CONTINUOUS-WAVE OSCILLATION OF HOLMIUM-DOPED SILICA FIBRE LASER

Indexing terms: Lasers and laser applications, Optical fibres, Doping

Laser emission at 2·04 μm has been observed in a silica fibre doped with Ho^{3+}. When pumped with an argon laser at 457·9 nm an absorbed threshold power of 46 mW and a slope efficiency of 1·7% were measured.

Introduction: The incorporation of rare-earth ions into silica fibres has led to a number of efficient low threshold laser sources. At present the reported wavelength range available from such lasers extends from the visible[1] out to nearly 2 μm,[2] although long wavelengths have been demonstrated in lasers based on fluorozirconate fibres.[3,4]

Ho^{3+} is of potential interest as an activator ion because it has a transition at about 2 μm and a wavelength region which may prove useful for eye-safe coherent radar and medical applications. Laser oscillation of the Ho^{3+} ion in a bulk silicate glass was first reported by Gandy and Ginther in 1962.[5] Recently Brierley *et al.*[3] reported pulsed (3 kHz) operation at 2·08 μm of a Ho^{3+}-doped fluorozirconate fibre laser.

The results reported in this letter represent the first observation of continuous wave operation of a Ho^{3+}-doped glass laser on the ≃2 μm $^5I_7$–$^5I_8$ transition, the first observation of lasing from Ho^{3+} in a silica host, and the longest emission wavelength (2·04 μm) reported to date for a silica fibre laser.

Experimental: In this experiment a germano-silicate-based fibre fabricated by the solution doping technique[6] was used. The fibre was characterised by a Ho^{3+} concentration of ≃200 ppm, numerical aperture of 0·21, cut-off wavelength of 2·165 μm and core diameter of 8 μm.

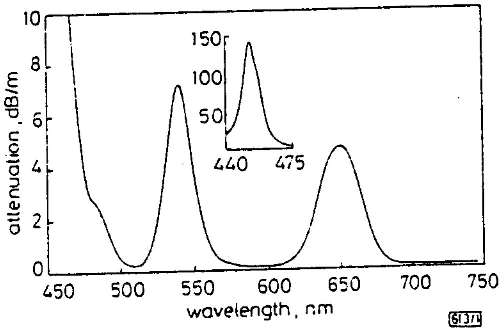

Fig. 1 *Absorption spectrum of Ho^{3+} in silica*

As can be seen from Fig. 1, Ho^{3+} in fused silica has a strong absorption in the blue between 450 nm and 460 nm with much weaker bands at around 488 nm, and in the green and red at around 540 nm and 650 nm, respectively. We have therefore used an argon ion laser at 457·9 nm and a DCM dye laser at ≃650 nm as the pump sources for these experiments. The fluorescence spectrum of Ho^{3+} under DCM pumping is shown in Fig. 2. Plot *a* shows the spectrum for light leaving the end of a 50 cm length of fibre (end-light) and plot *b* for side-light emitted perpendicularly to the fibre axis. Comparison of these spectra shows that self-absorption on this near three-level $^5I_7$–$^5I_8$ transition (Fig. 3) causes an apparent shift in the peak emission of end-light to longer wavelengths. By chopping the pump beam and measuring the fluorescence decay, the lifetime of this 2 μm emission was found to be ≃600 μs. This lifetime is considerably shorter than the calculated radiative lifetime of 45 ms obtained from the absorption line strength, and suggests a significant contribution to the decay from nonradiative routes. These values indicate a radiative quantum efficiency of only ≃1·5%.

