Direct generation of radially-polarized output from an Yb-doped fiber laser

D. Lin, J. M. O. Daniel, M. Gecevičius, M. Beresna, P. G. Kazansky, W. A. Clarkson
Optoelectronics Research Center, University of Southampton, Southampton, SO17 1BJ, UK
dl1n10@soton.ac.uk

Abstract: A simple technique for directly generating a radially-polarized output beam from an ytterbium-doped fiber laser using an intracavity S-waveplate is reported. The laser yielded 7W of output with a corresponding slope efficiency of 67%.

OCIS codes: (140.3510) Laser, fiber; (260.5430) Polarization; (050.6624) Subwavelength structures

1. Introduction

Radially-polarized light is characterized by a donut-shaped intensity profile and exhibits axially symmetry both in field-amplitude and polarization direction. Radially-polarized beams can produce a strong longitudinal electric field component along the beam axis under the condition of tight focusing [1]. This unique property leads to a range of promising applications in material processing, high-resolution microscopy, particle acceleration and trapping.

Fiber lasers benefit from a geometry that is advantageous for scaling average power and hence could be a promising route to high power radially-polarized beams. Indeed, several recent investigations were conducted in ytterbium-doped and erbium-doped fiber lasers by employing either a birefringent crystal aligned for propagation along the optic axis [2], a segmented wave plate [3] or a photonic crystal grating[4]. However, these schemes produced rather low output powers or had relatively low efficiency. The highest laser power and slope efficiency reported to date for a fiber lasers with a radially-polarized output is 2.5 W and 46% respectively [4], which is far below the performance reported for bulk solid-state lasers.

Here, we present an alternative approach for efficiently generating radially-polarized output directly in an Yb-doped fiber laser by employing a S-waveplate in an external feedback cavity arrangement. The S-waveplate consists of spatially-variant sub-wavelength gratings which are 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, which is aligned at an angle $\varphi/2$ from the azimuthal angle φ [5].

2. Experiment and Results

The experiment set-up, illustrated in Fig. 1, comprised a 2m length of non-polarization maintaining Yb-doped fiber with an external feedback cavity. The fiber had a core diameter of 20 µm, numerical aperture (NA) of 0.07, and an inner-cladding diameter of 125 µm. The corresponding V-number is approximately 4.07 guaranteeing that only the fundamental LP_{01} mode and its neighboring LP_{11} modes could be guided within the fiber. The end of fiber adjacent to the external cavity was cleaved at 8° to suppress the broadband feedback and hence parasitic lasing between the fiber end facets. The opposite end was perpendicularly-cleaved to serve as the output coupler. Pump light was provided by a fiber-coupled 976nm laser diode (LD) with a 105 µm core diameter and 0.12NA, which was free-space coupled into the output end of the fiber via a dichroic mirror. The light emerging from the angle-cleaved end of fiber was collimated by an aspheric lens and feedback for lasing was provided by a plane high reflectivity mirror at 1.06 µm. A S-waveplate and a polarization beam splitter (PBS) were placed in the external cavity between rear mirror and fiber collimating lens. The PBS allowed only p-polarized light to pass through it and then transmit to the S-waveplate. When the orientation of the S-waveplate, shown by the arrow in Fig. 1(a), is aligned parallel to the p-polarization, it converts the p-polarized beam into radially-polarized light, which is then coupled into the fiber to excite the radially-polarized TM_{01} mode.

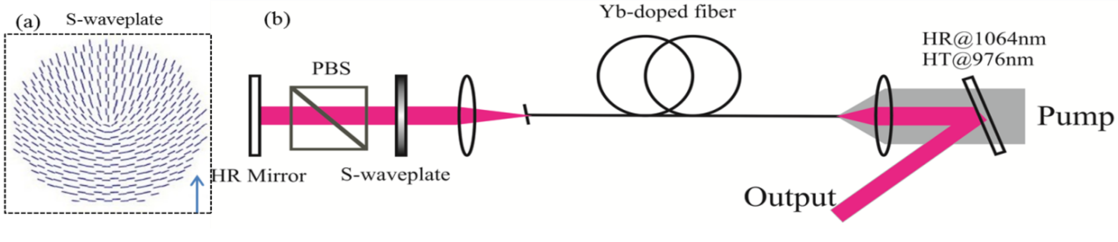

Fig. 1 (a) Schematic of nanogratings orientation in SVPC, (b) Experimental laser set-up.

