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ABSTRACT

We have demonstrated for the first time, to the best of our knowledge, the successful direct amplification of a cylindrical-vector beams with axially symmetric polarization and doughnut-shaped intensity profile in picosecond MOPA system based on a double-clad ytterbium-doped spun tapered fiber with a ring-shaped active core. The output radially polarized beam with absolute contrast between bright and dark zones carries 10 ps pulses at 1030 nm with a 14.5 W average power level, 91 kW peak power and 0.97 μJ pulse energy.

Keywords: fiber laser, active tapered fiber, active spun fiber, ring-shaped core active fiber, radially polarized beam, structured light

1. INTRODUCTION

Active large mode area (LMA) tapered double-clad fibers (T-DCF) have been widely used in high-power pulsed fiber Master Oscillator Power Amplifier (MOPA) systems during the past decades. Researchers have recently shown increased interest in fiber MOPA systems, especially setups based on T-DCF. The interest has been determined by capability of such system to deliver a few MW-level peak power and several hundred watts of average power with several tens of microjoules pulse energy [1,2]. The achieved high peak power and pulse energy (storage energy) were generally determined by the special longitudinal profile of T-DCF [1].

Cylindrical-vector beams with axially symmetric polarization and doughnut-shaped intensity profile have attracted great interest in recent years, owing to a wide range of applications, such as particle acceleration and trapping, high-resolution microscopy, optical data storage and material processing driving a significant performance improvement [3]. The generation and amplification of radially and azimuthally polarized beams have been demonstrated in CW and nanosecond laser systems [4-6], where the radially polarized TM_{01} mode was excited by a spatially-variant waveplate (S-waveplate) and amplified in an isotropic round-shape core LMA fiber. Despite the capability of an isotropic fiber to amplify beams with spatial inhomogeneous polarization, they were not an optimum solution. The round-shaped core of the fiber amplified both the beam's bright and dark zones, resulting in intensity contrast degradation. On another side, the isotropic fiber was characterised of random variation of birefringence in the core leading to the uncontrolled distortion of the spatial distribution of polarization and destroying the radial or azimuthal polarization profile. Recently, we have demonstrated a new type of T-DCF - so-called spun T-DCF (sT-DCF) with small birefringence supporting the propagation and amplification of radially polarized light with minimum distortion [7].

In this work, we develop the idea of sT-DCF fiber further implementing a ring-shape core for high contrast amplification of radially polarized beams carrying picosecond pulses. The MOPA system based on a unique sT-DCF with a ring-shaped core delivered 10 ps pulses with an average power of 14.5 W, peak power of 91 kW and 0.97 μJ pulse energy preserving a doughnut-shaped radially polarized output beam.

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2. EXPERIMENTAL RESULTS

The central part of the experiment setup was the sT-DCF with a ring-shaped core used for the last amplification stage, which allowed achieving the high average and peak power without polarization profile distortion of axially symmetric polarized cylindrical-vector beams. For manufacturing the sT-DCF with a ring-shaped core we used a step-index Yb-doped preform made by REPUSIL technology, which refractive index profile is shown in the inset of the Figure 1(a). The in-core absorption value was equal to 800 dB/m at 976 nm, the numerical aperture was 0.1 with the core-cladding-diameter ratio equaled to 8.25. The fiber drawing process was performed by continuous variation of the drawing speed to obtain the fiber tapering, at the same time the preform was rotated with the constant velocity, which resulted in the constant sT-DCF pitch 30 mm. The spun architecture of the fiber ensured small net birefringence supporting the propagation and amplification of the radially polarized light. The longitudinal profile of the ring-shaped sT-DCF with outer cladding variation along the fiber length is depicted in Figure 1. The narrow side of the sT-DCF had a core diameter of 14.5 μm and ensured the V-number 4.44 at 1030 nm for undistorted propagation a radially polarized TM_{01} mode in the core. The wide side of the fiber had core diameter around 47 μm and outer cladding diameter of 390 μm, which allowed elevation of the threshold for undesired nonlinear effects. The end face image of the sT-DCF obtained from the wide side is depicted in Figure 1 (inset).

