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EFFICIENT CLADDING PUMPING OF AN Er^{3+} FIBRE.

J.D.Minelly, Z.J.Chen, R.I.Laming and J.E.Caplen.

Optoelectronics Research Centre,
University of Southampton,
Southampton SO17 IBJ.

Abstract

We report for the first time efficient operation of a cladding pumped Er^{3+} fibre configured in both fibre laser and fibre amplifier form. The fibre was of a double clad design compatible with beamshaped 980nm broadstripe pump lasers. An efficiency in excess of 40% has been achieved.

Introduction

Cladding pumping is now a well established technique for power scaling fibre lasers and amplifiers. A second cladding provides a multimode waveguide for pump light from a high power broadstripe laser or diode bar. Absorption of the pump light is achieved in a length proportional to the area of the cladding waveguide relative to the area of the inner core containing the rare-earth ions.

Most of the published work on cladding pumping has concentrated on the 4-level 1.06μm transition in Nd^{3+} fibres, [1], [2]. By pumping with fibre bundle coupled diode bar sources, power levels approaching 10 Watts have been achieved. The fibre bundle dimensions have typically had a numerical aperture of 0.40 with diameters around 400μm. Due to the large cladding to core waveguide area ratio these fibre lasers have typically been several tens of metres in length. This is not a problem for 4-level lasers because the length scaling causes only a marginal increase in the cavity loss and therefore a minimal reduction in efficiency and a small threshold penalty.

The situation with 3-level systems such as the important 1540nm transition in Er^{3+} is more complicated. In such cases the performance is critically dependent on the area ratio of the cladding and core waveguides. The reduced pump rate inherent to the double clad fibre geometry will generally result in a prohibitive increase in threshold power. One way of overcoming the problem is by co-doping with a high concentration donor ion such as Yb^{3+} and pumping the Er^{3+} ion by energy transfer [3]. While this technique remains attractive another solution is provided by a recent development in re-shaping the beam profile of high power diodes which enables focusing the pump beam in fibres of much smaller diameter than has hitherto been considered practical [4].

The beamshaper to which we refer utilises two parallel high reflecting mirrors to chop the beam into segments and stack vertically the line output from a collimated diode bar or broadstripe. This re-shaping enables subsequent focusing into a small near circular spot. A 100μm spotsize with a divergence equivalent to a 0.2 NA has been reported for a beamshaped 10 W diode bar. For broadstripe diodes in the 1 to 4 Watt power regime spotsizes of between 10 and 40μm should be easily attainable. In this paper we assess the performance of a double-clad Er^{3+}-doped fibre designed for compatibility with a beamshaped 1 Watt broadstripe pump diode. The initial measurements described were performed using a Ti:sapphire pump laser under suitable launch conditions. The results of actual diode pumping will be presented at the conference.

Fibre Design and Spectra

The refractive index profile as measured on a York S14 profiler is shown in Figure 1. The double-clad Er^{3+} doped fibre was fabricated by a modified solution doping technique. The refractive index of the inner cladding layers was raised by germania doping from the gas phase. The inner core contains further germania as well as alumina and Er^{3+} ions incorporated from solution. The resulting structure has an inner cladding waveguide with an NA of 0.18 and 22μm diameter and an inner-core with NA of 0.12 and 6μm diameter. The LP_{11} cutoff wavelength, (calculated assuming an infinite inner cladding), is approximately 940nm. Since only the inner core is doped with Er^{3+} preferential gain for the LP_{01} mode is assured. The Er^{3+} concentration is approximately 1200ppm.

The pump absorption spectra of the fibre's inner-cladding waveguide as measured with a white light source and scanning monochrometer is shown in Figure 2. This indicates a pump absorption at 980nm of approximately 3dB/m, an order of magnitude less than we would expect when pumping directly into the fibre core, which is consistent with the relative dimensions of the inner-cladding and doped inner core. The absorption is still sufficient however for a practical device to be implemented in a reasonable length.

Lasing characteristics

The fibre was first configured as a laser and characterised by pumping with a 980nm Ti:sapphire laser under launch conditions in which the pump waist spotsize was approximately 20μm. The fibre was butted against a 980nm/1540nm dichroic reflector at the pump input end which acted as the high reflector for the laser cavity. The 4% reflection from the cleaved output end completed the laser cavity.

