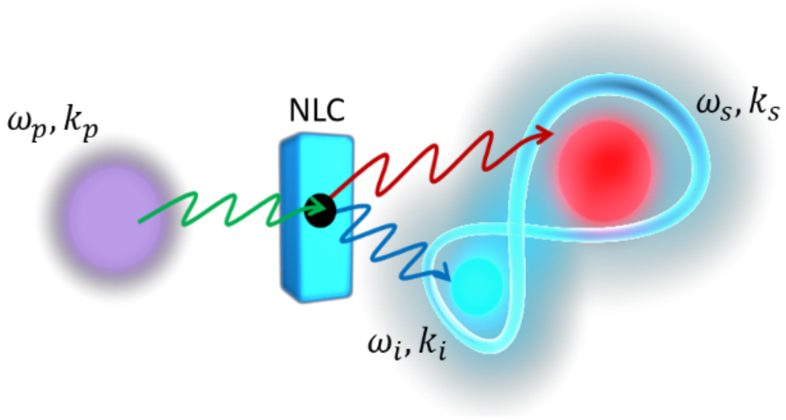
QP-TECH.EDU

Experimental Quantum Technologies

Spontaneous parametric down-conversion (SPDC) sources



Introduction and Theory:

One of the means to generate correlated pairs of photons is spontaneous parametric down-conversion (SPDC). SPDC is a second-order nonlinear process in which a pump photon of higher energy (E_p) spontaneously decays in a non-linear crystal to create two photons of lower energies, conventionally known as signal and idler.

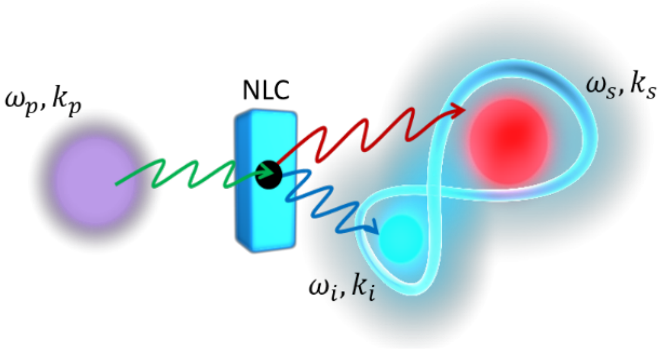


Figure 1: Spontaneous parametric down conversion (SPDC) process.

In this process, energy is conserved, which results in the following equivalent conditions for the frequencies and wavelengths of the generated photons:

$$E_p = E_s + E_i, \quad (1)$$

$$\hbar\omega_p = \hbar\omega_s + \hbar\omega_i, \quad (2)$$

$$\frac{1}{\lambda_p} = \frac{1}{\lambda_s} + \frac{1}{\lambda_i}. \quad (3)$$

Here, $\hbar$ denotes the reduced Planck constant, ω the angular frequencies and λ the wavelengths. The suffixes (p, s and i) denote the pump, signal and idler photons respectively.

In addition to energy conservation, efficient nonlinear interaction also requires the conservation of the momentum, resulting in the following condition:

$$\vec{k}_p = \vec{k}_s + \vec{k}_i \quad (4)$$

$$n_p \vec{\omega}_p = n_s \vec{\omega}_s + n_i \vec{\omega}_i \quad (5)$$

This condition ensures, that the propagating modes are phase-matched, i.e. propagate with the same phase such that the photon energy can be transferred from the pump to the signal and idler waves. Fulfilling this phasematching condition is a major challenge in all nonlinear conversion phenomena, since dispersion effects lead to different phase velocities for different participating wavelengths. Using birefringent materials with different refractive indices for different polarizations can provide a solution to the above equations. In the context of SPDC, depending on which polarization and refractive index is used, the different processes are classified according to the polarizations of the involved photons.

Since refractive indices depend on the temperature, it is possible to tune the frequencies of the SPDC photon pair by varying the crystal temperature. An example for this is shown in Figure 2, where spectra of the emitted photons are plotted for different temperatures. For temperatures around $42\,°C$, the phase matching condition is satisfied for degenerate signal and idler wavelength of about $810\,nm$. At that point, both signal and idler photons are generated with the same spectrum centered at that wavelength. For increasing temperature, phasematching is fulfilled for different combinations of signal and idler wavelengths, resulting in spectra with two distinct maxima corresponding to the signal and idler wavelengths.

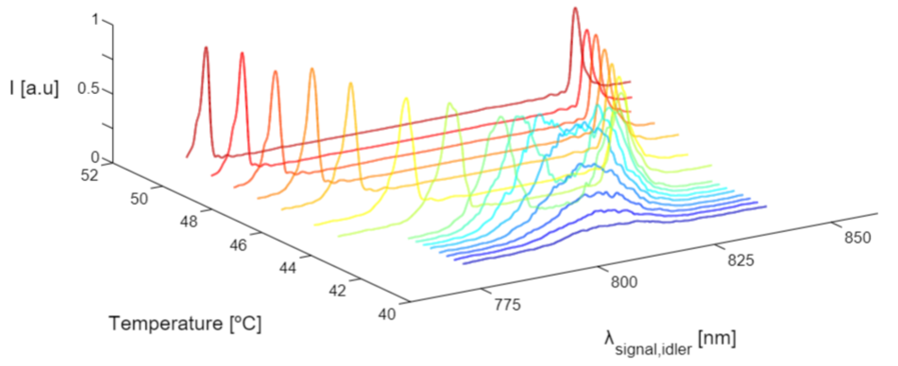


Figure 2: Experimentally observed normalized SPDC spectra for 20 mm PPKTP crystal (poling period=3.425µm) pumped with a 405.4 nm CW laser diode for varied phase-matching temperature. The photons were coupled into a single-mode fiber and analyzed in a grating spectrometer with a resolution of 0.4 nm. Figure taken from [1].

References:

[1] Fabian Steinlechner, Pavel Trojek, Marc Jofre, Henning Weier, Daniel Perez, Thomas Jennewein, Rupert Ursin, John Rarity, Morgan W. Mitchell, Juan P. Torres, Harald Weinfurter, and Valerio Pruneri, "A high-brightness source of polarization-entangled photons optimized for applications in free space," Opt. Express 20, 9640-9649 (2012).