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Super-Critical Phase-Matching for Generation of Structured Light Beams

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Radially and azimuthally polarized light beams have garnered increased interest for their properties and uses in fundamental and applied optics. Radial polarizations are parallel to the central axis of the beam (at all points pointing toward the beam center); azimuthal polarizations are orthogonal to this, running perpendicular to the central axis of the beam. Photon pairs with these polarizations have applications in quantum information, such as alignment-free quantum key distribution and superdense coding. 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 phase-matching, 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 forming the surface of a cone. 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 phase-matching conditions.

We have simulated the output distributions for the signal and idler photons in type I and type II phase-matching. For type II phase-matching, the signal and idler photons are emitted along three concentric cones, which we have named 'super-cones'. These photons will have orthogonal polarizations: one will be radially polarized and the other azimuthally polarized. In type I phase-matching, the signal and idler photons will both be azimuthally polarized, and will be emitted along a single super-cone that is collinear with the pump beam.

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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