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

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

Laser emission has been observed in a monomode fibre doped with ytterbium. A wide tuning range has been observed, 1·015 μm to 1·140 μm, when pumped by a dye laser at 840 nm. Diode pumped operation has also been achieved in a cooled fibre.

Introduction: Laser oscillation in ytterbium-doped glass was first reported by Etzel *et al.*[1] in 1962 and further detail of its laser behaviour was reported by Snitzer[2] in 1966. However, there has been relatively little interest in this laser system since the neodymium glass laser, with much the same emission wavelength, was found to have a generally superior performance. In this letter we present the first report of laser oscillation in an ytterbium-doped fibre pumped with either a dye laser or a diode laser. The motive for our investigation was that the ytterbium system offered a number of interesting aspects. For example, there is an absence of excited state absorption (ESA), since apart from the laser levels all other levels are in the UV region. This lack of ESA, together with the broad spectral range observed in fluorescence[2] indicated that a significant tuning range might be achieved. The work reported here has confirmed this, and the range of wavelengths covered so far, 1·015–1·140 μm, exceeds that covered by the Nd fibre laser.[3,4] A further interesting aspect was that, despite the large detuning from the available pump absorption transition, the ytterbium system offered the convenience of pumping with commercially available AlGaAs diode lasers. This is possible because in the form of a fibre a long absorption length can be tolerated and thus a weak absorption exploited.

Experimental: The optical fibres used in this work were prepared by the solution doping technique.[5] Two different ytterbium doping concentrations have been used: 2500 ppm and 600 ppm. Otherwise the fibres had similar characteristics: numerical aperture $\simeq 0{\cdot}16$–$0{\cdot}17$, cutoff wavelength $\simeq 800$ nm, and core diameter $\simeq 3{\cdot}7\,\mu m$. For most of the work the pump source was provided by a CW Styryl 9M dye laser operating at $\simeq 840$ nm. As seen from the energy level diagram (Fig. 1*a*), a longer pump wavelength would give better absorption. However, we chose 840 nm to assess the performance at the longest wavelength readily available from commercial AlGaAs diode lasers. With 840 nm as the pump wavelength the detuning from the absorption peak at 915 nm corresponds to $\simeq 900\,cm^{-1}$.

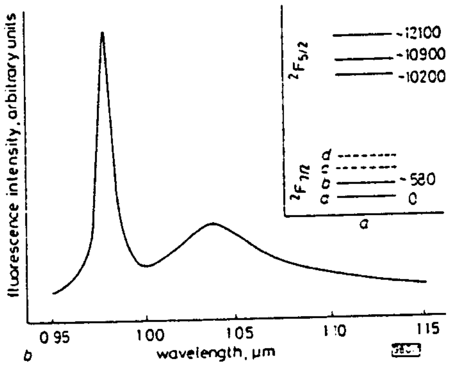

Fig. 1

a Energy level diagram for Yb^{3+} in silica host
b Side-light fluorescence spectrum for Yb^{3+}-doped fibre used in these experiments

The fluorescence spectrum excited by the 840 nm pump is shown in Fig. 1*b*. This was obtained by observing side light from the fibre, thus avoiding self-absorption effects. The emission peaks at 0·979 μm and 1·038 μm are clearly resolved. The spectrum differs from that observed by Snitzer[2] in a silicate glass host in that the latter peak is shifted (from $\simeq 1{\cdot}015\,\mu m$). Also the peak at 1·06 μm which was clearly evident in Snitzer's data is not resolved in the silica host, although the shape of the long wavelength tail suggests its presence. Our observation of laser operation at 1·076 μm in a resonator without wavelength selective elements also suggests the presence of an unresolved transition in this region.

The energy level diagram in Fig. 1*a* shows the three energy levels of the $^2F_{5/2}$ manifold which are resolved in absorption. The $^2F_{7/2}$ manifold is shown as having four levels, labelled *a*, *b*, *c* and *d*, the lower two being clearly resolved in the fluorescence. Levels *c* and *d* are unresolved but are believed to be responsible for the long wavelength tail of the fluorescence.

