EFFICIENT OPERATION OF AN Yb-SENSITISED Er FIBRE LASER PUMPED IN 0·8 μm REGION

Indexing terms: Lasers and laser applications, Optical fibres, Doping, Optical properties of substances

The dependence of threshold and slope efficiency on pump wavelength around 0·8 μm has been investigated for an Yb-sensitised fibre laser. Results confirm a wider choice of pump wavelength compared with unsensitised Er fibre. A 5 mW threshold and slope efficiency of 8·5% were observed for 820–830 nm pumping.

Introduction: Erbium-doped monomode fibre lasers[1] and amplifiers[2] are of great interest for optical communications as their operating wavelength falls within the silica transmission window at around 1·55 μm. Attention is currently being directed towards the problem of developing an effective scheme for Er involving cheap and reliable sources such as the AlGaAs diode laser. Whilst pumping by such diode lasers has been demonstrated,[1] the performance is adversely affected by the weak absorption of the $^4I_{15/2} - {}^4I_{9/2}$ pump transition and by the presence of excited state absorption (ESA) of the pump light.[3] In a recent paper[4] we reported results obtained for a fibre with an alternative pumping scheme, first reported for bulk glass[5] and recently for a fibre,[6] in which the Er fibre is codoped with Yb, so that pump light is absorbed by the Yb and the excitation is then transferred to the Er. The Yb pump transition $^2F_{7/2} - {}^2F_{5/2}$ provides absorption in the range 800–1070 nm, thus greatly extending the range of possible pump wavelengths. Here we give details of results obtained when pumping with a Styryl 9M dye laser operating over the range 800–845 nm. These results are consistent with the presence of pump-induced excited state absorption, which has been observed in the form of green emission at 543 nm. This emission is believed to originate by decay to the ground state from the $^4S_{3/2}$ state in Er. The excitation spectrum of the 543 nm emission clearly shows peaks at 800 and 840 nm, where increased laser thresholds have also been observed, as detailed below. The benefit of the Yb sensitiser is also clearly demonstrated in that efficient pumping is possible in the 820–830 nm range where ESA is greatly reduced and where efficient pumping is not possible in the unsensitised Er fibre.

Experimental: The silica based fibre was fabricated using a solution doping technique[7] to give dopant concentrations of 1·7% Yb and 0·08% Er, with a core radius of 2·3 μm and LP_{11} mode cutoff at 1·5 μm. The laser resonator was formed by cleaving the fibre ends and butting them against two dielectric mirrors. The input mirror transmission was pump wavelength dependent, ranging from 60% to 87% between 800 nm and 845 nm, but >99% reflective around 1·55 μm. The output coupler was 28% transmissive at 1·55 μm and around 22% reflective for the pump.

The performance of the Yb : Er fibre laser was investigated using a Styryl 9M dye laser to end pump the fibre at wavelengths between 800 nm and 845 nm. The aim of the investigation was to assess the requirements and expected performance for pumping with AlGaAs diode lasers and to examine the effect of ESA. The limit of 845 nm was chosen as it corresponds with the long wavelength limit for readily available AlGaAs diode lasers, while the short wavelength limit of 800 nm was imposed by the need for sufficient absorption by the Yb.

The measurements made were of threshold and slope efficiency at several wavelengths (Figs. 1 and 2) for a 70 cm fibre length. A second series of measurements was also made for a 40 cm length, where the shorter length reduces self-absorption and makes the losses due to ESA more apparent.

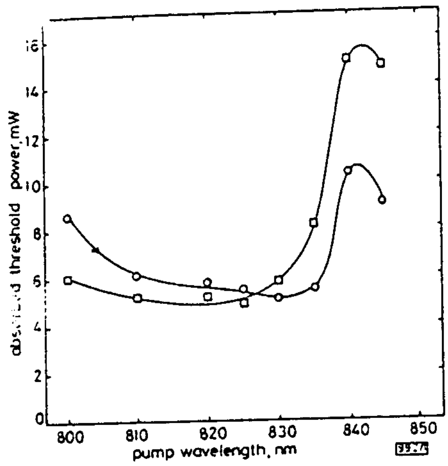

Fig. 1 *Variation of absorbed threshold power with pump wavelength for 70 cm and 40 cm fibre lengths*

