Flower-shaped modes generation from a tunable optical vortex parametric laser

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Optical vortex beam exhibits a ring-shaped spatial profile and carries an orbital angular momentum (OAM), characterized by an azimuthal phase term, $e^{-i\ell\Phi}$(ℓ is a topological charge and Φ is the azimuthal angle) [1], and has been widely applied in a variety of fields, such as optical tweezing and manipulation, and material processing [2]. Also, flower-shaped modes, i.e. coherent superposition of optical vortices with different OAM states also receive much attention, because their unique properties provide potentially advanced applications, including optical trapping [3] and quantum optics [4]. The aforementioned applications strongly desire a versatility of wavelength and OAM state to optical vortex sources [5].

In this presentation, we report on the first demonstration of a tunable vortex laser with versatile flower-shaped modes based on an optical vortex pumped optical parametric oscillator (OPO) formed of a non-critical phase-matching LiB_3O_5 (NCPM-LBO) crystal in a linear cavity configuration with a cavity length of 60 mm. Figure 1 shows a schematic diagram of our system. The pump laser used was a 1.06 μm nanosecond Nd:YAG laser with a pulse duration of 10 ns, and a pulse energy of 9.7 mJ, and its output was converted into a second-order vortex mode with $\ell_p = 2$. It is noteworthy that the pump laser exhibited a rather shorter coherence length of < 1 cm than the cavity length. The 45 mm long NCPM-LBO crystal was mounted on an oven, so as to tune the lasing wavelengths of signal and idler outputs. With this system, the signal and idler should share the OAM of the pump ($\ell_p = 2$) according to the OAM conservation law.

Figure 2 shows the spatial intensity profiles and OAM states of signal and idler outputs. Interestingly, the signal output exhibited versatile flower-shaped modes with 8, 6, and 4 petals, corresponding to the coherent superpositions of ±4, ±3, and ±2 merely by tuning its wavelength within a region of $0.74-1.86\ \mu$m. The resulting idler outputs showed wheel-shaped modes, manifesting coherent superpositions of vortex modes with $\ell_i = -2, 6;\ -1, 5;$ and $0, 4$. Also, the maximum pulse energy of the signal output was measured to be 1.18 mJ at the pump power of 7.7mJ, corresponding to an optical conversion efficiency of 15.3%.

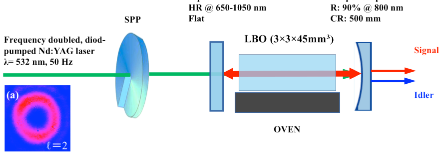

Fig.1 Experimental setup of LBO-OPO.

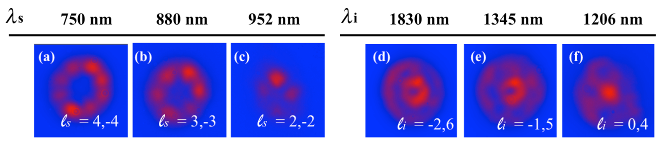

Fig. 2 Spatial intensity profiles and OAM states of outputs.

References

[1] L. Allen, W. Beijersbergen, R. C. Spreeuw, and J. P. Woerdman, Phys. Rev. A 45, 8185 (1992).
[2] K. Masuda, R. Shinozaki, Y. Kinezuka, J. Lee, S. Ohno, S. Hashiyada, H. Okamoto, D. Sakai, K. Harada, K. Miyamoto, and T. Omatsu, Opt. Express 26, 22197-22207 (2018).
[3] Jeffries GD, Edgar JS, Zhao Y, Shelby JP, Fong C, Chiu DT, Nano Lett, 7(2), 415–420 (2007).
[4] R.Fickler, R.Lapkiewicz, W.N.Plick, M.Krenn, C.Schaeff, S.Ramelow, A.Zeilinger, Science,338(6107):640–643, (2012).
[5] T. Omatsu, K. Miyamoto, A. J. Lee, Journal of Optics 19 (12), 123002 (2018).