Two different fibre resonator configurations have been used. The simplest involved mirrors butted at each end of the fibre. The fibre ends were prepared in various ways, but the best results were obtained using a mechanical cleaver. Measurements with the low dopant fibre (600 ppm) showed that the laser wavelength was dependent on fibre length, with typical results ranging from 1·084 μm for a 7 m length of fibre to 1·038 μm for a 1 m length. This behaviour is the result of self-absorption which can be significant even for the transition to level *c*, since with the assumed energy of $\simeq 900\,cm^{-1}$ this level would contain $\simeq 1\%$ of the total ytterbium population at room temperature. As the fibre is progressively shortened the self-absorption is decreased, allowing lasing at shorter wavelengths. For short enough fibres lasing is favoured on the transition terminating on level *b*, since the higher emission cross-section of this transition then outweighs the greater self-absorption.

Using an output mirror of 20% transmission and a fibre length of 7 m a threshold (absorbed power) of 8 mW was obtained. The resonator losses (including self-absorption) were measured by observation of relaxation oscillation behaviour[6] to be $\simeq 30\%$ per pass. The slope efficiency under these conditions was found to be 15% with respect to absorbed power (Fig. 2). Significant improvement on these figures can be expected with lower loss resonators of optimised output mirror transmission.

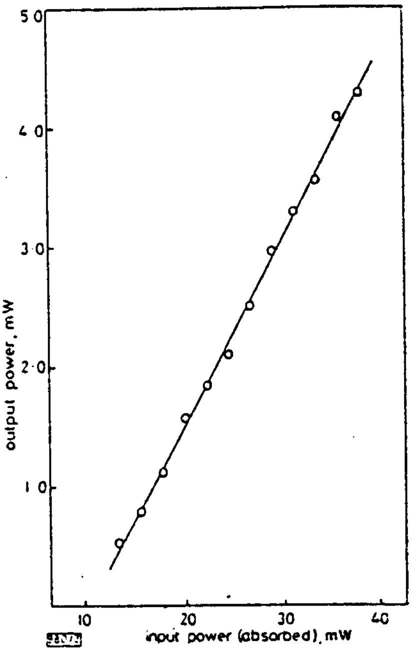

Fig. 2 *Slope efficiency for Yb^{3+} fibre laser*

To investigate further the tuning behaviour a resonator containing a dispersion prism was used with an intracavity GRIN (gradient index) lens adjacent to the fibre end to provide a collimated beam through the prism. Tuning was provided by tilting the resonator mirror adjacent to the prism. For these measurements the heavily doped (2500 ppm) fibre was used. With a 30 cm length of fibre it was found that continuous tuning over the range 1015 nm to 1140 nm could be obtained. This tuning range of 125 nm compares very favourably with dye laser tuning ranges. With improvements to this rather lossy resonator a significant further extension of range should be possible.

For preliminary tests of diode laser pumped operation we made use of an available diode laser operating at 822 nm, with a total output of 12 mW. With this limited pump power and shorter wavelength than desired it was found necessary to cool the fibre to reduce the threshold. A 20 m length of fibre (600 ppm) was used with most of this length (apart from the ends) coiled and immersed in a Dewar containing liquid nitrogen. This essentially emptied level *b*. Under these conditions a threshold of 2 mW absorbed power was achieved and laser emission was seen over a range of wavelengths between 1028 nm to 1064 nm. Extrapolation of these results for the cooled fibre suggest that room temperature operation with an 840 nm diode laser should be readily achievable.

Conclusion: We have demonstrated wide tuning range and diode laser pumped operation in an ytterbium doped fibre laser. Since all the reported results have been obtained under unoptimised conditions there is considerable scope for improvements in performance and in particular for room temperature operation of a diode laser pumped system.

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