Sub. Electron. Lett. 1292

Efficient distributed feedback erbium-doped germanosilicate fibre laser pumped in the 520 nm band

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Abstract

We demonstrate that the efficiency of short cavity single frequency erbium-doped fibre lasers can be dramatically increased by pumping in the green absorption band. For a 10 cm distributed feedback erbium fibre laser pumped at 523.5 nm, a slope efficiency of 10% is achieved, compared to 1% efficiency obtained with conventional 980 nm pumping.

Introduction: Single frequency erbium fibre lasers are attractive for a variety of applications in optical communication and sensor systems, with strong interest focussing on distributed Bragg reflector (DBR) and distributed feedback (DFB) laser configurations[1-3]. In both cases, however, the cavity lengths need to be kept reasonably short (several cm) in order to ensure robust single mode operation. This has typically resulted in low laser efficiencies of $<1\%$ due to the limited pump absorption incurred over such short fibre lengths. In the case of DBR erbium fibre lasers, the length constraint is particularly severe, limiting the laser output powers to $\sim 100\ \mu W$[1,2] for tens of mW of pump power. Output powers of up to 1 mW have been achieved with single grating-based DFB fibre lasers[4], which enable laser lengths to 10 cm long while maintaining stable single mode operation; however, there is clearly considerable room for improvement still.

There are, broadly speaking, two basic approaches for dealing with the problem of low efficiency in such fibre lasers, which is either by re-using (or recycling) the unabsorbed pump power, or increasing the pump absorption within the short fibre length. In the former case, the most common approach has been to subsequently redirect the unabsorbed power after the laser to pump a fibre amplifier, thereby boosting the low laser output[1]. More recently, we have suggested the use of intracavity pumping as a means of recycling the pump power in order to boost the laser output directly[5]. Alternatively, the use of co-doped Er^{3+}/Yb^{3+} phosphosilicate fibres can be very effective in increasing the pump absorption by at least an order of magnitude, hence improving the laser efficiency considerably. However, grating fabrication in these low photosensitivity fibres continues to be an issue, although steady progress is being made[6].

In this Letter, we demonstrate that efficient laser operation can be achieved simply by pumping in the green wavelength band rather than at 980 nm. While 980 nm pumping is conventionally considered to be an excellent choice for pumping erbium-doped fibre amplifiers (EDFAs), due to the lack of excited state absorption, the situation is less clear for erbium-doped fibre lasers (EDFLs). Recently, we have found that longer wavelength (resonant) pumping of EDFLs can improve their stability[7]. In the current work, we show that, due to the extremely large absorption cross-section, efficient laser operation is possible even with short laser cavities when pumped in the 520 nm absorption band.

Theory: The expected improvement in laser efficiency due to an increase in the pump absorption cross-section can be quickly estimated by consideration of the rate equation for the ground state level:

$$\frac{dN_1}{dt} = -\Gamma_p \sigma_p N_1 \frac{I_p}{h\nu_p} + \Gamma_s \sigma_s (N_2 - N_1) \frac{I_s}{h\nu_s} + \frac{N_2}{T_1}$$

where I_p, I_s are the pump and signal (lasing) intensities, and Γ_p, Γ_s, σ_p, σ_s, $h\nu_p$, $h\nu_s$ their respective mode confinement factors, absorption cross-sections and photon energies. For simplicity, we have assumed the absorption and emission cross-sections are the same at the lasing wavelength. N_1 and N_2 are the ground state and metastable state populations, and T_1 the metastable lifetime. For the strongly lasing condition, we can neglect the spontaneous decay rate, and the steady state lasing intensity has the simple dependence

$$I_s = \frac{\Gamma_p}{\Gamma_s} \frac{\sigma_p}{h\nu_p} \frac{h\nu_s}{\sigma_s} \frac{N_1}{N_2 - N_1} I_p$$

Thus, by pumping in the green wavelength band where the absorption cross-section is ~20 times greater than at 980 nm[8], we can expect an order of magnitude improvement in the slope efficiency, even with the higher pump photon energy taken into account.