The typical output beam intensity distribution at the maximum output power is shown in Fig. 2 (a). Fig. 2 (b)-(d) show the two-lobe structures of beam after passing through a polarizer oriented at different angles verifying its radial polarization. The polarization purity was measured to be 87% according to the method described in [4].

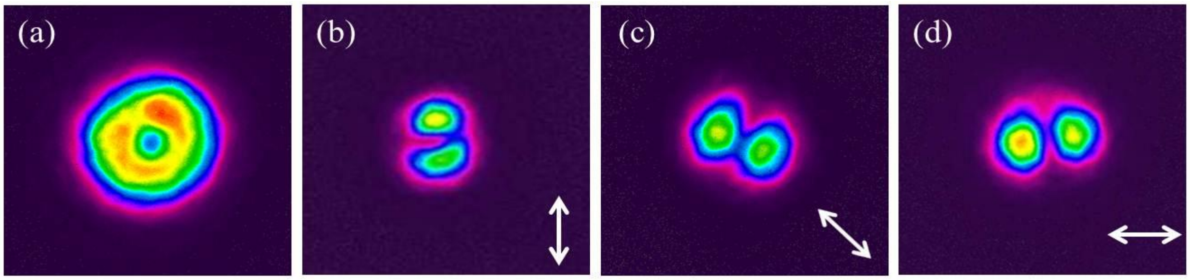

Fig. 2 Experimentally measured beam intensity distribution (a) without polarizer, (b) with polarizer at 90°, (c) with polarizer at 45°, (d) with polarizer at 0°.

The one-dimensional intensity distribution across the center of beam in Fig. 2 (a) is shown in Fig. 3. There is residual intensity at the center of the beam indicating that the fundamental LP_{01} mode was also excited. However, the power ratio of the LP_{01} to TM_{01} mode is approximately 1:2.5 confirming that most of the power is in the radially-polarized mode. Parasitic laser oscillation on the LP_{01} mode can be attributed to the high-doping density of Yb ions at the center of fiber core resulting in a higher single pass gain for the LP_{01} mode than for TM_{01} mode in the fiber. This could be suppressed by using a better tailored core design with a dip in the Yb concentration at the center of the fiber. The laser output power as a function of incident pump power is shown in Fig. 4. The laser reached threshold at a pump power of 1.5 W and yielded 7 W of output at the maximum incident pump power of 12 W with a corresponding slope efficiency of 67%. The beam propagation factor (M^2) was measured to be 1.7, which is slightly less than theoretical value of 2 due to the presence of the fundamental LP_{01} mode.

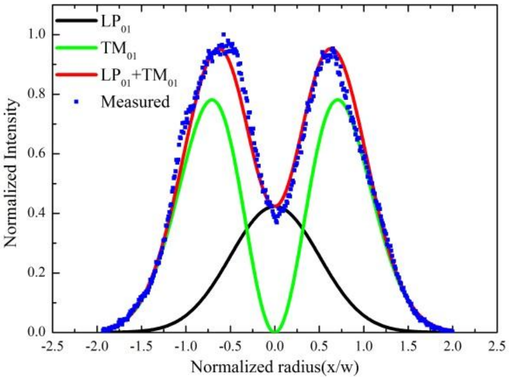

Fig. 3 The calculated and measured transverse intensity distribution of output beam.

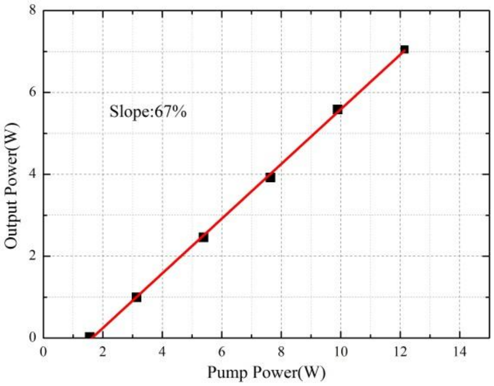

Fig. 4 Laser output Power versus pump power

3. Conclusion

In summary, a fiber laser with an intracavity S-waveplate has been described which efficiently generates a donut-shaped output beam with radial polarization. A maximum power of 7 W was obtained with a slope efficieny of 67%. To the best of our knowledge, this is the highest power and highest slope efficiency for radially-polarized fiber laser to date. The prospects for further improvement in performance will be discussed.

4. References

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