Direct generation of green vortex from a Pr:YLF laser by an optical needle pump geometry

Taku Miike[1], Takuya Morohashi[1], A Srinivasa Rao[1,2], Katsuhiko Miamoto[1,2], and Takashige Omatsu[1,2]
[1] Graduate School of Engineering Chiba University Chiba 263-8522, Japan
[2] Molecular Chirality Research Centre, Chiba University, Chiba 263-8522, Japan
E-mail: omatsu@faculty.chiba-u.jp

Optical vortex has been receiving tremendous interests in a wide range of applications such as fluorescence microscopy with a high spatial resolution beyond the diffraction limit [1], optical manipulation [2], and materials processing [3]. In general, visible green vortex laser sources largely rely on frequency doubling of infrared vortex modes [4]. However, such nonlinear frequency conversion impacts frequently the quality of generated vortex modes owing to the doubled topological charge and undesired coherent mode coupling. Here, we report on the first demonstration of an ultra-compact green vortex Pr:YLF laser source by employing an off-axis optical needle pumping geometry and without nonlinear frequency extension. Our system without any additional optical elements for wavefront modulation should open the door towards new advanced bio-imaging and microfabrication technologies.

An experimental setup of our system is shown in Fig. 1(*a*). A 442 nm blue laser diode and a 5 mm long *a*-cut Pr:YLF crystal were used as a pump source and a laser medium, respectively. A focusing lens with spherical aberration allows us to create a quasi-non-diffractive optical needle pump beam with a small spot and a long confocal length in the laser crystal. The beam propagation of the focused pump beam is seen in Fig 1(*b*). A concave mirror with a curvature of 150 mm was used as an output coupler (OC) with 98.3% high reflection for 523 nm. The cavity length was then fixed to be only 8 mm. The OC was mounted on a three-dimensional translation stage to provide transverse (off-axial) displacements along the *x*- and *y*-axes with steps as small as $\Delta x = \Delta y = 0.5$ μm, enabling the off-axis pumping [5].

The spatial modes generated from the laser cavity as a function of off-axis displacements are shown in Fig. 1(*c*). The on-axis pumping allows straightforwardly the laser to operate at a fundamental Gaussian mode. The off-axis (*x* or *y*) displacement of OC forces the laser to generate $HG_{1,0}$ or $HG_{0,1}$ mode. Further, both the *x* and *y* displacements of OC will enable us to produce $LG_{0,\pm1}$ $(=1/\sqrt{2}\times(HG_{1,0}\pm iHG_{0,1}))$ vortex modes. The generated green optical vortices, mapped on an orbital Poincaré sphere, exhibit a maximum output power of ~300 mW at a slope efficiency of 12%.

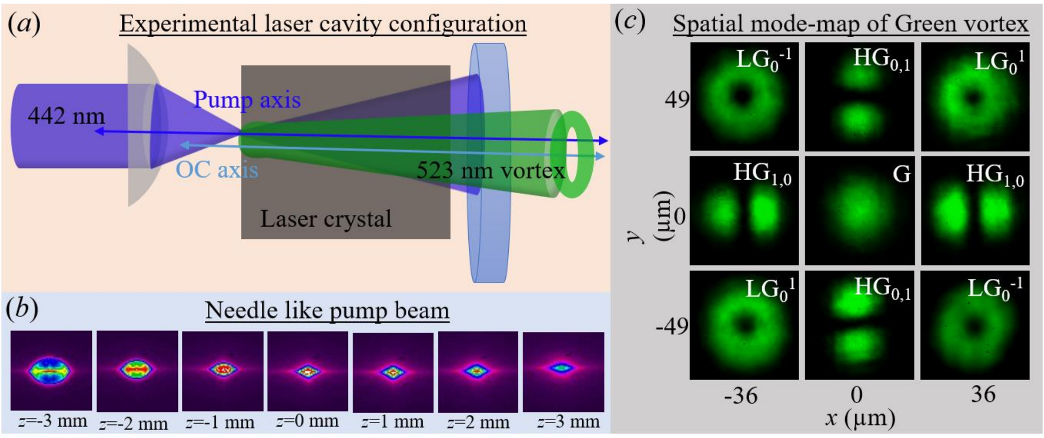

Fig.1 (a) Experimental setup of laser cavity for Green vortex beam; (*b*) Pump beam propagation dynamics in the laser crystal propagation dynamics (*c*) Spatial mode-map of Green vortex generated from the laser cavity.

Acknowledgements
This work was supported partially by the grant from JSPS fellowship (ID: P19352). The authors also acknowledge support from the Japan Society for the Promotion of Science (JSPS) KAKENHI Grants (JP 16H06507; JP 18H03884), and the Japan Sceince and Technology Agency (JST) Grants (Core Research for Evolutional Science and Technology (JPMJCR1903)).

References

[1] S. W. Hell and J. Wichmann, Opt. Lett.**19**, 780–782 (1994).
[2] D. McGloin, David, and J. P. Reid, Opt. Photon. News **21.3**, 20-26 (2010).
[3] T. Omatsu, K. Masuda, K. Miyamoto, K. Toyoda, N. M. Litchinitser, Y. Arita, and K. Dholakia, J. Nanophotonics **14**, 010901 (2020).
[4] Y. Sasaki, M. Koyama, K. Miyamoto, Y Ariga, T. Onda, I. Shoji and T. Omatsu, Opt. Exp. **22,** 12829-12835 (2014).
[5] A. S. Rao, K. Miamoto, and T. Omatsu, Ultraviolet intracavity frequency-doubled Pr 3+: LiYF 4 orbital Poincaré laser. Optics Express, **28**, 37397-37405 (2020).