Efficient High-Gain Erbium-Doped Fibre Amplifier Pumped with a Frequency-Doubled Nd:YAG Laser

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Introduction

An optical amplifier consisting of an erbium-doped germanosilicate fibre optically pumped at 532nm is described. Negligible excited-state absorption at 532nm allows efficient pumping, enabling a gain of 34dB at 1536nm to be obtained for only 25mW of pump power.

Since the early demonstrations of optical amplification in rare-earth-doped fibres[1], erbium-doped fibres have generated much interest as optical amplifiers in the third telecommunications window around 1.55μm[2,3].

Published results to date have shown gains as high as 29dB[2,3], but have employed impractical Argon-ion (514.5nm) or argon/dye lasers (665nm) as pump sources. Moreover, these pump wavelengths both possess a degree of pump excited-state absorption (ESA)[4]. ESA occurs when the highly-populated inverted metastable responsible for the gain at 1.53μm is depleted by pumping to an unfortunately-located higher energy level. It results in reduced gain and pumping efficiency.

An ideal pump band should show substantial ground-state absorption (GSA) with zero ESA to ensure all pump absorption is associated with signal gain. From a practical standpoint the pump source should ideally be compact and solid-state, i.e. a semiconductor laser diode or a diode-pumped mini-YAG. An absorption band in erbium-doped silica fibres exists around 810nm, but the presence of strong ESA at these wavelengths reduces its attractiveness. Direct pumping using an 807nm laser diode has recently been achieved[5] using a very high NA (0.3) fibre design in order to maximise the pump intensity in the fibre core. The presence of ESA gives relatively poor pumping efficiency resulting in less gain than previously achieved[2,3].

We report very-high small-signal gain (34dB) from an erbium-doped-fibre amplifier optically pumped at a wavelength of 532nm using a power level easily obtainable from diode-pumped frequency-doubled mini-YAG lasers. The fibre had a conventional NA of 0.15.

Experimental Set-Up

Figure 1 shows a schematic of the experimental set-up. The pump source used was a mode-locked Nd:YAG laser externally frequency-doubled using a KTP crystal. Due to the high mode-locking repetition rate (100MHz) and the long metastable lifetime of the fibre gain medium (15ms), the mode-locked laser could essentially be considered as a CW pump source. No modulation of the amplifier gain was observed at the mode-locking frequency.

Figure 1: Experimental setup.

The pump power was coupled into the erbium-doped fibre with a dichroic coupler which was fabricated to give a high coupling coefficient at 532nm and low coupling at 1536nm. The fibre was doped with 0.1-wt% Er^{3+} and 15-wt% GeO_2 and had a second mode cutoff of 1070nm. The signal from a DFB semiconductor laser at 1536nm was launched into the doped fibre using the other port of the coupler. In order to prevent Fresnel feedback into the amplifier, both the fibre ends were terminated to eliminate reflections and an optical isolator was placed between the input fibre end and the DFB laser.

Figure 2: Growth of signal and amplified spontaneous emission and decrease in pump throughput along the fiber amplifier. Upper and lower signal curves are for signal inputs of 8.5μW and 150nW, respectively.

The amplifier was characterised by measuring (i) amplified signal output, (ii) amplified spontaneous emission (ASE) in the absence of signal and (iii) pump throughput as a function of fibre length. The results in Figure 2 show a peak signal output of 0.4mW (a gain of 34dB for a fibre length of 5m and an input power of 150nW. The gain is limited by the launched pump power of 25mW. At higher signal output powers (>1mW), reduced gain (22dB) is observed due to gain saturation of the amplifier (see curve for input signal power of 150μW). The dotted curve shows the axial variation of ASE with fibre length and at the position of maximum small-signal gain (5m) the ASE power referred to the input is ~60nW, measured to be in an optical bandwidth of 2–3nm.

Maintaining other fibre parameters constant, increasing the fibre NA to 0.3 would be expected to give similar small-signal gain for pump power in the region of 5mW.

Conclusion

In conclusion, we have demonstrated small signal gain of 34dB in an erbium-doped telecommunicationscompatible silica fibre amplifier optically pumped with 25mW of 532nm light. This pump wavelength is seen to be efficient owing to significant ground- state absorption and negligible ESA which enables high gain to be obtained at only 25mW of pump power. Since compact frequency-doubled, diode-pumped mini-YAG lasers are readily available with this power output, a practical in-line high-gain fibre amplifier can now be realised.

