Single Polarisation Fibre Lasers Using an Integral Polariser

J. T. Lin, D. N. Payne, L. Reekie, L. Li and J. D. Minelly

Introduction

Fibre lasers[1] represent a new class of active fibre devices with considerable potential for use in telecommunications, sensors and laboratory measurements. For these applications the realisation of a practical single-polarisation single-mode (SPSM) fibre laser is of considerable interest. In this paper we report an integral fibre polariser technique for making SPSM fibre lasers. The corresponding theory, design method and experimental results are also presented. It is shown that it is far more efficient to use an intra-cavity polariser than to polarise the output light with an external polariser.

Theory

Based on existing laser theory and a knowledge of the polarisation anisotropy of rare-earth ions in a glass matrix, a theoretical model analysing the polarisation effects in fibre lasers has been developed[2,3]. Experimentally we have found that the polarisation state of a fibre laser output depends strongly on the orientation of the (linearly-polarised) pump source, an unexpected result. Since a fibre laser can have two orthogonally-polarised eigenmodes[2], we define the polarisation efficiency η, as:

$$\eta = \frac{P^x}{P_{ab}} \tag{1}$$

where P_{ab} is the total absorbed pump power, and P^x is the fraction of P_{ab} which contributes to the operating polarisation mode, say the x-mode. The efficiency η is a function of the polarisation anisotropy of the active ions, as well as the launching orientation angle α of the linearly-polarised pump light to the birefringent axes of the single-mode fibre cavity. Figure 1 theoretically compares the polarisation efficiency of Nd^{3+} and Er^{3+}-doped SPSM fibre lasers having intra-cavity polarisers with fibre lasers having a polariser located outside the cavity. The experimental results for a Nd^{3+}-fibre laser is also shown. It can clearly be seen that the SPSM fibre laser offers a much higher polarisation efficiency. This is because a higher proportion of the total population inversion of excited ions has contributed to the operating polarisation if the undesired polarisation component has been suppressed within the resonator.

Construction

Instead of splicing a fibre polariser[4] to the fibre laser, integral fibre polarisers can be fabricated from rare-earth-doped fibres themselves. A conventional rare-earth-doped optical fibre preform is made, after which a flat is

Figure 1: Polarisation efficiency as a function of pump launching orientation, showing a higher polarisation efficiency for SPSM fibre lasers.

ground onto the preform to form an optical interaction surface. The resultant D-shaped preform is then fused into a sleeving tube to form a composite preform. After drawing, the fibre contains a longitudinal hollow sector (Figure 2(a)). When part of this hollow sector is filled with metal it acts as a polariser, since the polarisation component aligned in a direction normal to the metal surface is differentially absorbed. An alternative design (Figure 2(b)) is fabricated by drilling holes in a rare-earth-doped fibre preform, and then pulling into single-mode fibre.

Advantages of these integral fibre polarisers are:

1. minimal interfacial scattering,
2. accurate separation between the core and the metal surface,
3. choice of metal/glass interaction length,
4. automatic alignment of the birefringent axes with the interaction surface and
5. zero splicing loss.

A disadvantage is the difficulty of obtaining high-quality cleaves, which affects the laser performance when using a mirror-butting configuration[1]. It is believed, however, that this problem can be solved by an end-polishing technique.

A third integral polariser design (Figure 2(c)) is made by evaporating metal onto a side-polished fibre. The active fibre cladding is removed to expose the core using a novel fibre polishing technique[5], after which aluminium or silver is evaporated to form the polariser. A metal film of 0.2μm to 0.5μm thickness is typically used. This technique dramatically simplifies the fabrication procedure, since it uses a conventional fibre design and leaves the fibre ends unaffected, thus alleviating the problem of cleaving. However, misalignment between the birefringent axis and the metal interaction surface can reduce laser performance.

Figure 2: (a) D-shaped. (b) Twin-hole. (c) Metal-plated. Cross-sections of integral fibre polarisers.

Design

The performance of the fibre polariser is described by the insertion loss of the undesired y-mode L_y, and the attenuation ratio r of the y-and x-modes, $r = L_y/L_x$, which is a function of the metal used. L_y is proportional to the metal length and depends on the normalised separation d/a, where a is the core radius and d the distance between the metal surface and the core centre. The minimum L_y required for a given absorbed pump power is given by

$$L_y \geq 2KP^y - L + \ln R_2, \qquad (2)$$

where P^y is the effective absorbed pump power[3] for the y-mode, L is the intrinsic cavity loss, which is identical for both x and y-modes, R_2 is the reflectivity of the output mirror, K is the laser parameter[6] related to pumping efficiency, saturation density and the cross-sectional area of the fibre cavity. Both L and K can be determined experimentally[6].

