EFFICIENT PUMP WAVELENGTHS OF ERBIUM-DOPED FIBRE OPTICAL AMPLIFIER

Indexing terms: Optical fibres, Lasers, Optical communications

By choosing pump wavelengths at which excited state absorption does not occur, efficient high gain operation of erbium-doped fibre amplifiers is possible. Practical pump wavelengths of 532 nm and 980 nm are identified as optimal, giving gains as high as 1·35 dB/mW and 2·2 dB/mW of pump at the two wavelengths, respectively.

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 1·53 μm.

Previous demonstrations of high gain (>25 dB) erbium amplifiers have required in excess of 100 mW of pump power from a dye[2] or argon ion[3] laser operating at 665 nm or 514·5 nm. A more practical pump source is the semiconductor diode laser pumping into the 807 nm absorption band,[5] 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 metastable level responsible for the gain at 1·53 μm. These excited state absorption transitions have the effect of depleting the pump light resulting in a reduction of pumping efficiency and hence gain. Thus, pumping at 807 nm requires high pump power to overcome the poor pump efficiency 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* have shown that ESA is small or non-existent, namely 532 nm and 980 nm. Using standard NA Er^{3+} doped fibres, we show that for 532 nm pumping, high gains (34 dB) can be obtained for relatively low pump powers (25 mW), whereas for 980 nm pumping where no ESA exists, a gain of 24 dB is obtainable for an unprecedented 10·5 mW of pump, i.e. 2·2 dB/mW. In terms of gain per unit pump power these are the highest values yet reported. The power levels employed are compatible with the outputs available from frequency-doubled diode-pumped mini-YAG (532 nm) and semiconductor diode lasers[7] (980 nm GaAsSb–AlGaAsSb).

Experimental: The amplifier characteristics were tested with copropagated signal and pump light. In the first experiment approximately 25 mW of average power at 532 nm from a frequency-doubled mode-locked YAG laser and the signal from a DFB laser (1535 nm, the gain peak of the fibre) were launched into the amplifier fibre via a dichroic coupler. A germano-silicate erbium-doped fibre (0·1 wt% Er_2O_3) fibre was tested. The fibre was characterised by an NA of 0·16 and λ_{cutoff} at 1070 nm.

A fibre with the same composition and NA but with λ_{cutoff} at 975 nm was employed for the second experiment involving pumping at 980 nm from a CW dye laser.

* LAMING, R. I., POOLE, S. B., and TARBOX, E. J.: 'Pump excited-state absorption in erbium-doped fibres', to be published in *Opt. Lett.*

Results: The dependences of amplified signal and throughput pump power on fibre length are shown in Fig. 1 for a constant input pump power of about 25 mW at the pump wavelength of 532 nm where there is minimal ESA. Results are shown for signal input powers of 150 nW and 8·5 μW. As can be seen the pump power is absorbed approximately linearly along the fibre length indicating bleaching of the ground state absorption and minimal ESA. Consequently, for the small signal input of 150 nW, a maximum gain of 34 dB was obtained, limited only by the launched pump power of 25 mW. At the higher signal input power of 8·5 μW a reduced gain of 22 dB was observed due to gain saturation of the amplifier.

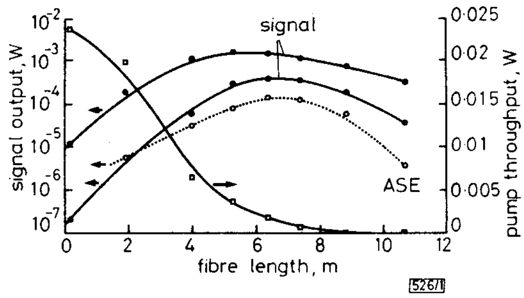

Fig. 1 *Amplified signal, ASE and pump throughput for erbium doped germano-silicate fibre optically pumped at 532 nm*

The results for 980 nm pumping shown in Fig. 2 for signal input powers of 250 mW, 1·6 μW and 70 μW 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 24 dB for a fibre length of 9 m. This value of gain (2·2 dB/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 relatively standard NA. The maximum gain of 24 dB was limited only by the pump power available and gains in excess of 30 dB can be projected for around 15 mW of pump.

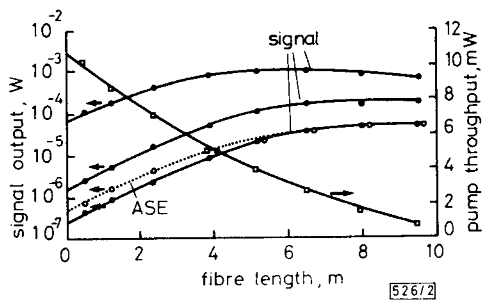

Fig. 2 *Amplified signal, ASE and pump throughput for erbium doped germano-silicate fibre optically pumped at 980 nm*

Table 1 PUBLISHED GAIN AND PUMP REQUIREMENTS FOR ERBIUM AMPLIFIERS PUMPED AT VARIOUS WAVELENGTHS

Fibre type	NA	λ_{pump}	P_{pump}	Gain	Gain/P_{pump}	Reference
			mW	dB	dB/mW	
SiO_2/GeO_2	0·16	532 nm	25	34	1·35	†
SiO_2/GeO_2	0·16	980 nm	10·5	24	2·2	†
SiO_2/Al_2O_3	0·18	514 nm	100	22	0·22	3
SiO_2/Al_2O_3	0·14	514 nm	100	16	0·16	6
SiO_2/Al_2O_3	0·14	528 nm	100	31	0·31	6
SiO_2/GeO_2	0·2	665 nm	100	26	0·26	2
SiO_2/GeO_2	0·3	807 nm	20	8	0·4	5
SiO_2/Al_2O_3	0·12	1·49 μm	14	2	0·14	8

† This work

The large signal gain is seen to saturate at a value of 11·5 dB where an output power of 0·2 dBm 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 532 nm and 980 nm pump wavelengths are nearly an order of magnitude more efficient than results obtained in the presence of pump ESA.

Conclusions: By pumping an Er^{3+} doped fibre amplifier at previously unexplored wavelengths, we have conclusively shown the major advantage of using pump bands where no ESA is present. We have demonstrated gain of 34 dB for approximately 25 mW of pump power at 532 nm, thus demonstrating frequency-doubled mini-YAG lasers as practical pump sources.

We have also identified the 980 nm pump band as ideal, being entirely free of ESA. A gain of 24 dB is obtainable for only 10·5 mW 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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