Optimising Tm-Doped Silica Fibres for High Lasing Efficiency

P. C. Shardlow, D. Jain, R. Parker, J. Sahu and W.A. Clarkson

Optoelectronics Research Centre, University of Southampton, Southampton, UK

Two-micron lasers are of great interest for a range of applications, from spectroscopy to polymer machining and laser surgery, as well as being an important stepping stone for wavelength generation further into the mid infra-red band. Tm-doped silica fibre lasers are especially attractive as they are capable of operating at wavelengths from below 1700nm to more than 2100nm, and can be pumped by commercially available high power laser diodes operating around ~793nm. Moreover, by optimising the dopant concentration within the Tm fibre core a beneficial two-for-one cross-relaxation process can be exploited allowing efficiencies far-above the quantum limit for 793nm pumped Tm fibre lasers [1]. Indeed, efforts to optimise the core composition to enhance this process have been the subject of many studies, but as yet the best slope efficiencies reported for high power cladding-pumped Tm doped silica fibre lasers remain well below the theoretical maximum (~80%).

Here we report on our recent Tm fibre development work targeted at improving the two-for-one cross-relaxation efficiency through optimising core composition and doping profiles. The results of this study show that efficiencies close to the theoretical limit of ~80% are achievable with the appropriate core design. The Tm fibres evaluated in our study were all fabricated in-house via modified chemical vapour deposition (MCVD) and solution doping with great care to avoid unwanted contaminants (e.g. OH ions). Figure 1 shows the results of laser slope efficiency measurement (using a simple cavity configuration) for the fabricated Tm fibres as a function of Tm doping concentration, whilst keeping the concentration ratio for Tm to Al approximately constant. It can be seen that the fibre with a Tm concentration of 3.6 wt.% yielded a slope efficiency with respect to absorbed pump power of ~70% and with power levels up to 100W limited by available pump power. Detailed measurements of the Tm doping concentration were performed with a combination of energy dispersive x-ray spectroscopy (EDS) in conjunction with measurement of the pump absorption of the core material.

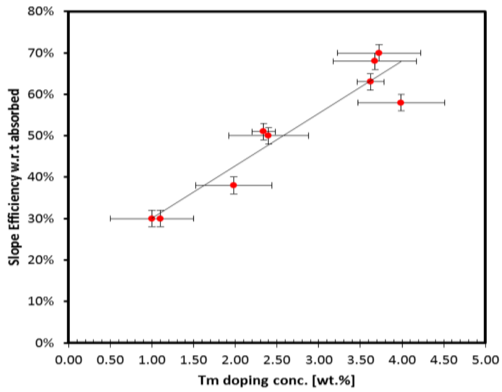

Fig. 1. Slope efficiency obtained for 793nm pumped Tm doped fibre free running at ~2μm as a function of the Tm^{3+} doping concentration.

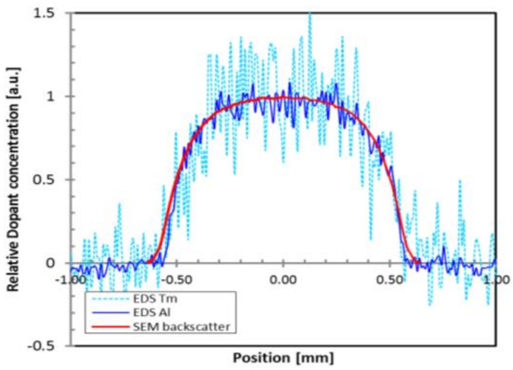

Fig. 2. Cross section Al and Tm dopant profiles across a 3.6wt% Tm preform core overlayed with the SEM backscatter signal.

Figure 2 shows a cross-section of a preform core showing the Tm and Al distribution of a 3.6wt% Tm preform core normalised to show relative shapes. Overlayed is also the SEM backscatter cross-section which gives a map of the average electron distribution through the material, which in the case of a Tm:Al silica preform core gives a high resolution map of the Tm distribution. The fact that the Tm doping level varies across the core will almost certainly lead to a variation in the cross-relaxation efficiency with position in the core. As a consequence, the cross-relaxation efficiency will decrease towards the edges of the core where the Tm concentration is lower. Calculations which take into account the spatial overlap of the laser mode with the Tm doping profile reveal that this is the main reason for the slope efficiency not exceeding 70%. Modification of core design using a high Tm doping level around 3.6 wt% in combination with a more uniform doping profile and the use of a passive alumina-silicate ring around the Tm doped region to increase the core diameter should, subject to the maintaining low loss, lead to efficiencies close to the theoretical limit. This will, in turn, reduce thermal loading density and offer the prospect of significantly higher output power in the two-micron band than has been achieved to date.

References

[1] S. D. Jackson and S. Mossman, “Efficiency dependence on the Tm^{3+} and Al^{3+} concentrations for Tm^{3+}-doped silica double-clad fiber lasers,” Appl. Opt, **42**, 15, 2702-2707 (2003)