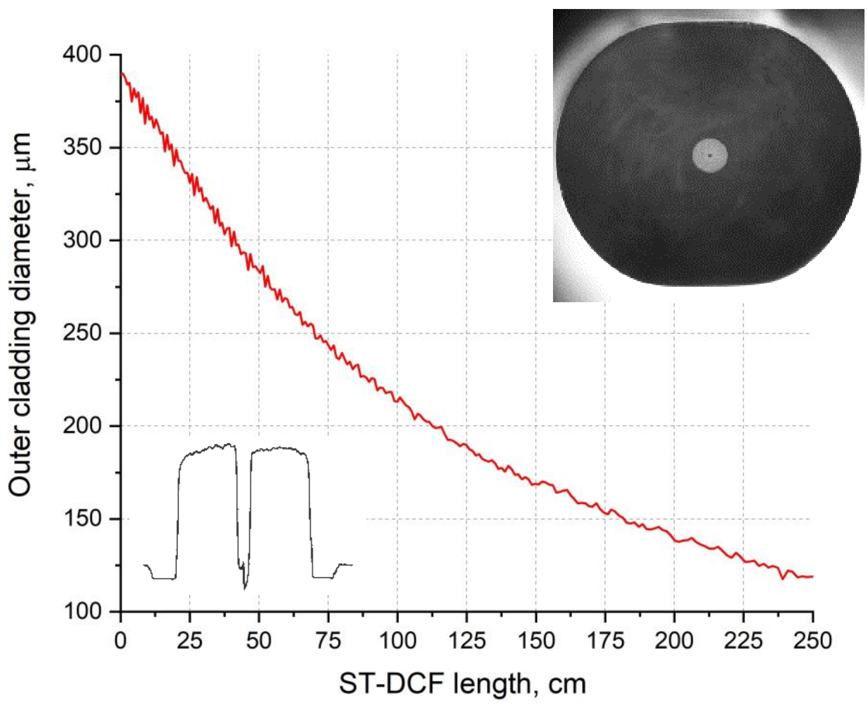

Figure 1. The longitudinal profile of the ring-shaped sT-DCF (insets: refractive index profile in the lower left corner; face image of the fiber facet in the upper right corner).

The schematic of the experimental high-power MOPA system is shown in Figure 2. The linearly-polarized beam carrying 10 ps pulses at a 15 MHz repetition rate was generated by a nonlinear amplifying loop mirror (NALM) seed laser and pre-amplified up to 50 mW. The radially polarized beam was formed by a S-waveplate and injected into the narrow side of sT-DCF with the ring-shaped core. The pump light, provided by a laser diode at 976 nm, was launched through the dichroic filter into the fiber from the wide side.

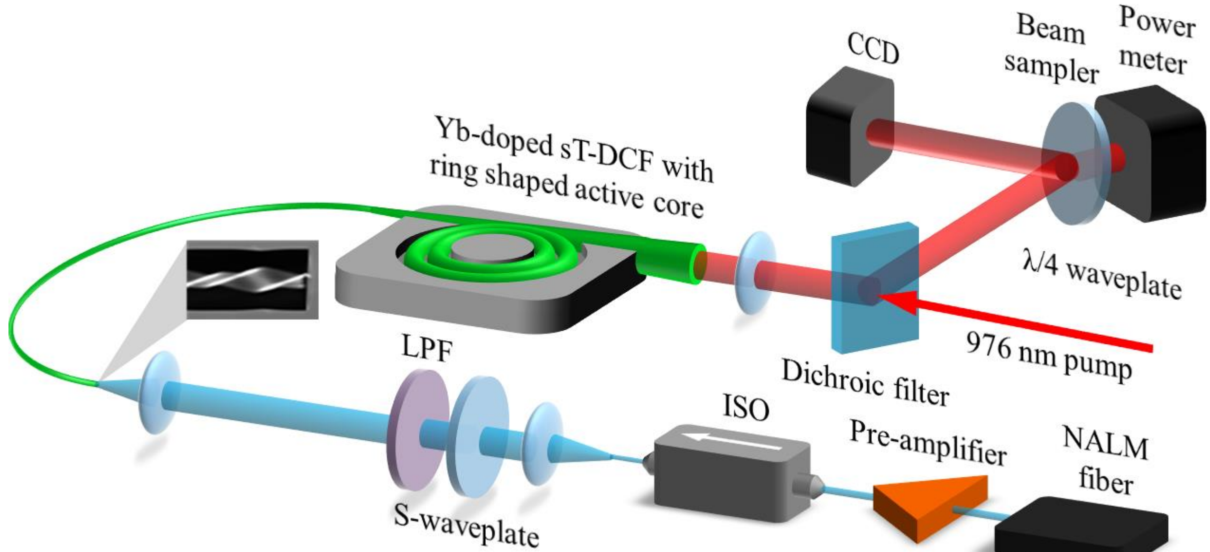

Figure 2. The schematic of the experimental setup (inset: the side view of the sT-DCF). ISO - optical isolator; CCD - charged coupled device; LPF - longpass filter.