For a typical laser-diode (LD)-pumped Nd^{3+}-doped fibre laser, $L = 0.03$, $K = 0.1/\text{mW}$, $R_2 = 80\%$, $P^y = 0.27$, P_{ab} = 2.5mW. Thus it can be determined that $L_y \geq 0.24$. Using the experimental figure $r = 60$ for Ga, we find that the insertion loss $L_x = 0.004$ (or 0.017dB) indicating a very low additional loss for the operating polarised mode.

In practice, the extinction ratio of the output from a SPSM fibre laser is limited by the superfluorescence of the unwanted polarised mode. Increasing L_y leads to a higher extinction ratio, at the expense of less output power. Figure 3 shows calculated curves for a LD-pumped SPSM laser for two different L_y.

Results

A variety of Nd^{3+} and Er^{3+}-doped SPSM fibre lasers have been constructed using the integral fibre polariser technique. Typical results are summarised in Table 1. The lasing characteristics of the LD-pumped, Nd^{3+}-doped, SPSM fibre laser using a metal-plated integral polariser listed in the right-hand column of Table 1 are shown in Figure 4. A CW output power of 3mW, a 25dB extinction ratio and 37% slope efficiency have been obtained.

Figure 3: Theoretical curves of extinction ratio as a function of absorbed pump power for two sets of integral polariser parameters.

Table 1:

Conclusions

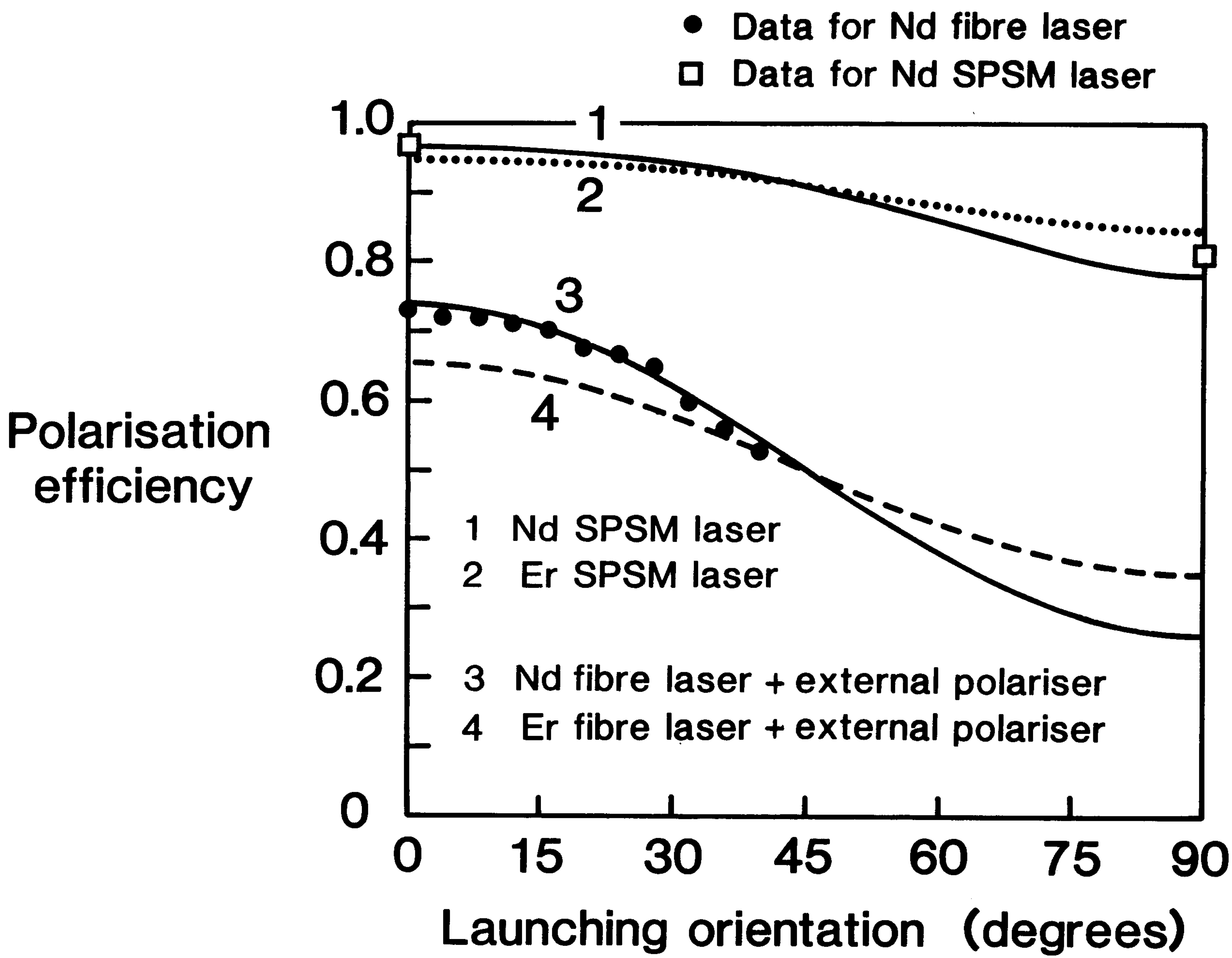
The integral-polariser technique provides a convenient and useful means for obtaining single-polarisation operation of a fibre laser. The polariser is one of a number of fibre devices which can be employed intra-cavity to enhance the performance of fibre lasers.

