Non-uniformity induced distinguishability of nonlinearly generated photon pairs

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Photon pairs source are basic blocs for many quantum cryptography protocols. Some of these require polarization entangled pairs, which can be achieved through spontaneous parametric down conversion (SPDC) or spontaneous four wave mixing (SFWM), placing the nonlinear media within a Sagnac interferometer. Entanglement quality is directly related to indistinguishability of pairs emitted in both propagation directions. Yet, SPDC and SFWM rely on phase matching condition, which may be subject to change along waveguides.

Considering the propagation of a pump pulse without deformation inside a guide, in absence of photons other than the pump ones prior to the propagation, the pair state is given by its joint spectrum amplitude of generation probability (JSA):

$$\mathrm{JSA}(\omega_s, \omega_i) = C\,\chi^{(n)}\,g(\omega_s, \omega_i)\,f(\omega_s, \omega_i)$$

With ω_s and ω_i the pulsations of the pair photons, C a constant and $\chi^{(n)}$ the n-th order nonlinear susceptibility. The function g is entirely determined by the pump pulse characteristics and carries the energy conservation condition, while f expresses momentum conservation and is written :

$$f(\omega_s, \omega_i) = \int_0^L e^{-i\,\Delta k_G\,z}\,dz$$

With L the guide length and Δk_G the generalized phase matching condition defined by [1] and which expression can depend on the exact phase matching mechanism (like SPDC in PPLN [2] or SFWM in fibers [3]). In uniform media (constant Δk_G), f reduces to the well-known cardinal sinus relation. For position dependent Δk_G (as in a tapered fiber) one can't find an analytical expression for f, except in specific case. We established the f analytical form for a linearly varying Δk_G and calculated the emitted spectrum for two opposite propagation direction (Fig. 1). We observe a broadened spectra with reduced peak intensity compared to the uniform case. But more importantly the emitted spectra becomes non-reciprocal, leading to distinguishable photon pairs once the nonlinear media will be placed within a Sagnac interferometer in order to achieve polarization entanglement.

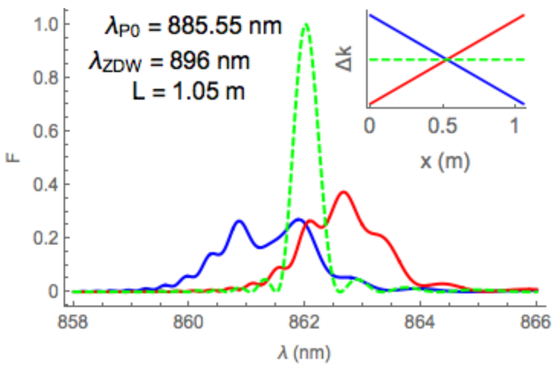

Figure 1: Emission spectrum $F = |f|^2$ of idler photon for the same fiber as that of [4] in the uniform case (green), a linear variation of Δk_G between a +1 nm shift of λ_{ZDW} at input and 0 at output (blue) and the inverse case (red).

We will present a model describing emission spectrum for any Δk_G variation and discuss the loss of indistinguishability of pairs emitted from contra-propagating pumps and its consequences on pairs entanglement as it is done in Sagnac interferometer. The analytical model will also allow us to quantify this distinguishability and to propose solutions to reduce it, which will be presented.

References

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