The pump absorption was found to vary between 1.8dB/m and 5dB/m depending on the modal excitation conditions. The lower pump absorption corresponded to adjusting the launch conditions to maximising the pump throughput power while the higher absorption corresponded to maximising the signal power. To confirm genuine cladding pumping conditions at the higher pump absorption we cut back the fibre to 20cm and observed the farfield pattern of the throughput pump light to be characteristic of a highly multimode excitation. We would expect the pump absorption with a diode to be somewhere between the extreme measured values. When the pump throughput was optimised the absorption could be enhanced from its initial value by bending and twisting the fibre to induce mode coupling. The divergence and far field diffraction pattern of the lasing signal confirmed lasing only in the LP_{01} mode.

The lasing characteristic at the optimum length of 3.9 metres is shown in Figure 3, indicating a threshold power of 150mW, a maximum output power of 300mW and a slope efficiency of 40%. Under launch conditions where the pump throughput was optimised the slope efficiency dropped to 27% with the reduction mainly due to a greater proportion of the launched power being unabsorbed at the optimum length. While the fibre is by no means optimised the efficiencies obtained are still significantly higher than have previously been obtained in cladding pumped $Er^{3+}Yb^{3+}$ co-doped fibres.

Amplifier characterisation

The main reason for developing this fibre is for a power amplifier therefore we also tested the performance in the amplifier configuration shown in Figure 4. For ease of pump/signal multiplexing we double passed the signal and launched the pump through a dichroic filter as before. We employed a fibre coupled optical circulator to isolate the signal source and separate the input and output signals.

The gain and output signal of an optimised 3 meter amplifier, measured at 1560nm with a launched pump power of 850mW are shown in Figure 5. A net small signal gain of 33dB and a saturated output power of 24 dBm are observed. Including the 1dB loss of the circulator the fibre output power is estimated to be in excess of 25dBm, corresponding to a ~37% conversion efficiency. Figure 6 plots the output power for input signals in the wavelength range 1520-1565nm and power -5dBm. A near constant output power around +24dBm is obtained for signals in the wavelength range 1529-1565nm confirming the device potential as a power amplifier.

Conclusions.

We have demonstrated for the first time efficient cladding pumping of an Er^{3+}-doped fibre. Diode pumping with beamshaped broadstripe diodes are expected to yield devices with several hundred milliwatts of output power in efficient power amplifier configurations.

References

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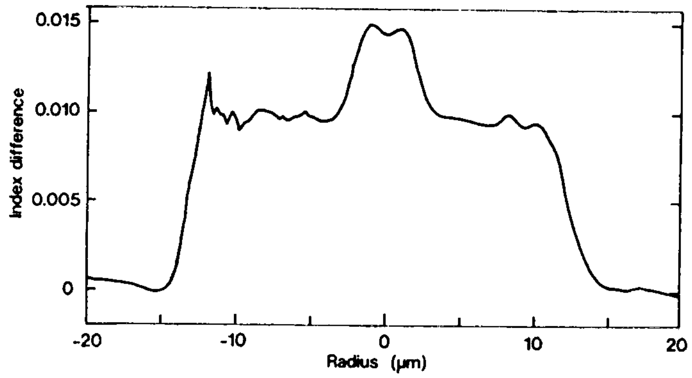


Figure 1. **Refractive index profile of the double-clad Er^{3+}-doped fibre.**

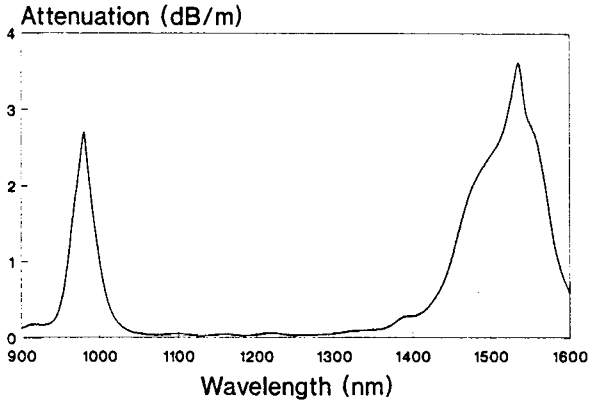
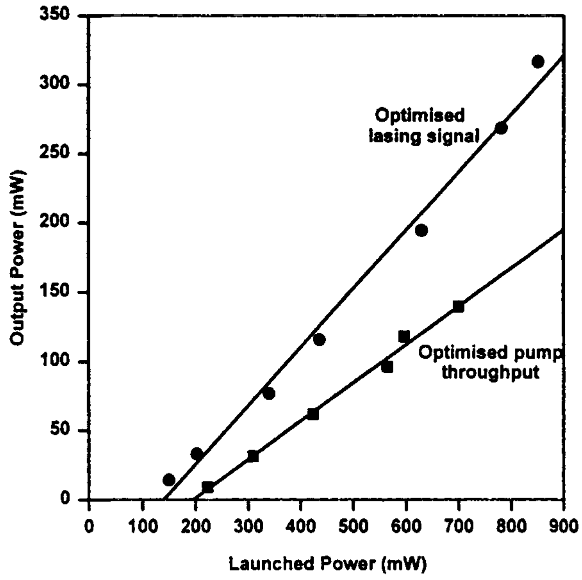