Figure 4: Experimental characteristics of a LD-pumped Nd^{3+}-doped fibre laser using an Al-plated integral polariser.

References

1. Poole, S. B., Reekie, L., Mears, R. J. and Payne, D. N., "Neodymium-doped silica single-mode fibre lasers", Elect. Lett., Vol. 21, 1985, pp. 738–740.
2. Lin, J. T., Morkel, P. R., Reekie, L. and Payne, D. N., "Polarisation effects in fibre lasers", Proc. ECOC. '87, Helsinki, Vol. I, 1987, pp. 358–360.
3. Lin, J. T., Gambling, W. A. and Payne, D. N., "Modelling of polarisation effects in fibre lasers", Proc. CLEO. '89, Baltimore, Vol. II, 1989, Papers No. TUJ25.
4. Li. L., Wylangowski, G., Payne, D. N. and Birch, R. D., "Broad-band metal/glass single-mode fibre polarisers", Elect. Lett., Vol. 22, 1986, pp. 1020–1022.
5. Hussey, C. D. and Minelly, J. D., "Optical fibre polishing with a motor driven polishing wheel", Elect. Lett., Vol. 24, 1988, pp. 805–807.
6. Koechner, W., Solid-State Laser Engineering, Springer-Verlag, 1976.

400 fig1



21.5 to 8.0

Fig1

400

fig 2 (a)