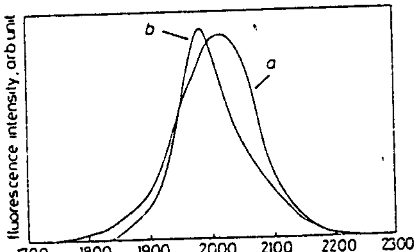

Fig. 2 *Fluorescence spectrum of Ho^{3+} in silica at around 2 μm*

a Light exiting end of 50 cm length
b Light scattered perpendicular to fibre axis

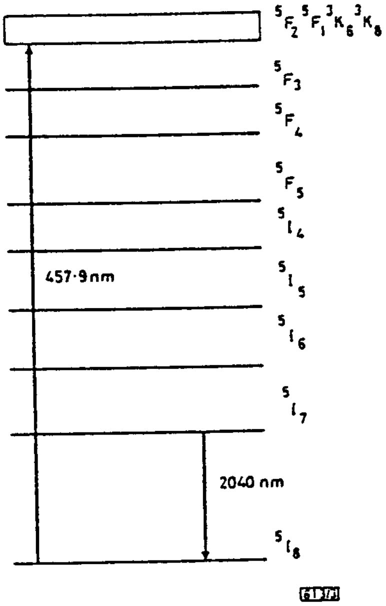

Fig. 3 *Energy level diagram for Ho^{3+} in silica*

Laser oscillation at 2·04 μm was achieved using the argon laser at 457·9 nm as pump, launched by a 10× microscope objective into a short (17 cm) length of fibre, with butted mirrors at each end of the fibre. The input mirror had a transmission of 80% at 457·9 nm and ≃99% reflectivity at 2·04 μm. It was determined that ≃50% of the pump light was launched into the core of the fibre. The output coupler had 98% reflectivity at the lasing wavelength. The 17 cm fibre length used was the shortest that could be accommodated

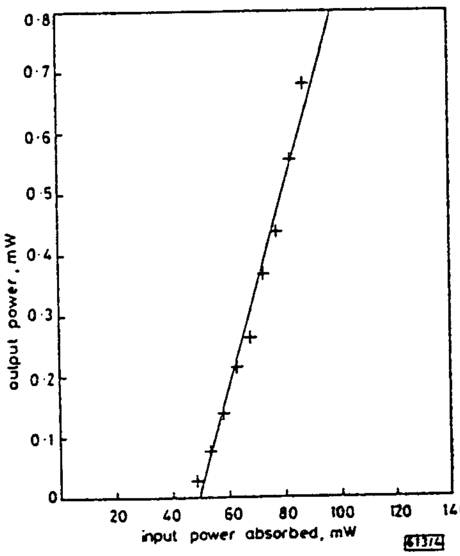

Fig. 4 *Slope efficiency plot for Ho^{3+}-doped silica fibre laser*

with our arrangement using fibre manipulators to butt the fibre against the resonator mirrors. With this length of fibre 97% of the launched power was absorbed; with longer lengths threshold could not be reached, probably as a result of the greater self-absorption losses on this quasi-3-level transition.

The absorbed pump power for the threshold of laser oscillation was measured to be 46 mW (95 mW incident). The slope efficiency was measured to be 1·7% (Fig. 4) with respect to absorbed pump power (0·8% with respect to incident pump power) with a maximum extracted power of 0·67 mW for an absorbed power of ≃85 mW. Attempts to achieve lasing with DCM pumping were unsuccessful. In the light of the results obtained with the blue pump, this lack of success with the red pump is not unexpected as a much weaker absorption is involved, thus requiring a longer length of fibre for the same amount of pump absorption.

Conclusions: We have observed continuous wave laser action at 2·04 μm in a Ho^{3+}-doped silica fibre laser. Our measurements suggest that rapid nonradiative decay from the upper laser level is responsible for the high threshold relative to other silica fibre lasers. Despite this it should be possible to achieve a useful improvement in performance by optimisation of the fibre characteristics, for example using a smaller core diameter. The fact that this threshold could only be reached with the shortest fibre that we could accommodate suggests that further improvement could be obtained by going to shorter lengths and thus reducing self-absorption. To make a more practical system it would clearly be desirable to achieve pumping with a diode laser. In fact by codoping with Tm^{3+} it is possible to introduce a pump band at around 800 nm and Ho^{3+} can then be excited by energy transfer from Tm^{3+} to Ho^{3+}. This process which can give an overall pump quantum efficiency of 2 has been observed to operate efficiently in a crystal host.[7] The feasibility of such a scheme in a silica fibre will be examined in future work.

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