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High-power widely tunable Tm fibre lasers in cladding-pumped and core-pumped cavity configurations

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Cladding-pumped Tm-doped fibre lasers operating in eye-safe 2-µm spectral region have attracted growing interest in recent years owing to their numerous applications in areas such as lidar and medicine. In contrast to conventional 'bulk' solid-state lasers, fibre-based sources benefit from a geometry that allows relatively simple thermal management and hence offer the prospect of higher output power and improved beam quality. A particular attraction of Tm-doped fibre lasers is the very broad transition linewidth offering the prospect of wide tunability over the ~1700-2100 nm regime. Direct pumping of double-clad Tm-doped silica fibre lasers with diode lasers at ~790 nm [1] and, more recently, Tm-doped silica fibre lasers sensitized by co-doping with Yb at 975 nm [2] has been demonstrated with output powers up to 30 W (limited by available pump power) and 75 W (limited by fibre damage) respectively. In the latter, the slope efficiency was rather low (~ 26%), due, in part, to the relatively high quantum defect heating (~51%), hence suggesting that power scaling may prove rather difficult via this scheme. An alternative, and more promising, approach for power scaling of Tm fibre lasers is to pump directly into the upper level manifold with an Er fibre laser at 1.55-1.62 ìm. This has the attraction of a very high Stokes efficiency (~0.75-0.85) and hence low quantum defect heating, opening up the prospect of very high lasing efficiencies. In addition, the good beam quality available from high-power Er-doped fibre lasers allows direct pumping into the Tm-doped fibre core leading to the possibility of much shorter device lengths. This is critically important for extending the tuning range of Tm fibre lasers to shorter wavelengths. In this paper we report highly efficient operation of Tm-doped silica fibre lasers, pumped by a high-power cladding-pumped Er,Yb fibre laser at 1565nm, in both cladding-pumped and core-pumped resonator configurations. In the cladding-pumped Tm fibre laser we obtained up to 19 W of output at 1991 nm with a slope efficiency of 69% with respect to absorbed pump power, and in the core-pumped laser we obtained a maximum output power of 12.1W at 1860nm limited by available pump power. Using tunable cavity configurations the cladding-pumped and core-pumped Tm fibre lasers could be tuned from 1861 to 2061nm and from 1725 to 1973nm at multi-watt power levels respectively. To the best of our knowledge this represents the broadest tuning range and shortest operating wavelength from a high-power Tm-doped fibre laser reported to date.

The Tm fibre used in our experiments had a Tm-doped alumino-silicate core of 20 µm diameter and 0.12 NA, surrounded by a pure silica D-shaped inner-cladding of 200 µm diameter and 0.49 NA (calculated), with a low refractive index polymer outer-cladding. The pump source was an Er-Yb co-doped fibre laser cladding pumped by a high power diode-stack at 975 nm, which provided up to 58W of output at 1565nm in a beam with M^2=1.9. The effective absorption coefficient in the Tm-doped fibre (i.e. for cladding-pumping) at this pump wavelength was measured to be ~1.5 dB/m, and hence a fibre length of ~5 m was selected for reasonably efficient pump absorption (~82%). The laser cavity was formed between the perpendicularly-cleaved fibre end-facet at the pump launch end of the fibre (which also served as the output coupler), and a simple external cavity comprising a collimating lens and a plane mirror with high reflectivity at ~1.8-2.1 µm at the other end of the fibre. A dichroic mirror with reflectivity >99.8% at ~2 µm and transmission >92 at ~1.5 µm was used to extract the output beam. The laser reached threshold at a launched pump power of 3.1W and produced a maximum output power of 19.2 W at 1991 nm at the maximum available pump power corresponding to 38.2 W launched. The slope efficiency with respect to the absorbed pump power was 69%, which compares favourably with the upper limit of ~78% determined by the Stoke efficiency. Wavelength tuning was achieved by modifying the external cavity design to include a simple diffraction grating (600 lines/mm) aligned in the Littrow configuration to provide wavelength selective feedback. In these experiments a shorter length of fibre (~2.5m) was employed and a simple arrangement for retro-reflecting the unabsorbed pump light after a single-pass to improve the pump absorption efficiency. Using this resonator configuration, we obtained a maximum output power of 17.4 W at 1941 nm for 38.2 W of launched pump power, and the lasing wavelength could be tuned over 200 nm from 1861 to 2061 nm with an output linewidth (FWHM) of <0.5 nm. For the core pumping experiments, similar cavity configurations were employed, but with a much shorter length of fibre (~24 cm) due to the higher absorption coefficient (~150 dB/m) for the pump light. For the non-tunable cavity configuration, a maximum output power of 12.1 W at 1861 nm was generated with a slope efficiency of 58.5% with respect to the absorbed pump power. For the tunable cavity, we obtained up to 8.4 W of output and operating wavelength was tunable over 248 nm from 1725-1973 nm at multi-watt power levels. The prospects for further improvement in performance will be discussed.

1. D. Y. Shen, J. I. Mackenzie, J. K. Sahu, W. A. Clarkson and S. D. Jackson, "High-Power and Ultra-Efficient Operation of a Tm^{3+}-doped Silica Fiber Laser," Advanced Solid-State Photonics 2005, paper MC6, 2005.
2. Y. Jeong, P. Dupriez, J. K. Sahu, J. Nilsson, D. Shen, W. A. Clarkson, S. D. Jackson, "Thulium-ytterbium co-doped fiber laser with 75W of output power at 2 microns," *SPIE European Symposium on Optics and Photonics for Defence & Security* London 25-28 Oct 2004 Paper. 5620-4.