Cavity-enhanced polarization-insensitive frequency converter for vector beams

R.H Chen[1,2], Z.Y Zhou[1,2], and B.S Shi[1,2]

[1] *CAS Key Laboratory of Quantum Information, University of Science and Technology of China, Hefei, China*
[2] *Hefei National Laboratory, Hefei, China*
Contact Email: chenrenhui@mail.ustc.edu.cn

Vector beams with spatially inhomogeneous states of polarization have garnered significant interest due to their unique intrinsic spin-orbit coupling (SOC) within the light field. These beams provide distinct advantages in applications such as high-capacity optical communications, super-resolution imaging, and quantum information processing [1–3].

The manipulation of vector beams has become increasingly significant in modern optics, both in fundamental research and technological applications. Nonlinear frequency conversion provides an efficient method for tuning the spectral properties of light fields. However, optical frequency conversion via second-order nonlinear effects is restricted by the polarization states of interacting light due to phase-matching constraints. A promising strategy to overcome this challenge is to utilize a nonlinear Sagnac interferometer [4]. The fundamental principle of this configuration relies on converting the orthogonally polarized states separately and then coherently superimposing them.

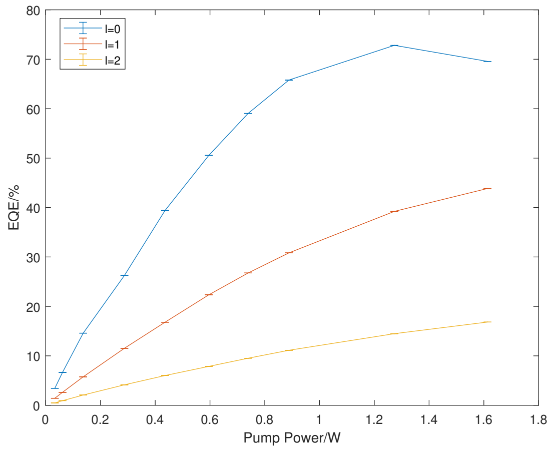

Figure 1: Polarization-insensitive frequency converter external quantum efficiency. The blue, red, and yellow curves represent the SOC states $\left|H^l\right\rangle$ for l $=$ 0, 1, and 2, respectively.

In this work, we demonstrate a polarization-insensitive frequency converter utilizing a pump-enhanced cavity in a Sagnac-loop interferometer, achieving high conversion efficiencies for the SOC state. The pump-enhanced cavity is a standing-wave cavity for 1600-nm light with a finesse of 160. The 780-nm signal light and the 1600-nm pump light were mixed in the periodically poled lithium niobate (PPLN) crystal to generate 1522-nm light via type-0 sum-frequency generation. This configuration enabled highly efficient conversion of SOC states $\left|H^l\right\rangle = \frac{1}{\sqrt{2}}\left(|R,+l\rangle + |L,-l\rangle\right)$ $(l = 0,1,2)$. Figure 1 shows the external quantum efficiency (EQE) of the frequency converter for SOC states. The maximum EQE values obtained were 72.81%, 43.85%, and 16.83% for $(l = 0,1,2)$, respectively. After accounting for 82% optical component losses, the internal quantum efficiencies were 88.02%, 53.01%, and 20.35%, respectively. We reconstructed the density matrices of SOC states $\left|H^l\right\rangle$ $(l = 1,2)$ based on spatial-Stokes measurement [5], with measured fidelities of 97% $(l = 1)$ and 95% $(l = 2)$, respectively. This work establishes a promising platform for manipulating vector beams across wavelengths, polarization-resolved imaging systems, and high-capacity optical communication networks.

References

[1] A. E. Willner, H. Huang, Y. Yan, et al., Adv. Opt. Photonics 7, 66 (2015).

[2] Y. Kozawa, D. Matsunaga, and S. Sato, Optica 5, 86 (2018).

[3] V. Parigi, V. D'Ambrosio, C. Arnold, et al., Nat. Commun. 6, 7706 (2015).

[4] R. H. Chen, S. J. Niu, Z. Ge, et al., Phys. Rev. Appl. 22(1), 014020 (2024).

[5] J. Yuan, X. Wang, G. Chen, et al., Laser Photon. Rev. 18, 2400368 (2024).