SUPER-CRITICAL PHASEMATCHING FOR GENERATION OF STRUCTURED LIGHT BEAMS

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Radially and azimuthally polarized light beams are characterized by particular non-uniform polarization patterns. They have attracted recent interest for their properties and uses in applied and fundamental optics. A radial polarization points to a light beam's central propagation direction (i.e. the beam axis) everywhere in the beam's spatial profile. An azimuthal polarization is everywhere orthogonal to the radial polarization. That is, it is tangential to a circle centered on the beam axis [1]. Photon pairs with these polarizations have applications in quantum information, such as alignment-free quantum key distribution [2] and protocols to carry multiple bits of information on one photon (e.g. superdense coding) [3]. We present a method to directly produce, through spontaneous parametric down-conversion (SPDC), photon pairs with radial and azimuthal polarizations.

In SPDC, a pump photon is absorbed and two lower-frequency photons, the signal and idler, are produced such that energy and momentum are conserved (i.e. phasematching). These photons may be produced in the same direction as the pump beam, in collinear phasematching, and may have polarizations that are parallel (Type I) or orthogonal (Type II). In our new geometry, the pump beam is a Bessel-Gauss beam, which we have modeled as a distribution of Gaussian beams propagating along the surface of a cone towards its apex. This cone is centered on the crystal axis, which is parallel to the central pump propagation direction. The opening angle of this cone is set so that each Gaussian pump beam in the pump distribution meets the conditions needed for phasematching. Bessel-Gauss beams have been used to pump the opposite process, second-harmonic generation, but in these cases the phasematching conditions were non-critical and therefore distinct from the phasematching conditions considered here [4,5].

SUMMARY

This paper presents a novel geometry for spontaneous parametric down-conversion that will directly produce photon pairs with radial and azimuthal polarizations.

SIMULATION RESULTS

We have simulated the probability densities for the signal and idler photon for Type II degenerate, collinear phasematching from 405 nm to 810 nm, as shown in Fig. 1. The phasematching is simulated in a 500 μm thick β-barium-borate (BBO) nonlinear optical crystal. The opening angle of the pump beam is set to 41.8°, which is the degenerate collinear phasematching angle in BBO for a 405 nm pump. This pump beam is then strongly non-paraxial, and so it was convenient to model the pump beam as a distribution of paraxial Gaussian sources, each with central $\mathbf{k}$-vector $\mathbf{k}_p^0(\varphi_p)$, where φ_p is the azimuthal angle of spherical coordinates. We can then calculate the complex amplitude for the signal and idler to have $\mathbf{k}$-vectors $\mathbf{k}_s$ and $\mathbf{k}_i$, respectively, and sum these amplitudes for each Gaussian beam in the pump distribution. These calculations follow those outlined by Boeuf *et al.* [6]. Summing and squaring the amplitudes for each signal(idler) emission direction gives the marginal probability density $P(\mathbf{k}_{s(i)})$ to produce a signal(idler) with k-vector $\mathbf{k}_{s(i)}$. We have plotted these marginal probability densities ($P(\mathbf{k}_s)$, $P(\mathbf{k}_i)$) for the signal and idler photons in Fig. 1.

CONCLUSION

We have demonstrated a novel method to directly produce radially and azimuthally polarized photon pairs. These unique polarization states have applications in quantum information and quantum metrology, and are opening new research directions in these fields.

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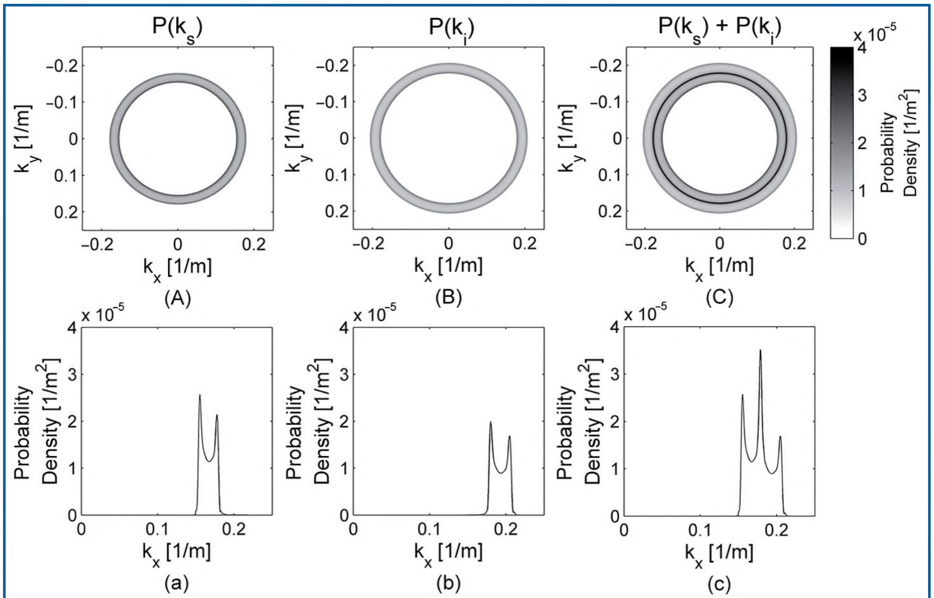

Fig. 1 Marginal probability density (P($\mathbf{k}_s$), P($\mathbf{k}_i$)) for Type II degenerate down-conversion. The pump cone half-angle is 41.8° in a 500 μm thick BBO crystal. The pump beam wavelength is 405 nm and the signal and idler wavelengths are 810 nm. Plots (A), (B), and (C) give (A) the probability density of generating a signal photon at $\mathbf{k}_s$, (B) the probability density of generating an idler photon at $\mathbf{k}_i$, and (c) P($\mathbf{k}_s$) + P($\mathbf{k}_i$), which is proportional to the photon flux. Plots (a), (b), and (c) are produced from plots (A), (B), and (C), respectively, by plotting along $k_y = 0$.

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