The MOPA system generated an output power of 14.5 W for the directly amplified short-pulsed signal at the 27 W pump power. Output beam profiles with 1.9 W (M^2 = 2.05) and 14.5 W (M^2 = 2.05) output power demonstrated high beam quality preservation during the amplification process (Figure 3 (a,b)). At the same time, the amplified beam was characterized by high homogeneousity of polarization state along the azimuth orientation. The amplified up to 14.5 W beam profiles after passage through a rotated linear polarizer with axis settings at 0°, 45°, 90° and 135° are shown in Figure 3 (c-f). The further amplification of the beam was limited by growing amplified spontaneous emission (Figure 3 (g)) distorting polarization profile and intensity distribution contrast.

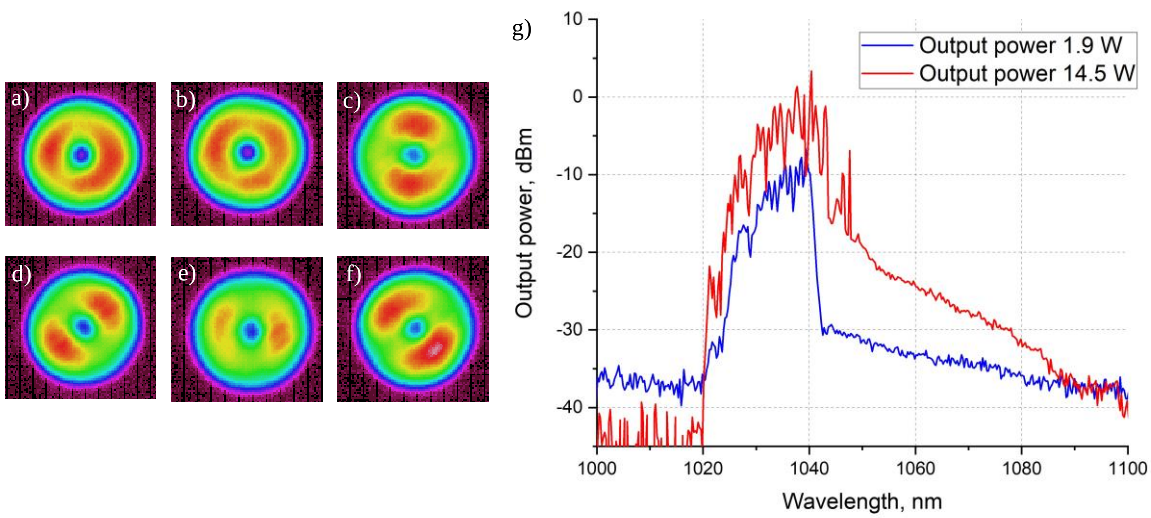

Figure 3. (a,b) Experimental output intensity distributions in the near-field for (a) 1.9 W and (b) 14.5 W output power; (c-f) amplified beam (14.5 W) profiles after passage through a rotated linear polarizer, linear polarizer axis settings at 0°(c) 45°(d), 90°(e) and 135°(f); (g) experimental output spectrums for 1.9 W and 14.5 W output power.

3. CONCLUSION

In conclusion, we have demonstrated for the first time, to the best of our knowledge, a unique spun active tapered double clad fiber with a ring-shaped core as a gain medium for amplification of cylindrical-vector beams with axially symmetric polarization and doughnut-shaped intensity profile. The successful amplification of the doughnut-shaped beam with low beam profile distortion (both in intensity and polarization) in the manufactured sT-DCF with a ring-shaped core has been realized in the 10 ps MOPA system with an average power of 14.5 W, peak power of 91 kW and 0.97 μJ pulse energy.

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