References

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371 fig 1

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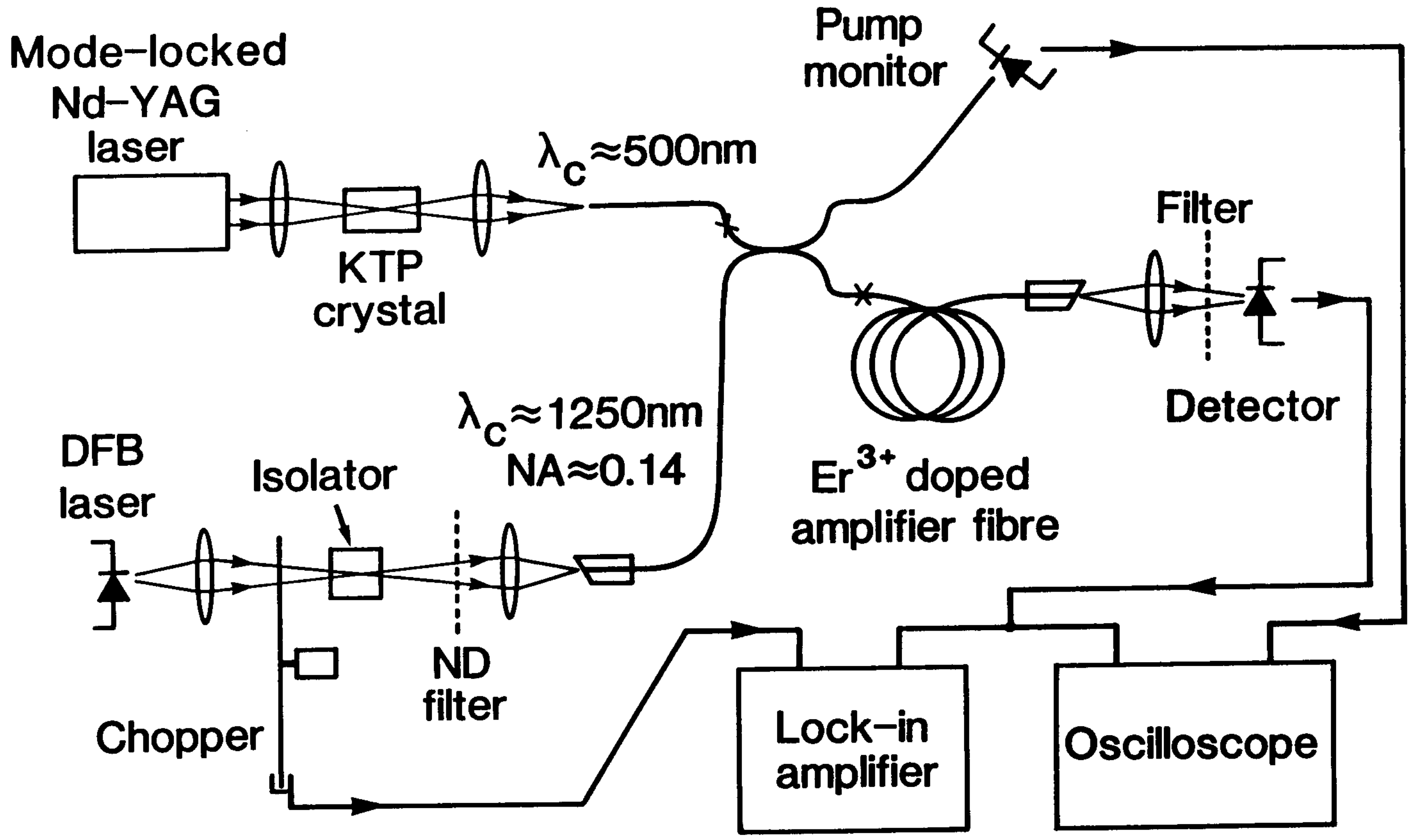
Figure 1 18.4 to 8.0



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20·4 to 8·0

371 fig 2