Tm-doped fibre laser with radially-polarized output beam at 2μm

D. Lin, P. Shardlow, M. Beresna, P. G. Kazansky and W. A. Clarkson

Optoelectronics Research Centre, University of Southampton, SO17 1BJ, UK

Radially-polarized beams have attracted growing interest for a variety of applications including, laser processing of materials, high-resolution microscopy and particle manipulation due to their unique properties. Recently, we have demonstrated efficient generation of radially-polarization from an Yb-doped fibre laser in the one-micron band based on the use of a nanograting spatially-variant half-waveplate (S-waveplate) as an intracavity polarization-controlling element [1].

Here, we present preliminary results for a cladding-pumped Tm-doped silica fibre laser directly generating radially-polarized output with high polarization purity. The required polarization discrimination was achieved by employing an external feedback cavity arrangement containing a linear polarizer and an S-waveplate designed for use in ~2μm wavelength band with very low scattering loss. The latter was fabricated in-house and comprised two layers of spatially-variant sub-wavelength gratings produced by femtosecond laser pulse direct writing in a fused-silica window. These grating structures induce form birefringence with slow and fast axes aligned parallel and perpendicular to the grating direction respectively. The grating direction was continuously varied with azimuthal angle φ and aligned at an angle $\varphi/2$, so that a linearly-polarized incident aligned at φ=0° is converted to a radially-polarized beam.

The experiment layout for the laser, illustrated in Fig. 1(a), comprised a ~2.2m length of non-polarization maintaining double-clad Tm-doped fiber with a 17μm diameter (0.15 NA) alumino-silicate core co-doped with 2wt.% thulium. The calculated V-number of fiber was ~4 at 2μm and hence the fiber could support the LP_{00} modes and LP_{01} group modes. Feedback for lasing was provided by a perpendicularly-cleaved facet at the output end of fibre, serving as the output coupler, and an external feedback cavity at the opposite end of the fibre. The latter contained a polarising beam splitter (PBS) and the two-micron S-waveplate together with a collimating lens and a diffraction grating aligned in the Littrow configuration to select the operating wavelength and narrow the laser emission bandwidth. The fibre end adjacent to the external cavity was cleaved at 8° to suppress the broadband feedback and hence parasitic lasing between the fibre end facets. This arrangement leads to preferential lasing on the radially-polarized TM_{01} mode. Pump light was provided by a fibre-coupled 793nm laser diode coupled into the inner-cladding at the output end of the fibre with the aid of a dichroic mirror.

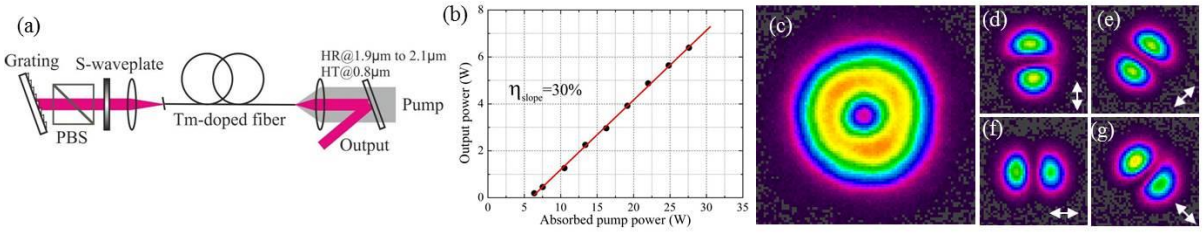

Fig. 1 (a) Experimental layout; (b) laser output power versus pump power; (c) beam intensity distribution in the far-field; (d)-(g) beam profile after passing through a rotated linear polarizer.

Fig. 1(b) shows the output power of the donut-shaped TM_{01} mode as a function of the absorbed pump power. The output power increased linearly with absorbed pump power with a slope efficiency of 30%. The laser yielded a maximum output power of 6.4W at wavelength of 1970nm with a 3-dB spectral bandwidth of 0.1nm at an absorbed pump power of 27.6 W. Fig. 1(c) shows a typical intensity profile measured for an output power of 2 W. The output beam had a pronounced donut-shaped intensity pattern with very low residual intensity at the centre of beam. The mode purity (i.e., fractional content TM_{01} versus total power) was measured to be ~94%. However, this value decreased to ~82% at the maximum output power of 6.4W showing that the LP_{01} mode content increases with pump power, but remains relatively low for the operating conditions used in our experiment. The presence of parasitic laser oscillation on the LP_{01} mode is mainly attributed to undepleted inversion at the centre of core due to the null in intensity for the TM_{01} donut mode. Figs. 1(d)-(g) shows the two-lobe structure of the output beam after passing through a linear polarizer oriented at different angles thus verifying that the polarization is indeed radial. The polarization purity was measured to be > 90% over the full range of output power. The beam propagation factor (M^2) was measured to be 2.2 at the maximum output power and hence in close agreement with the theory confirming the high quality and purity of radially-polarized TM_{01} mode that was generated. To the best of our knowledge, this is the first report of lasing on the radially-polarized TM_{01} mode from a Tm fibre laser oscillator. The prospects for further improvement in efficiency and higher output power through the use of better optimised fibre designs will be discussed.

References

[1] D. Lin, J. M. O. Daniel, M. Gecevicius, M. Beresna, P. G. Kazansky, and W. A. Clarkson, "Cladding-pumped ytterbium-doped fiber laser with radially polarized output," Opt. Lett. 39, 5359 (2014).