OPTIMAL PUMPING OF ERBIUM-DOPED-FIBRE OPTICAL AMPLIFIERS

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ABSTRACT

By choosing pump wavelengths which avoid excited-state absorption, efficient, high-gain, erbium-doped fibre amplifiers are possible. Practical pump wavelengths of 532nm and 980nm are identified as optimal, the latter giving a gain as high as 2.2dB/mW of pump.

INTRODUCTION

Since the early demonstration of optical amplification in fibres[1] the Er^{3+}-doped optical fibre amplifier has stimulated much research interest[2-6] as it offers the potential of high gain, low-noise[4], fibre-compatible amplifiers for operation in the third telecommunications window around 1.53μm.

Previous demonstrations of high-gain (>25dB) erbium amplifiers have required in excess of 100mW of pump power from a dye[2] or argon-ion[3] laser operating at 665nm or 514.5nm. A more practical pump source is the semiconductor-diode laser pumping into the 807nm absorption band[6], but at this wavelength (and to a lesser extent at the other two wavelengths) efficient pumping is severely impeded by pump excited-state absorption (ESA). Pump ESA is a problem particular to 3-level end-pumped optical amplifiers and occurs when a further pump transition to a higher energy level is possible from the highly-populated inverted level responsible for the gain at 1.53μm. Broadly, the effect is similar to the fibre possessing a large unwanted loss at the pump wavelength which dissipates the pump power as heat and reduces pump efficiency and gain. Thus pumping at 807nm requires very high pump-power and an undesirably large NA fibre to increase the pump intensity before high gain can be achieved.

In this paper we investigate the possibility of pumping at previously-unexplored wavelengths where spectral excited-state measurements[5] have shown that ESA is small or non-existent, namely 528-532nm and 980nm. Using standard NA Er^{3+}-doped fibres, we show that for 528nm pumping, high gains (>30dB) can be obtained for relatively-low pump powers, whereas for 980nm pumping where no ESA exists, a gain of 24dB is obtainable for an unprecedented 11mW of pump, i.e. 2.2dB/mW. These figures are the best yet reported and are compatible with the outputs available from frequency-doubled diode-pumped mini-YAG (532nm) and diode lasers[7] (980nm GaAsSb-AlGaAsSb).

EXPERIMENTAL

The amplifier characteristics were tested with co-propagated signal and pump light. For the first experiment, 100mW of pump light at 528nm from an argon-ion laser and the signal from a DFB laser (1532nm) were launched into the amplifier fibre via the two arms of a a dichroic coupler. The 514.5nm pump wavelength where ESA is known to occur was also used in a separate experiment to provide a datum. To ensure the best possible datum result, an alumino-silicate erbium-doped (0.3 wt% Er_2O_3) fibre was used, as this fibre type is known to exhibit reduced ESA at 514.5nm[5]. The fibre was characterised by an NA of 0.14 and λ_{CUTOFF} at 1250nm.

An erbium-doped (0.1 wt% Er_2O_3) germano-silicate fibre with an NA of 0.16 and λ_{CUTOFF} at 975nm was employed for the second experiment involving pumping at 980nm from a CW dye laser. In this case the DFB operated at 1535nm, the gain peak for this fibre type.

RESULTS

The dependence of amplified signal and throughput pump power on fibre length are shown in Figure 1(a,b) for a constant input pump power of 100mW at both the datum pump wavelength of 514.5nm and the reduced-ESA wavelength of 528nm. Results are shown for signal powers of 1, 10 and 100μW.

It can be seen that for the datum 514.5nm pump, the pump light is absorbed rapidly and exhibits an exponential decay with length, as would be expected in the presence of a large unwanted absorption due to ESA. The loss of pump power to this (unsaturable) absorption results in a low maximum gain of 16dB for a fibre length of only 1.25m, and low saturation output power of 3.5dBm. However, when pumping at 528nm the pump power is seen to decay approximately linearly with length, indicating that the pump absorption band is saturable due to the absence of pump ESA. Consequently, a higher maximum gain of 32dB and a saturated output power of 9dBm is obtained. This clearly demonstrates the advantages of selecting a pump wavelength where erbium exhibits both a significant ground-state absorption (GSA) and lack of ESA. The experiment was repeated using a frequency-doubled Nd:YAG laser operating at 532nm and similar results were obtained.

The results for 980nm pumping shown in Figure 2 for the same range of signal powers indicate this to be a very favourable transition indeed. As can be seen the pump power is again absorbed approximately linearly along the fibre, indicating a lack of ESA, and the small-signal gain peaks at 24dB for a fibre length of 9m. This value of gain (2.2dB/mW of pump) is by far the most efficient yet reported and is well within the reach of GaAsSb-AlGaAsSb laser diodes, even though the fibre has a relativeiy-standard NA. The maximum gain of 24dB was limited only by the pump power available and gains in excess of 30dB can be projected for around 15mW of pump. Increasing the NA to 0.3 would drop the pump requirements to a few mW.

The large signal gain is seen to saturate at a value of 11.5dB where an output power of 1.2dBm is available.

The results reported to date for erbium fibre amplifiers pumped at various wavelengths are shown in Table 1 where it can be seen that 980nm pumping is nearly an order of magnitude more efficient.

CONCLUSIONS

By pumping an Er^{3+}-doped fibre amplifier at previously unexplored wavelengths, we have conclusively shown the advantage of using pump bands where no ESA is present. Shifting from a pump wavelength of 514.5nm to 528-532nm results in a gain increase from a mediocre 16dB to an excellent 32dB for the same pump power, thus suggesting frequency-doubled mini-YAG lasers as practical pump sources.

We have also identified the 980nm pump band as ideal, being entirely free of ESA. A gain of 24dB is obtainable for only 11mW of pump, which is well within the reach of semiconductor diodes. A further advantage is the longer pump wavelength which ensures greater pump energy-efficiency, as well as allowing good overlap between pump and signal, since the fibre can be single-mode at both. The results obtained at this pump wavelength makes the Er^{3+}-doped fibre amplifier an attractive proposition for practical in-line repeaters.

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FIBRE TYPE	NA	λ_{pump}	P_{pump}	GAIN	GAIN/P_{pump}	REF.
SiO_2/GeO_2	0.2	665nm	100mW	26dB	0.26dB/mW	2
SiO_2/Al_2O_3	0.18	514nm	100mW	22dB	0.22dB/mW	3
SiO_2/Al_2O_3	0.14	514nm	100mW	16dB	0.16dB/mW	*
SiO_2/Al_2O_3	0.14	528nm	100mW	31dB	0.31dB/mW	*
SiO_2/P_2O_5	--	647nm	100mW	23dB	0.23dB/mW	8
SiO_2/Al_2O_3	0.12	1.49μm	14mW	2dB	0.14dB/mW	9
SiO_2/GeO_2	0.16	980nm	11mW	24dB	2.2dB/mW	*

* This work

Table 1 : Published gain and pump requirements for erbium amplifiers pumped at various wavelengths.