Experiment: To confirm the expected improvement in efficiency, we used a 10 cm long DFB laser fabricated in erbium-doped germanosilicate fibre (N.A. 0.17, single mode cut-off wavelength 930 nm), which had a small signal 980 nm absorption of 10 dB/m. Further details of this laser can be found in [5]. For the green pump source, a diode-array pumped all-solid-state 1.047 μm Nd:YLF laser was used, intracavity frequency-doubled with an LBO crystal to yield an output at 523.5 nm. The output from the solid-state laser was of sufficiently good beam quality to enable up to 90% of it to be coupled into the fibre. Fig. 1a shows the performance of the DFB fibre laser pumped at 523 nm. The threshold is less than 5 mW, with an output power of 17 mW for 190 mW pump, giving a reasonable slope efficiency of 10%, comparable to that recently achieved with Er^{3+}/Yb^{3+} fibre[6]. The cited output powers are measured following a pigtailed 1550 nm optical isolator spliced to the DFB laser, and thus includes insertion losses of about 1 dB. By contrast, the performance of the laser under 980 nm diode pumping is shown in Fig. 1b. The output power in this case is just 1 mW for 100 mW of pump, or an efficiency of 1%. Pumping at the shorter wavelength thus indeed produces an order of magnitude improvement in the laser efficiency.

Fig. 2 shows the optical spectrum of the DFB laser at maximum power, which is resolution limited to 0.05 nm. Observation with a Newport SuperCavity scanning Fabry-Perot interferometer shows the laser operates in 2 orthogonally polarised modes[4] (Fig. 2, inset. The small secondary peaks in the trace are the result of higher order transverse modes of the SuperCavity[9]). The optical linewidth, measured with the delayed-self-heterodyne technique using a 5 km delay line, was 260 kHz. This is significantly broader than the linewidth at low power, which was measured to be just 40 kHz (for 2 mW output power). The reason for this broadening is unclear at this point, although the same qualitative behaviour was also observed under high power 980 nm pumping using a Ti:Sapphire laser.

Conclusion: We have demonstrated that efficient operation of short cavity erbium-doped germanosilicate fibre lasers is possible by pumping in the 520 nm green absorption band. A slope efficiency of 10% has been achieved, which is an order of magnitude improvement over that attainable by conventional 980 nm pumping. It should be mentioned that use of green pumps for EDFAs have been investigated before[10,11], although interest had waned due to the ready availability of 980 nm and 1480 nm diodes. With compact green microchip lasers now commercially available, however, the work here indicates that green pump sources could be very attractive for short cavity EDFLs, particularly in the development of high power single frequency fibre laser sources (e.g. for CATV transmission).

Acknowledgements: This work was supported in part by the EC ACTS project PHOTOS. The Optoelectronics Research Centre is an EPSRC-funded Interdisciplinary Research Centre.

References

[1] BALL, G. A., HOLTON, C. E., HULL-ALLEN, G. and MOREY, W.W.: '60 mW 1.5 μm single-frequency low-noise fiber laser MOPA', *Electron. Lett.*, **6**, 1994, pp. 192-194.

[2] ZYSKIND, J. L., MIZRAHI, V., DiGIOVANNI, D. J. AND SULHOFF, J. W.: 'Short single frequency erbium-doped fibre laser', *Electron. Lett.*, **28**, 1992, pp. 1385-1386.

[3] KRINGLEBOTN, J. T., ARCHAMBAULT, J. L., REEKIE, L. and PAYNE, D. N.: 'Er^{3+}:Yb^{3+}-codoped fibre distributed feedback laser', *Opt. Lett.*, **19**, 1994, pp. 2101-2103.

[4] LOH, W. H. and LAMING, R. I.: '1.55 μm phase-shifted distributed feedback fibre laser', *Electron. Lett.*, **31**, 1995, pp. 1440-1442.

[5] LOH, W. H., SAMSON, B. N., HARUTJUNIAN, Z. E. and LAMING, R. I.: 'Intracavity pumping for increased output power from a distributed feedback erbium fibre laser', *Electron. Lett.*, **32**, 1996, pp. 1204-1205.

[6] LOH, W. H., DONG, L. and CAPLEN, J. E.: 'Single-sided output Sn/Er/Yb distributed feedback fiber laser', *Appl. Phys. Lett.*, to be published.

[7] LOH, W. H. and J. P. de SANDRO: 'Suppression of self-pulsing behaviour in erbium-doped fiber lasers with resonant pumping: experimental results', *Opt. Lett.*, to be published.

[8] MINISCALCO, W. J.: Erbium-doped glasses for fiber amplifiers at 1500 nm', *J. Lightwave Technol.*, **9**, 1991, pp 234-250.

[9] Newport Catalogue 1994, section 13.2.

[10] FARRIES, M. C., MORKEL, P. R., LAMING, R. I., BIRKS, T. A., PAYNE, D. N. and TARBOX, E. J.: 'Operation of erbium-doped fiber amplifiers and lasers pumped with frequency-doubled Nd:YAG lasers', *J. Lightwave Technol.,* **7**, 1989, pp. 1473-1477.