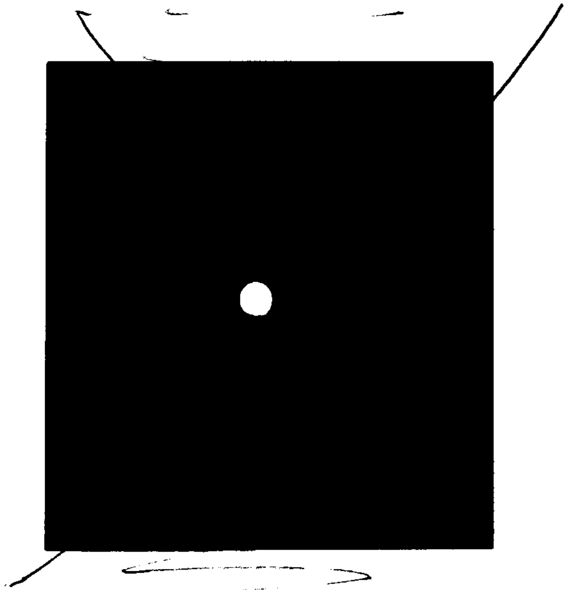
Screen

6·5
to
4·3

2a

400
Fig 2 (b)
& (c)

Screen

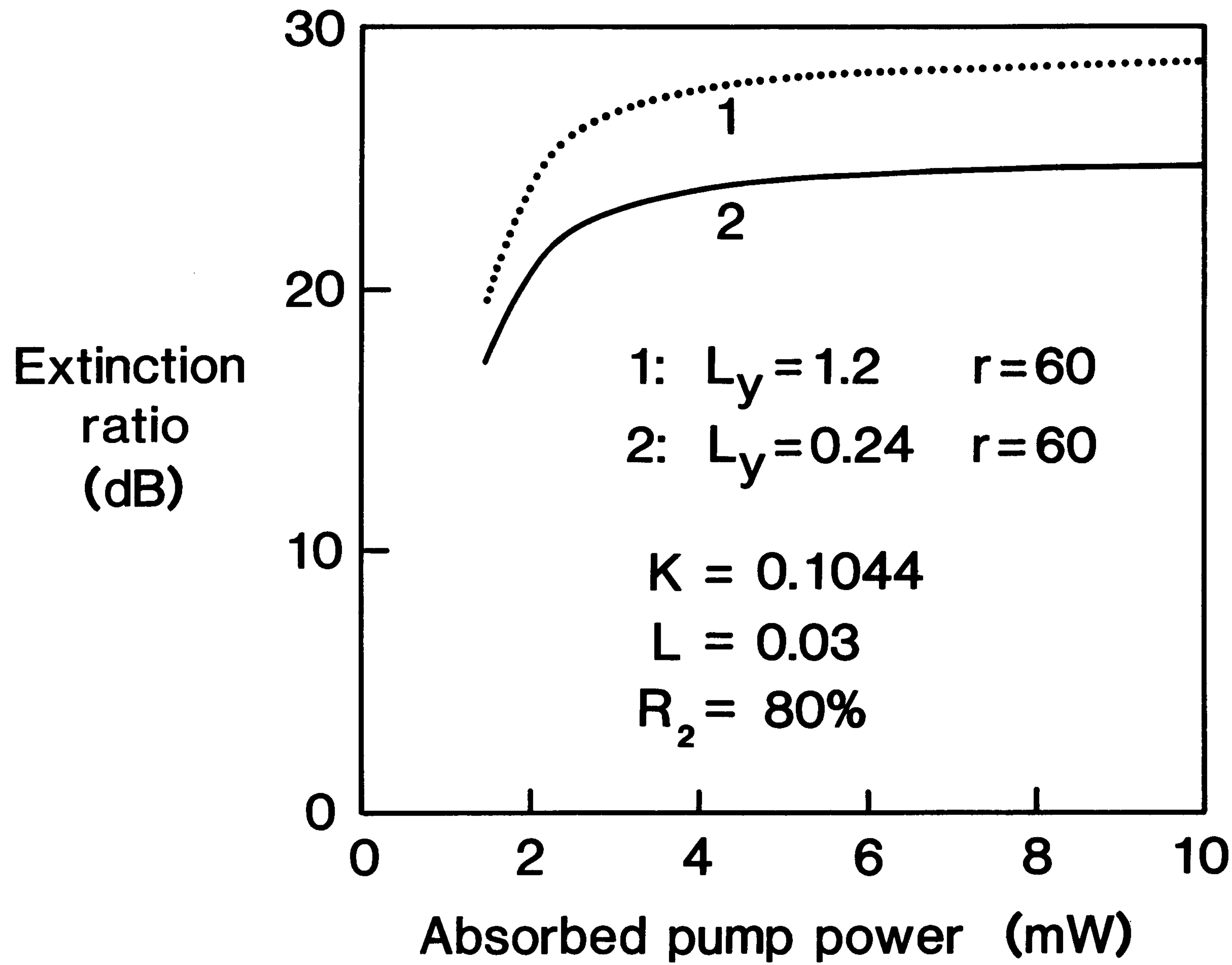


2b

2c

6.5
to
4.3

40 o fig 3



20.0
to
8.0

Fig 3

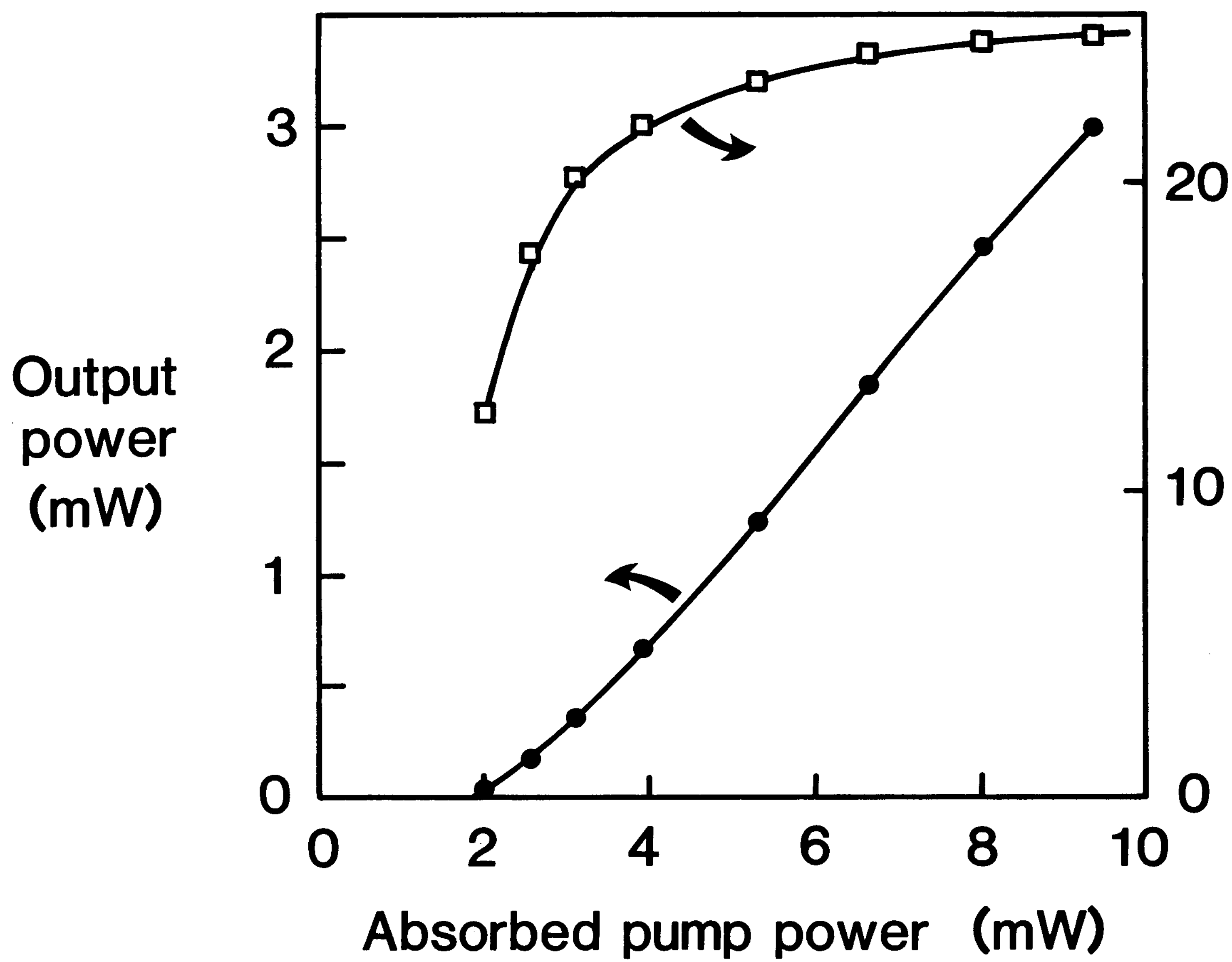


Fig 4

400 to 4

24.0 to 8.0

		D-SHAPED	TWIN-HOLE	METAL-PLATED
POLA-RISER	metal type	Ga	Ga	Al
	separation d/a	3.8	2.5	3.0
	metal length	35mm	7mm	15mm
CAVITY	dopant	Nd^{3+}	Er^{3+}	Nd^{3+}
	fibre length	200cm	140cm	26cm
	R_2	50%	80%	80%
