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HIGHLY EFFICIENT 978nm DIODE PUMPED ERBIUM-DOPED FIBRE AMPLIFIER WITH 24dB GAIN.

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ABSTRACT

We report an Er^{3+}-doped fibre amplifier pumped with a strained InGaAs/AlGaAs quantum-well diode laser operating at 978nm. Efficient optical coupling was achieved with a wedge-tipped fibre. An optical gain of 24dB at 1535nm was obtained with only 6.2mW of pump power, corresponding to a gain of 3.9dB/mW of pump power. This is the highest efficiency for a fiber amplifier reported to date.

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INTRODUCTION Erbium-doped fibre amplifiers operating around 1.53μm are of particular interest for optical communications owing to their low insertion loss, lack of polarisation sensitivity, high fibre to fibre gain and broad bandwidth[1,2]. Previous reports have demonstrated that the 980nm pump band is ideal and a gain coefficient as high as 2.2dB/mW has been obtained with a dye laser pump[3]. More recently, similar performance (2.1dB/mW) has been obtained employing a pump wavelength of 1490nm, obtained from a color centre laser[4].

Practical erbium fibre amplifiers must be pumped by diode lasers. Of the available pump bands (980nm or 1490nm) it is not clear at present which diode wavelength will be more suitable in terms of pump efficiency and diode performance. In this paper we discuss the optimisation of an Er^{3+}-doped amplifier fibre for 980nm pumping to obtain a high gain, low pump-power amplifier. A 978nm strained InGaAs/AlGaAs quantum well laser coupled to a wedge-tipped fibre was used to optically pump the amplifier. The pump light and the signal at 1535nm were coupled to the amplifier using a dichroic fibre coupler. An optical gain of 24dB at 1535nm was obtained with a mere 6.2mW of pump power, corresponding to a record gain of 3.9dB/mW of pump.

EXPERIMENT The experimental arrangement is shown in Figure 1. The strained $In_{0.25}Ga_{0.75}As$/AlGaAs quantum-well diode pump laser[5] had an oxide stripe width of 25μm, a length of 600μm, and the rear facet had a high reflection coating to increase the power from the output facet. The lasing spectrum is shown in figure 2 at an operating current of 250mA and it can be seen that the majority of the power output is centred at 978nm, within the 980nm pump band.

Efficient optical coupling into the fibre was obtained by employing a wedge-tipped fibre. The fibre was uptapered to approximately two times its nominal diameter and subsequently polished to form a wedge tip which was aligned with the laser, resulting in 10mW of launched pump power. This fibre was spliced to a dichroic coupler which had a loss of 0.2dB at the pump wavelength. The other coupler input was used to add the signal from a 1535.3nm DFB laser. The output port was spliced to the amplifier fibre, where splice losses of 0.3dB at 1535nm and 0.6dB at 980nm were obtained, resulting in 6.2mW of launch pump power in the amplifier fibre.

The germano-silicate erbium-doped fibre was characterised by an NA of 0.21, and λ_{cutoff} at 955nm and a measured mode-field-diameter of 7.3μm at 1555nm. The splice loss to a commercial dispersion shifted fibre was 0.3dB. For maximum pump/dopant overlap and therefore best pump efficiency, the fibre was designed with the erbium localised to the central region of the core[6]. This localisation of the erbium doping and the increase in fibre NA are the major reasons for improvements over previous 980nm pumped results[3], where the measured fibre mode-field-diameter was 8.3μm.

RESULTS The amplifier length was optimised for maximum gain at 11.5m. Figure 3a,b shows the amplifier gain plotted against input and output signal respectively. A gain of 24dB was obtained for a pump power of 6.2mW. A 3dB gain compression occurred for input signals of -27dBm, corresponding to an output signal of -6dBm. These are excellent characteristics for deployment as an optical pre-amplifier. In addition since the fibre design optimises the pump/dopant overlap and thus the gain medium inversion the amplifier noise figure is expected[7] to be very close to the theoretical minimum value of 3dB.

Under optimum operating conditions, the unabsorbed pump power emerging from the fibre amplifier was measured at 1.5mW. Of this, 0.75mW was attributed to the spectrally broad fluorescence background emission from the diode laser which failed to overlap with the erbium absorption at 980nm. The effect of higher diode pump powers was simulated by using a dye laser operating at 980nm and are compared with the actual diode results in Figure 4a,b. The figure shows gain as a function of input and output signal powers and suggests that a gain in excess of 40dB can be obtained in future diode-pumped amplifiers for only 20mW of pump power at 980nm.

CONCLUSIONS We have demonstrated an efficient, high-gain erbium fibre amplifier pumped with a 978nm strained InGaAs/AlGaAs quantum well diode laser. A gain of 24dB was obtained with only 6.2mW of pump power. Higher diode pump powers were simulated with a 980nm dye laser and demonstrate that gains in excess of 40dB can be obtained for only 20mW of pump power.

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REFERENCES

1). R.J. Mears, L. Reekie, I.M. Jauncey and D.N. Payne, Electronic Letters, 1987, 23, pp. 1026-1028.