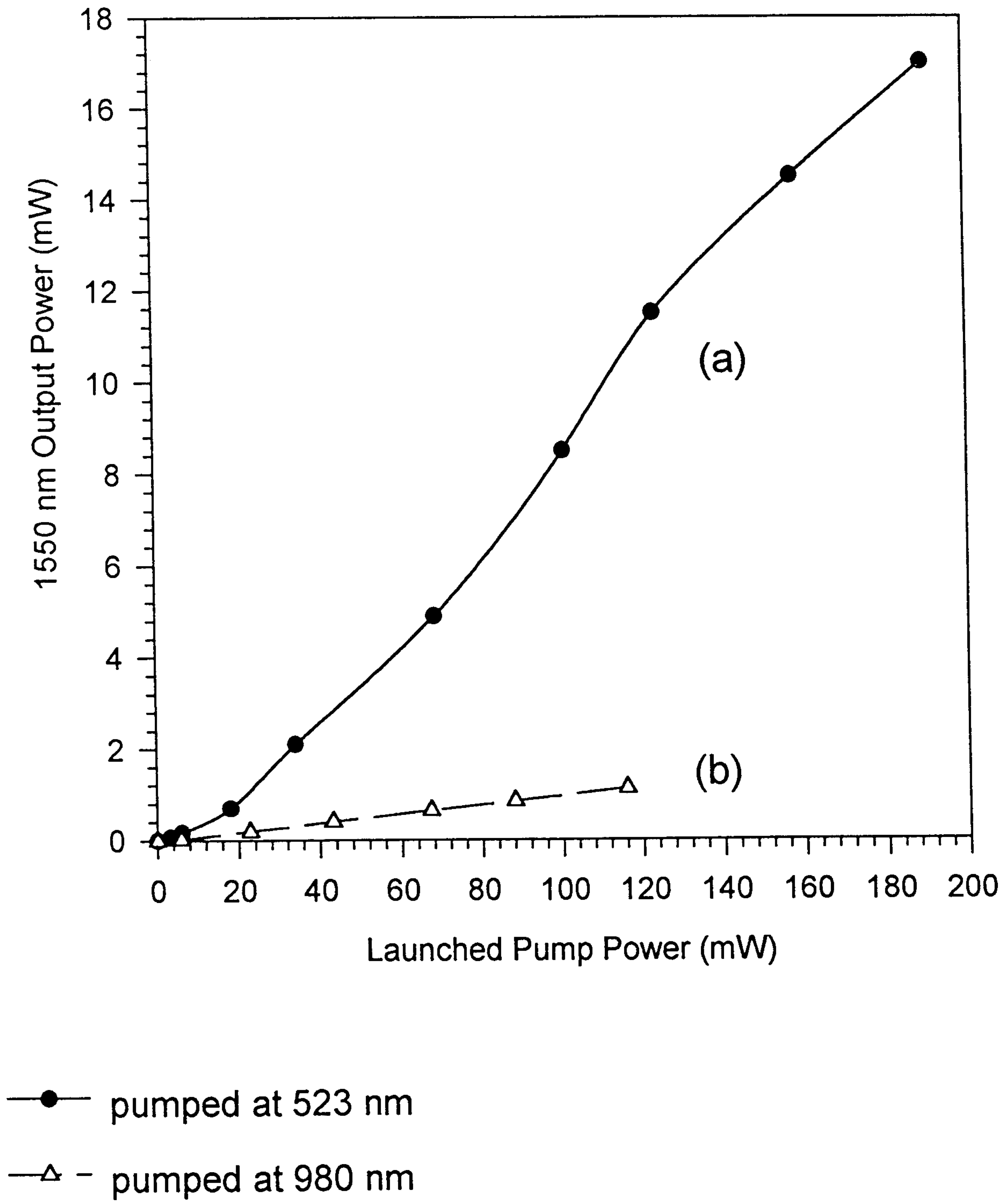
[11] KANNAN, K., FRISKEN, S. and ATHERTON, P. S.: 'Characteristics of an erbium-doped fiber amplifier pumped by a frequency doubled diode-pumped Nd:YAG laser', *IEEE Photon. Technol. Lett.,* **3**, 1991, pp. 124-126.

Figure Captions

Fig. 1 Lasing characteristics of 10 cm long distributed feedback erbium-doped germanosilicate fibre laser, (a) pumped at 523 nm and (b) pumped at 980 nm.

