad structure[4,5], ie. a multimode fibre surrounding a single-mode core. Pumping of 3-level systems such as erbium via double-clad structures is more difficult than 4-level systems eg. neodymium since the natural ground-state absorption must be bleached out before gain can be achieved. Direct pumping of $Er^{3+}$-doped fibre with diode-arrays is not realistic since the increase in absorption length in a double-clad geometry, (roughly proportional to the inner cladding/ core area ratio), causes a prohibitive increase in the threshold pump power. However the development of efficient $Er^{3+}/Yb^{3+}$ co-doped fibres[3] and the recent availability of diode arrays in the range 950nm-980nm radically changes this situation. The high absorption cross-section of $Yb^{3+}$ in this band compensates for the increase in absorption length due to the double-clad structure and allows efficient pump absorption in a short double-clad $Er^{3+}/Yb^{3+}$ co-doped fibre.

The double-clad fibre was fabricated by coating a standard phospho-alumino-silicate $Er^{3+}/Yb^{3+}$ co-doped single-mode fibre made by MCVD with a low-index silicone coating. The fibre had a diameter of 80$\mu$m, a second mode cutoff wavelength of 1$\mu$m, a core NA of 0.16, and an inner cladding NA of 0.4. The $Er^{3+}$ and $Yb^{3+}$ concentrations were 900ppm and 11000ppm respectively. The pump source was an SDL 6462 1W InGaAs diode array, centred at 962nm. The signal source was a DFB laser emitting at 1536nm.

Figure 1 shows schematically the arrangement for measuring the gain characteristics of the diode-array pumped amplifier. A pump/signal counterpropagating scheme was employed to ensure the gain was highest where the signal was strongest. Bulk optics were used to collimate and focus the pump light into the multimode waveguide with an efficiency of 70%. A 960nm/1535nm dichroic beamsplitter was used to separate the amplified signal beam from the incoming pump beam.

Figure 2 shows the saturated output signal power as a function of absorbed pump power for a constant input signal level of 0dBm. A slope efficiency of around 12% is indicated.

Figure 3 shows the gain characteristics with respect to signal power at a constant absorbed pump power of 620mW. The length of the doped fibre was 1.8 metres and the unabsorbed throughput pump power was 100mW. The device exhibits a small signal gain of 24dB and a maximum output power of +17dBm. However, it is clear that the gain is not fully saturated at the signal levels available and that output in excess of 20dBm should be possible.

In conclusion, we have demonstrated the feasibility of diode-array pumping of $Er^{3+}/Yb^{3+}$ double-clad fibre power amplifiers. Refinements in fibre geometry, especially inner cladding/ core area ratio and core composition should enable efficiencies approaching 30% to be obtained, indicating that output powers of at least 250mW are possible. A double-pass scheme incorporating an optical circulator at the signal input end and a dichroic reflector at the pump input would enable a fibre to fibre amplifier to be constructed.

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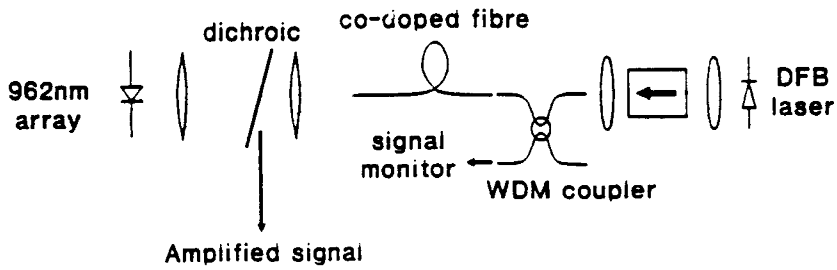


Figure 1. Schematic of amplifier configuration.

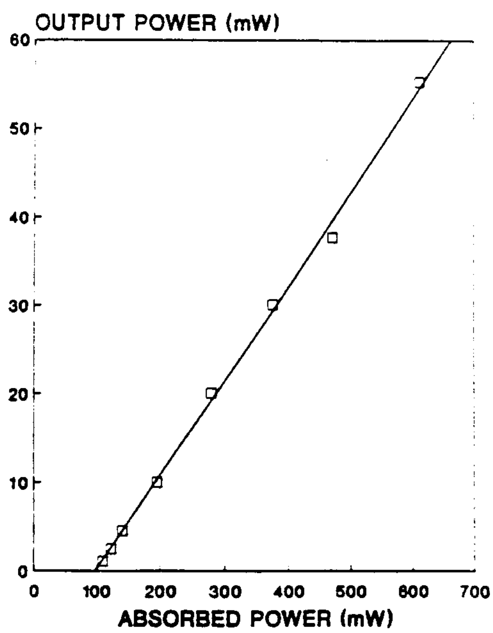


Figure 2. Amplifier slope characteristic.

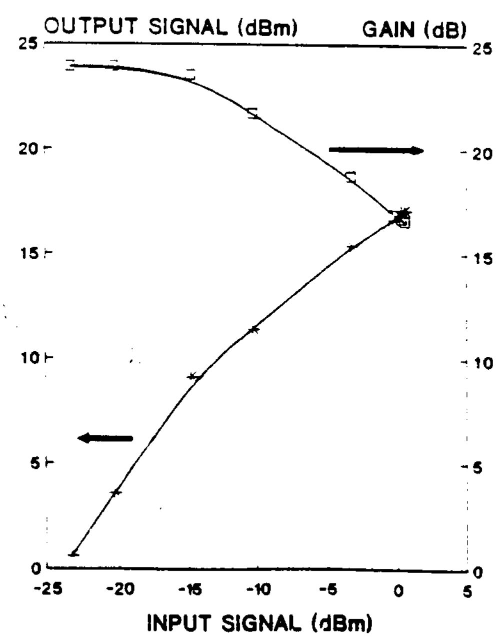


Figure 3. Amplifier gain characteristics.