Generation of photon pairs in a periodically-poled ring fiber using spontaneous parametric down-conversion

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Correlated photon pairs represent an indispensable tool in the field of quantum optics. Compact sources of photon pairs are needed in order to be implemented as parts of modern integrated devices.

Nonlinear optical fibers, which guide modes with defined orbital angular momentum (OAM) [1, 2], represent one kind of promising sources of photon pairs [3, 4]. As the interacting fields are confined in the transverse direction, the enhancement of photon pair emission occurs. Moreover, periodical poling provides an additional degree of freedom that allows to reach suitable phase-matching conditions.

The process of down-conversion has been numerically investigated in these periodically poled fibers with a ring-shaped core [3, 4]. The fibers are able to guide the modes with OAM steadily. This gives a unique opportunity to study the nonlinear interaction of modes with orbital angular momentum. The fiber core has been made of SiO_2 dopped by 19.3 mol% of GeO_2. The inner (outer) diameter of the core has been set to value 4 μm (5.5 μm). The cladding of the fiber has been made made of pure SiO_2. The fiber 10 cm long has been analyzed.

The quantum mechanical state of a photon pair has been obtained by solving the Schrödinger equation in the interaction picture in the first order in the nonlinear constant:

$$|\psi\rangle = -\frac{i}{\hbar}\int_{-\infty}^{+\infty} dt' \hat{H}_{\mathrm{int}}(t')|\mathrm{vac}\rangle. \quad (1)$$

The effective interaction Hamiltonian $\hat{H}_{\mathrm{int}}$ is expressed as

$$\hat{H}_{\mathrm{int}} = 2\varepsilon_0 \int d\mathbf{r} \sum_{j,k,l=x,y,z} \chi^{(2)}_{jkl} E_{p,j}(\mathbf{r},t)\hat{E}^{\dagger}_{s,k}(\mathbf{r},t)\hat{E}^{\dagger}_{i,l}(\mathbf{r},t). \quad (2)$$

The initial vacuum state $|\mathrm{vac}\rangle$ of the signal and idler quantum fields has been assumed. The pump electric field $\mathbf{E}_p$ has been assumed to be strong, while the signal and idler electric fields have been represented by quantum-operator electric fields $\hat{\mathbf{E}}_s$ and $\hat{\mathbf{E}}_i$, respectively. The pump, signal and idler electric fields have been expanded into the modes with defined orbital angular momentum.

The modes have been investigated with respect to stability of guidance. The most stable modes are HE_{11}, HE_{21}, TE_{01} and TM_{01}. According to the length of the periodically-poled grating, different nonlinear interactions among the modes may occur. If the pump beam propagates in mode HE_{21}, spectrally narrow-band generation of photon pairs is observed. In this process, the down-converted photons are generated into spectrally separated windows. On the other hand, if the pump beam is in mode HE_{11}, spectrally broad-band emission occurs giving rise to correlation times of the order of 10 fs. The number of emitted photon pairs are in the orders $N \sim 10^1 - 10^2$ s$^{-1}\mu$W^{-1}.

Parameters of the interaction can be chosen such that photon pairs maximally entangled in OAM are emitted. For the Gaussian temporal envelope of the pump pulse the entanglement in the frequency domain is determined. For the pump pulse with spectral FWHM equal to 2 nm the dimension of the entangled space reaches the values around 100. Dimensions of the entangled space including OAM degrees of freedom are about 200.

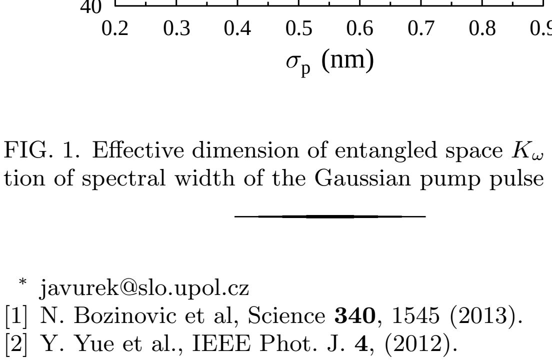

FIG. 1. Effective dimension of entangled space K_ω as a function of spectral width of the Gaussian pump pulse σ_p.

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