□□□ 70 cm ○○○ 40 cm

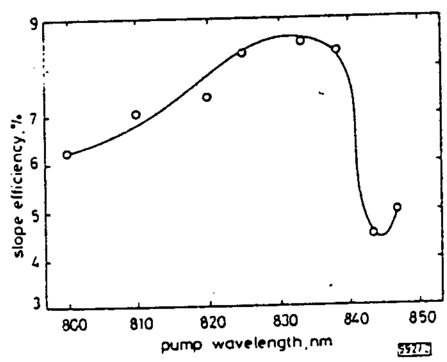

Fig. 2 *Variation of slope efficiency with pump wavelength for 70 cm fibre*

Results: From the experimental measurement of variations in threshold and slope efficiency with pump wavelength Figures 1 and 2 were plotted. Notice that either side of the 820–830 nm region the threshold (absorbed power) increases quite rapidly and the slope efficiency decreases correspondingly. When the length of fibre was reduced from 70 cm to 40 cm the threshold increased for wavelengths shorter than 830 nm and decreased for wavelengths longer than 830 nm, relative to the performance of the longer length. (Slope efficiency measurements were not possible for the 40 cm fibre as the reduced length meant less pump absorption took place and the output power was extremely low.)

Detailed modelling of this behaviour has not yet been carried out, in particular with regard to the effect of fibre length. However, it appears that the dependence of threshold and slope efficiency on pump wavelength is consistent with the presence of ESA absorption peaks at 800 nm and 840 nm.

The minimum threshold observed in these measurements was 5 mW (absorbed) and the best slope efficiency with respect to absorbed power was 8·5%, for pump wavelengths between 820 nm and 830 nm. These results are significantly better than for 1·064 μm pumping.[4]

The lasing wavelength was centred at 1·56 μm. Under some conditions it was observed that lasing could occur on an Yb transition at around 1·08 μm, as previously observed in fibre doped with Yb only.[8] Simultaneous lasing at 1·08 μm and 1·56 μm was also observed. Suppression of this 1·08 μm transition can easily be achieved by appropriate choice of mirror reflectivity. Lasing at 1·08 μm does not occur when pumped by Nd : YAG at 1·064 μm since this is then the pump transition.

Conclusion: We have shown that efficient, low threshold operation of Yb : Er fibre can be achieved by choosing a suitable pump wavelength in the region 820–830 nm, away from excited state absorption. Threshold powers indicate that diode laser pumping will be easily realised and promises efficient operation. With optimisation of various experimental parameters such as fibre length, core diameter and output coupling, further significant improvements can be envisaged.

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References

1 REEKIE, L., JAUNCEY, I. M., POOLE, S. B., and PAYNE, D. N.: 'Diode laser pumped operation of an Er^{3+}-doped single mode fibre laser', *Electron. Lett.*, 1987, **23**, pp. 1076–1077

2 MEARS, R. J., REEKIE, L., JAUNCEY, I. M., and PAYNE, D. N.: 'Low-noise erbium-doped fibre amplifier operating at 1·54 μm', *Electron. Lett.*, 1987, **23**, pp. 1026–1028

3 LAMING, R. I., POOLE, S. B., and TARBOX, E. J.: 'Excited state absorption in erbium-doped fibres', submitted to *Optics Lett.*

4 FERMANN, M. E., HANNA, D. C., SHEPHERD, D. P., SUNI, P. J., TOWNSEND, J. E., and TROPPER, A. C.: 'Efficient operation of an Yb sensitised Er fibre laser at 1·56 μm', *Electron. Lett.*, 1988, **24**, (18)

5 SNITZER, E., and WOODCOCK, R.: 'Yb^{3+}–Er^{3+} glass laser', *Appl. Phys. Lett.*, 1965, **6**, pp. 45–46

6 SNITZER, E., PO, H., HAKIMI, F., TUMMINELLI, R., and MCCOLLUM, B. C.: 'Erbium fibre laser amplifier at 1·55 μm with pump at 1·49 μm and Yb sensitised Er oscillator'. O.F.C. Conference, New Orleans, Louisiana, PD2-1, Jan. 1988

7 TOWNSEND, J. E., POOLE, S. B., and PAYNE, D. N.: 'Solution-doping technique for fabrication of rare-earth doped optical fibres', *Electron. Lett.*, 1987, **23**, pp. 329–331

8 HANNA, D. C., PERCIVAL, R. M., PERRY, I. R., SMART, R. G., SUNI, P. J., TOWNSEND, J. E., and TROPPER, A. C.: 'Continuous-wave oscillation of a monomode ytterbium-doped fibre laser', *Electron. Lett.*, 1988, **24**, pp. 1111–1113