CONTINUOUS-WAVE OSCILLATION OF A MONOMODE THULIUM-DOPED FIBRE LASER

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

Laser emission in the wavelength band 1·88–1·96 μm has been observed in a monomode fibre doped with thulium. When pumped with a dye laser at 797 nm an absorbed threshold power of 21 mW and a slope efficiency of 13% were obtained.

Introduction: It is well known that rare-earth ions can be incorporated into monomode silica fibres,[1,2] which can then form the basis of efficient lasers and amplifiers. The low thresholds obtainable with fibre lasers allow the possibility of pumping with semiconductor laser diodes in the 0·8 μm range for those rare-earth ions which have an absorption band near the diode wavelength. To date laser action in Nd,[3] Er,[4] Yb[5] and co-doped Yb–Er[6] fibres has been achieved with pump power thresholds and wavelengths available from semiconductor laser diodes.

Thulium-doped glass is of interest from a laser point of view because it provides emission in wavelength regions not covered by other rare-earth elements. Furthermore thulium has an absorption band near 800 nm[2] and is thus a candidate for pumping with a laser diode. Laser action in thulium-doped glass was first reported by Gandy *et al.*[7] in 1967. Flashlamp pumping of a liquid nitrogen cooled silicate glass rod gave rise to pulsed oscillation at 1·85 μm between the $^3H_4$ level and the ground state $^3H_6$ (labelling of Tm^{3+} states follows the convention of Reference 7). Operation at room temperature caused oscillation to a higher level in the ground state multiplet and resulted in emission at 2·015 μm, where the stimulated emission cross-section was smaller and the pump threshold consequently higher.

We report here the first operation of a Tm-doped fibre laser and present preliminary performance characteristics. The oscillation wavelength at $\simeq 1{\cdot}9\,\mu$m is the longest that has so far been reported in a silica fibre. The threshold power and absorption wavelength band suggest that diode-pumped operation is feasible.

Experimental: In the experiment a germano-silica based fibre produced by the solution doping technique[8] was used. The fibre was characterised by a Tm^{3+} concentration of approximately 830 ppm, numerical aperture of 0·15, cut-off wavelength of 1·7 μm and core diameter 9 μm.

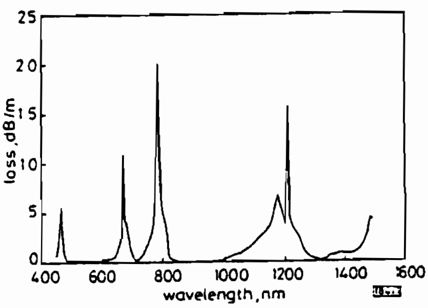

Fig. 1 *Absorption spectrum of Tm-doped fibre*

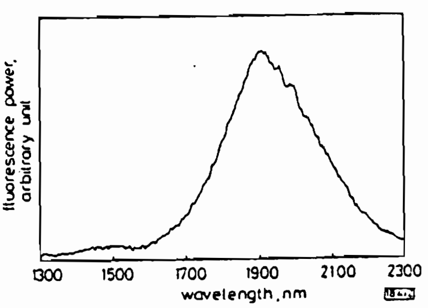

Fig. 2 *End-light fluorescence spectrum of Tm-doped fibre*

As can be seen from Fig. 1, thulium has a strong absorption band near 800 nm ($^3H_6$ to $^3F_4$). For this reason a Styryl 9M dye laser operating around 800 nm was used as the pump source in this experiment. A broad fluorescence band (see Fig. 2) was observed from $\simeq 1{\cdot}7\,\mu$m to $\simeq 2{\cdot}2\,\mu$m corresponding to the $^3H_4$ to $^3H_6$ transition. This spectrum shows the fluorescence exiting a 27 cm length of fibre at the far end after being guided down the fibre core. Shorter pieces showed a similar spectrum except that the fluorescence extends to shorter wavelengths as a result of reduced self-absorption, i.e. absorption due to thermally populated Stark levels in the ground state multiplet. The lifetime of the upper state was measured to be approximately 200 μs. A much weaker fluorescence near 1·5 μm is due to the $^3F_4$ to $^3H_4$ transition. The relative weakness of this emission is indicative of a fast non-radiative decay from the $^3F_4$ level, a conclusion which is supported by the experimentally estimated upper state lifetime of $\leq 10\,\mu$s.

