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Generation of watt-level orbital Poincaré sphere modes from a self-Raman Nd:GdVO$_4$ laser

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Abstract

We demonstrate the direct generation of watt-level orbital Poincaré sphere (OPS) modes operating at 1.173 μm, corresponding to the first-Stokes emission of the 882 cm^{-1} Raman shift in Nd:GdVO$_4$ crystal, by employing a tight needle pumping beam with an off-axis pumping geometry. Maximum Laguerre-Gaussian (LG) mode output power of ~1.2 W was achieved, corresponding an optical conversion efficiency of 14.0 %.

I Introduction

Orbital Poincaré sphere (OPS) [1-2] modes which are formed by the superpositions of left- and right-handed Laguerre-Gaussian (LG) modes with an annual spatial profile and an orbital angular momentum of $\ell\hbar$ (where ℓ = ±1 is the topological charge) per photon are termed first-order OPS modes. LG modes [3-5] are the paraxial eigenmodes of the electric-magnetic equation in cylindrical coordinate space. Their unique characteristics enable a wide range of applications, such as optical tweezing and manipulation, laser nano/micro-fabrication, and optical communications. These applications however require the generation of wavelength-versatile LG modes with high beam quality.

Self-Raman Nd:GdVO$_4$ lasers, in which a laser crystal also acts as a Raman active medium [6-8], facilitate the development of ultra-compact laser systems and fill in the wavelength gaps of solid-state lasers, notably, the ~1.2 μm 'water window' region.

In this paper, we report on the direct generation of 1.17 μm first-order OPS modes from a self-Raman Nd:GdVO$_4$ laser by employing a needle pumping beam with an off-axis pumping configuration. Maximum LG mode power of ~1.2 W was achieved, the highest value ever obtained from a self-Raman LG mode laser (to the best of our knowledge).

II Experiments

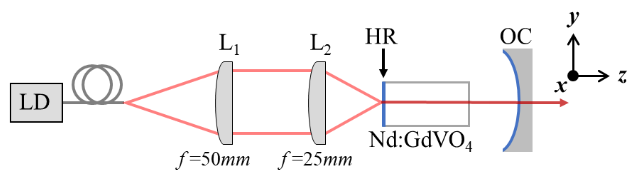

Figure 1 Experimental setup for direct generation of OPS modes in a self-Raman Nd:GdVO$_4$ laser with an off-axis needle pumping geometry.

Figure 1 shows the experimental setup of the self-Raman OPS mode laser system. A 10-mm long *a*-cut 0.3 at.% Nd:GdVO$_4$ crystal was used as the self-Raman gain medium, and its input facet was coated ultrahigh reflecting for 1.033-1.263 μm (R > 99.99 %) and high transmission for 0.879 μm (T > 99.93 %).

The self-Raman laser cavity was formed by the input facet and a curved output coupler (OC) with a partially reflecting coating (R > 99.99 % for 1.063 μm, R = 99.00 % for 1.173 μm). The pump source used was a 0.879 μm fiber-coupled laser diode (200 μm fiber core diameter, 0.22 numerical aperture), and its output was collimated and focused by two plano-convex lenses which produced a 'needle-like' pump spot (diameter of ~97 μm) onto the Nd:GdVO$_4$ crystal. The OC was shifted off-axis along the x and y axes, with displacements of Δx and Δy from the nominal optical axis of the cavity. The cavity length L

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was fixed at 15 mm. With this system, first-order OPS modes, including the Hermite-Gaussian (HG), LG, and Hermit-Laguerre-Gauss (HLG) modes, were produced from the laser with high efficiency.

III Results and Discussion

When Δx and Δy were ±23 μm and ±23 μm, the fundamental field (1.06 μm) had a mixed mode spatial profile with a central dark spot, while the Stokes field (1.17 μm) exhibited a perfect first-order LG mode owing to Raman beam cleanup effects [9]. The order of the LG mode was verified by observation of a pair of up/down and down/up Y-shaped fringes in the wavefront interference pattern (Fig. 2). We posit that selective handedness control of the fundamental and 1.17 μm outputs might be facilitated by breaking of the cylindrical symmetry of the cavity due to astigmatic thermal lensing effects via off-axis pumping. Maximum LG mode output power of 1.2 W was achieved at the pump power of 9.8 W, corresponding to an optical-optical conversion efficiency from the pump beam to the Stokes output of ~14%.

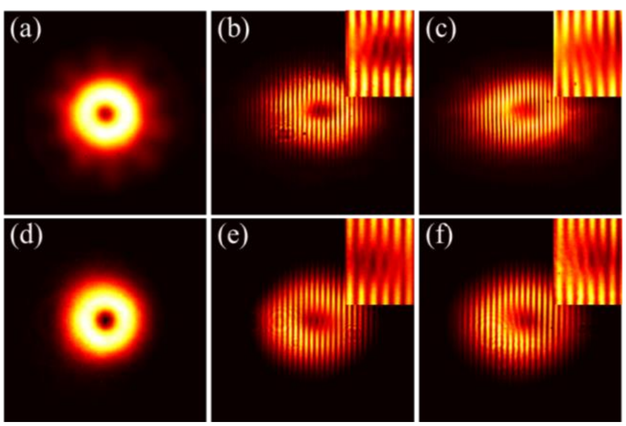

Figure 2 Spatial forms and self-interference fringes of (a-c) the fundamental (1.063 μm) and (d-f) 1.173 μm Stokes outputs.

Mapping of the first-order OPS modes was performed by sequentially varying the off-axial displacements (Δx, Δy) of the OC. The spatial profiles of these modes (formed from combinations of right- and left-handed $LG_{0,\pm1}$ modes) and their corresponding position on the surface of the OPS are shown in Fig. 3.

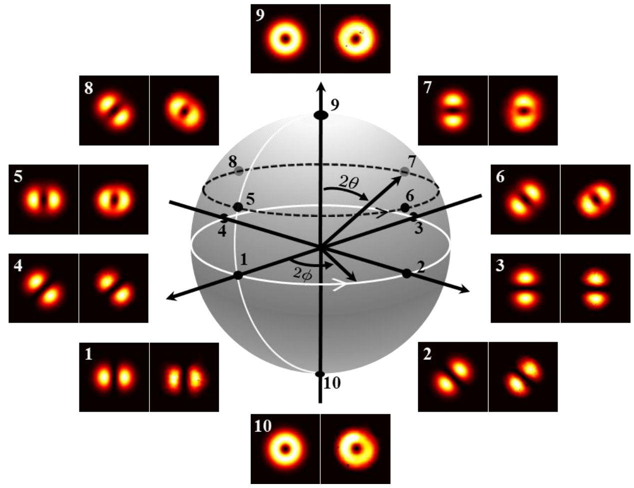

Figure 3 Spatial intensity profiles of theoretical modes (left images) and corresponding generated OPS modes (right images) of Stokes fields at 1.17 μm, mapped onto the PS.

IV Conclusion

We have demonstrated, for the first time to our knowledge, the direct generation of watt-level OPS mode outputs at 1.173 μm from a self-Raman $Nd:GdVO_4$ laser with an off-axis needle pumping beam geometry. A maximum LG mode output power of 1.2 W at 1.17 μm was achieved. We believe that such OPS mode sources in the 1.2 μm region have potential application in advanced bio-medical procedures and techniques.

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