PUMP	source	LD(Sony SLD 204V)	DCM Dye	LD
	wavelength	825nm	650nm	825nm
	absorbed power	10mW	50mW	10mW
SPSM-LASER		(CW) (Q-switched)	(CW)	(CW)
	output power	2.1mW 3.9W	1.2mW	3mW
	extinc. ratio	23dB 29dB	22dB	25dB
	pulse width	150ns		
	wavelength	1088nm	1536nm	1080nm

Table 1

145 to 8.0

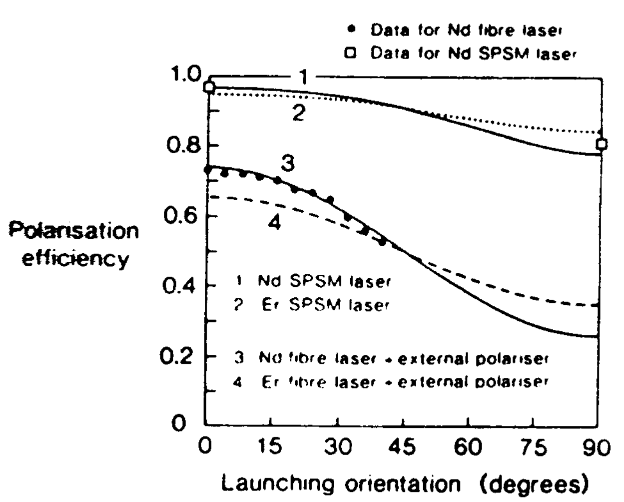


Fig.1
Polarisation efficiency as a function of pump launching orientation, showing a higher polarisation efficiency for SPSM fibre lasers.