Initial observations of laser action were made using a 1·3 m length of fibre, with highly reflecting mirrors butted against the cleaved fibre ends. With this length of fibre it was found necessary to cool the fibre by immersion in liquid nitrogen to reduce the self-absorption at the lasing wavelength, caused by population in the lower laser level. This arrangement, in which all but $\simeq$10 cm length of fibre at each end was immersed in liquid nitrogen, gave an incident pump threshold of 70 mW (50 mW absorbed) and the laser oscillation wavelength was observed to be 1·88 μm. Keeping the fibre length fixed, but decreasing the length of the cooled portion, the threshold was found to increase and laser emission shifted to longer wavelengths as the effect of self-absorption became greater.

Subsequently the fibre was removed from the nitrogen Dewar and cut back to reduce the effects of fluorescence self-absorption. Optimal results were achieved with a 27 cm length of fibre. Pumping at 797 nm, near the peak of the absorption band, and using high reflectivity mirrors, CW oscillation was observed at 1·96 μm with an incident pump threshold of 30 mW (21 mW absorbed). On changing the output coupling to about 3%, laser emission was seen at 1·94 μm. Here the threshold incident power was unchanged at 30 mW (21 mW absorbed), and a slope efficiency, measured with respect to absorbed power, of 13% was measured. The maximum extracted power in this configuration was 2·7 mW.

Discussion: We have observed CW laser action near 2 μm in a monomode thulium-doped silica fibre. The low thresholds obtained suggest that with optimisation of the laser cavity, operation using an AlGaAs diode as the pump should be possible. Oscillation has so far been observed between 1·88 μm and 1·96 μm. The broad fluorescence spectrum around 2 μm suggests that a wide tuning range could be available, where fluorozirconate fibres potentially have a low loss.[9] The long wavelength limit may in practice be limited by absorption of the silica host, although more heavily doped fibre could mitigate this problem. Further work will be aimed at investigating the available tuning range.

Acknowledgments: The UK Science and Engineering Research Council provided financial support in the form of grant GR/E/13679 as well as studentships for I.P., R.S. and J.T. A CASE studentship was provided for I.J. from Plessey Research (Caswell) Ltd.

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1st August 1988

References

1 POOLE, S. B., PAYNE, D. N., and FERMANN, M. E.: 'Fabrication of low-loss optical fibres containing rare-earth ions', *Electron. Lett.*, 1985, 21, pp. 737–738

2 AINSLIE, B. J., CRAIG, S. P., and DAVEY, S. T.: 'The absorption and fluorescence spectra of rare earth ions in silica-based monomode fibre', *J. Lightwave Technol.*, 1988, 6, pp. 287–293

3 MEARS, R. J., REEKIE, L., POOLE, S. B., and PAYNE, D. N.: 'Neodymium-doped silica single-mode fibre lasers', *Electron. Lett.*, 1985, 21, pp. 738–740

4 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

5 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, (17), pp. 1111–1113

6 HANNA, D. C., PERCIVAL, R. M., PERRY, I. R., SMART, R. G., and TROPPER, A. C.: 'Efficient operation of an Yb-sensitised Er fibre laser pumped in the 0·8 μm region', *Electron. Lett.*, 1988, 24, (17), pp. 1068–1069

7 GANDY, H. W., GINTHER, R. J., and WELLER, J. F.: 'Stimulated emission of Tm^{3+} radiation in silicate glass', *J. Appl. Phys.*, 1967, 38, pp. 3030–3031

8 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

9 BRIERLEY, M. C., FRANCE, P. W., and MILLAR, C. A.: 'Lasing at 2·08 μm and 1·38 μm in a holmium doped fluoro-zirconate fibre laser', *Electron. Lett.*, 1988, 24, pp. 539–540