Figure 2. **Absorption spectra of double-clad Er^{3+}-doped fibre for pump light propagating in the inner-cladding waveguide.**

Figure 3.
Characteristic of cladding pumped Er^{3+}-doped fibre laser under differing launch conditions.



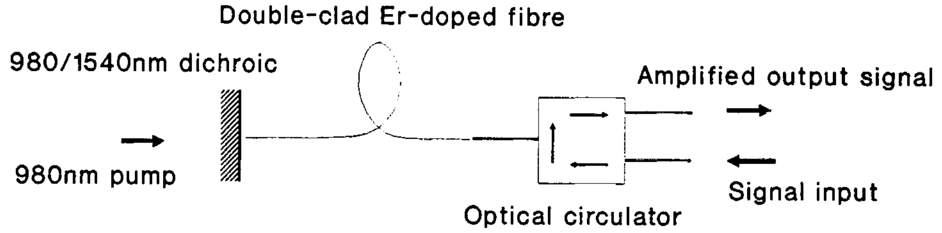
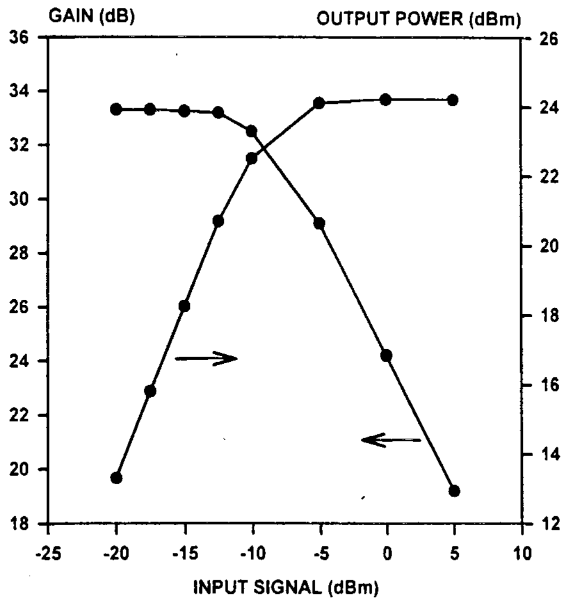


Figure 4. Double pass configuration of cladding pumped Er^{3+} fibre amplifier.



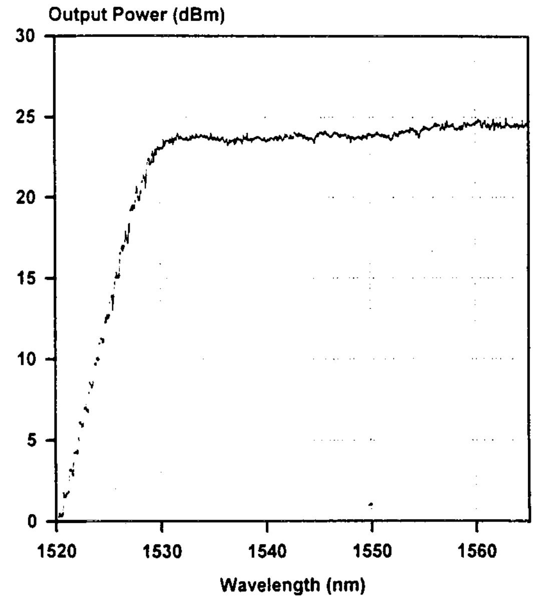


Figure 5.
Gain and saturation characteristics of cladding pumped Er^{3+} fibre amplifier.

Figure 6.
Spectral dependence of output power for the cladding pumped Er^{3+} fibre amplifier.