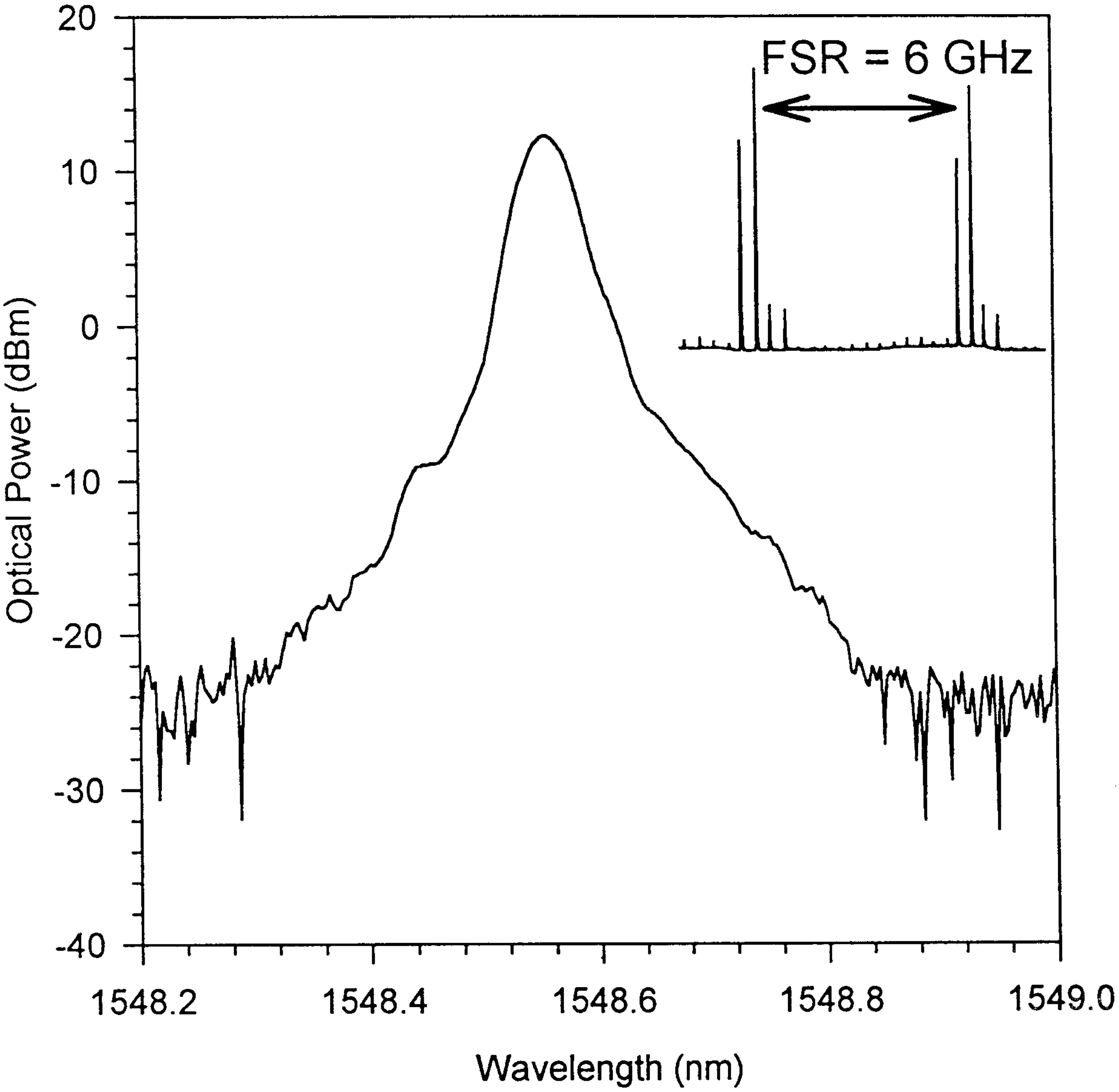
Fig. 2 Optical spectrum of laser at maximum output power of 17 mW.

Inset: Scanning Fabry-Perot interferometer spectrum showing dual polarisation mode operation.



18
16
14
12
10
8
6
4
2
0
1550 nm Output Power (mW)
(a)
(b)
0
20
40
60
80
100
120
140
160
180
200
Launched Pump Power (mW)
pumped at 523 nm
pumped at 980 nm

Fig. 1



20
10
0
-10
-20
-30
-40
Optical Power (dBm)
FSR = 6 GHz
1548.2
1548.4
1548.6
1548.8
1549.0
Wavelength (nm)

Fig. 2