2). E. Desurvire, J.R. Simpson and P.C. Becker, Optics Letters, 1987, 12, pp. 888-890.

3). R.I. Laming, M.C. Farries, P.R. Morkel, D.N. Payne, P.L. Scrivener, F. Fontana and A. Righetti, Electronic Letters, 1989, 25, pp. 12-14.

4). E. Desurvire, C.R. Giles, J.R. Simpson and J.L. Zyskind, Proc. CLEO, Baltimore, 1989, PD-20.

5). D.P. Bour, G.A. Evans, D.B. Gilbert, J.Applied Phys. Lett., 1989, 65, pp. 3340-43.

6). B.J. Ainslie, J.R. Armitage, S.P. Craig and B. Wakefield, Proc. ECOC'88, Brighton, U.K., 1988, IEE 292, 1, pp. 62-65.

7). R. Olshansky, Electronic Letters, 1988, 24, pp. 1363-1365.

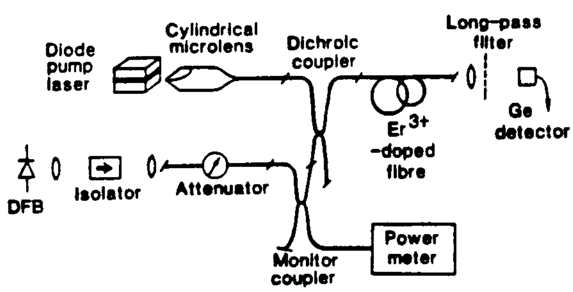

Figure 1.
Experimental arrangment.

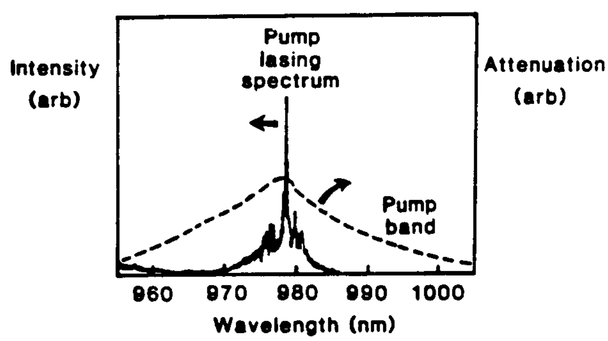

Figure 2. Spectrum of strained layer InGaAs/AlGaAs quantum well diode laser output and erbium pump band.

Figure 3a and 3b.
Gain versus input and output signal powers, respectively, for 978nm diode pumped amplifier.

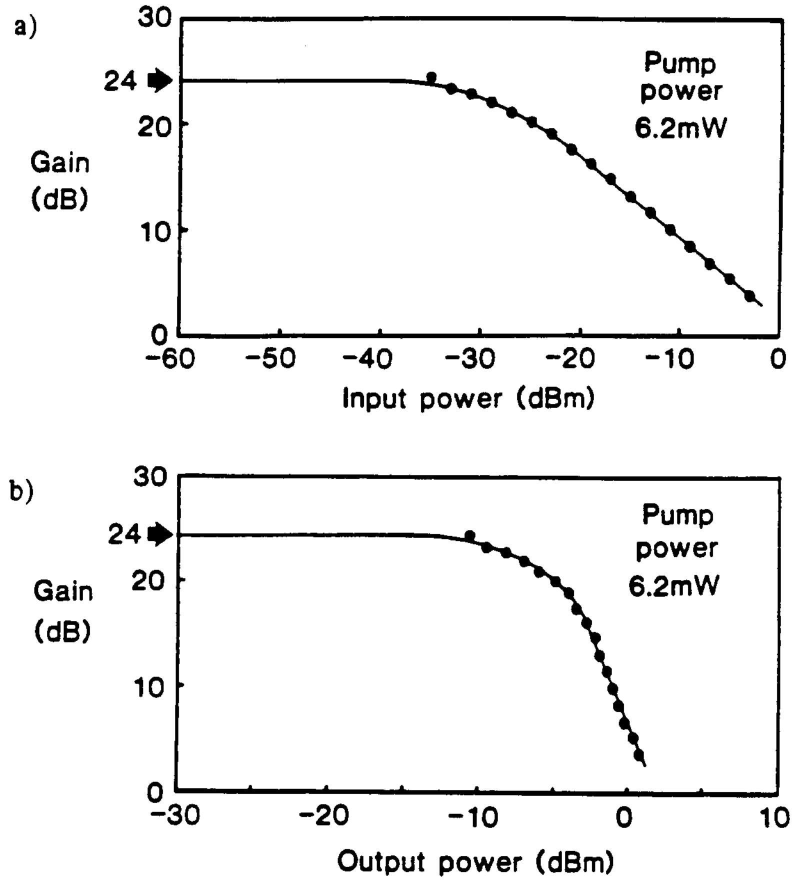

Figure 4a and 4b.
Gain versus input and output signal powers, respectively, for different pump powers.
▫ :980nm dye laser pump.
• :978nm diode laser pump.