Diode-pumped Pr^{3+}:YLF vortex laser source

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We demonstrate for the first time the direct generation of visible structured light beams, scalar and vector vortex modes with a wavelength of 640nm from a diode-pumped Pr^{3+}:YLF laser by employing an off-axis pumping technique. A maximum output of ~100 mW was achieved for a pump power of 1.2 W. Such red structured light beams will be potentially applied to super-resolution fluorescent microscope and micro-fabrications.

Structured light beams, such as scalar and vector vortex beams (*i.e.*, optical vortices and radially or azimuthally polarized modes) [1,2], carry unique features, for instance, an annular spatial profile, self-healing, longitudinal electric field, and an orbital angular momentum of $\ell\hbar$ per photon. They can be used in numerous applications, going from optical trapping and manipulation to high bit-rate optical communication. Direct generation of structured light beams from laser resonators allows us to work with very high-power structured light beams as eigen modes, with different wavelengths emission and excellent beam quality, without any additional phase modulating optical elements.

We present the first demonstration of the direct generation of a 640 nm first-order vortex and a radially polarized modes from an off-axially blue diode-pumped Pr^{3+}:YLF laser, with a simple linear cavity configuration and without any additional optical elements. A blue InGaN laser diode pumped Pr^{3+}:YLF laser exhibits visible laser transitions in the blue, green, orange, red, and deep red spectral regions [3], and it has been successfully demonstrated to achieve a continuous-wave, a Q-switching, and mode-locking operations. Such visible structured light sources will be potentially utilized in numerous applications due to its various spectral emission bands available.

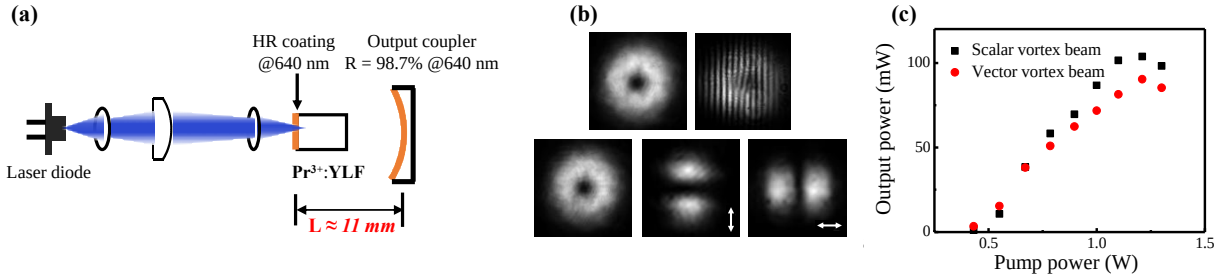

FIG 1. **(a)** Experimental setup for Pr^{3+}:YLF vortex laser with the off-axis pumping. **(b)** Spatial form and wavefront of the generated scalar vortex output (upper row). Total intensity distribution of vector vortex beam before and after passing through a linear polarizer (arrows indicate the direction of the polarizer). **(c)** Power scaling of the scalar and vortex outputs.

Figure 1(a) shows an experimental setup for generating the structured light modes from a Pr^{3+}:YLF laser with the off-axis pumping. A 5-mm-long c-cut Pr^{3+}:YLF crystal with 0.5 at.% Pr^{3+} ions doping was used to form a cavity, formed by an input facet with high reflection coating for 640 nm and antireflection for the pump (445 nm) along with a concave output coupler with a radius of 150 mm and a high reflectivity of >98.5%. The cavity length was ~11 mm. The pumping spot was slightly shifted with displacements of Δx and Δy from an optical axis of the cavity, *i.e.*, off-axis pumping. The laser generated a first-order vortex mode, as evidenced by an annular spatial form with a central dark core and a pair of upward and downward Y-shaped fringes produced by a laterally self-referenced interferometer. A maximum output power was measured to be 102 mW at a pump power of 1.2 W, corresponding to a slope efficiency of ~13%, as shown in Figs. 1(b) and (c). The laser also produced a radial vector vortex mode, as evidenced by a twin lobe beam along the polarization direction, with a maximum power of 90.4 mW.

Such structured light generation based on off-axially pumping geometry allows us to select the desired scalar or vector vortex emitted spatial mode without the use of any phase modulating optical elements or complex laser cavity configurations.

[1] L. Allen, M. W. Beijersbergen, R. J. C. Spreeuw, and J. P. Woerdman, "Orbital angular momentum of light and the transformation of Laguerre–Gaussian laser modes," Phys. Rev. A **45**, 8185–8189 (1992).

[2] A. M. Yao, M. J. Padgett, "Orbital angular momentum: origins, behavior and applications," Adv. Opt. Photon. **3**, 161–204 (2011).

[3] T. Gün, P. Metz, G. Huber, "Power scaling of laser diode pumped Pr^{3+}:$LiYF_4$ cw lasers: efficient laser operation at 522.6 nm, 545.9 nm, 607.2 nm, and 639.5 nm," Opt. Lett. **36**, 1002-1004 (2011).