Experimental demonstration of inhibited-coupling hollow-core fibers for shaping photon-pair time-frequency correlations

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Temporal modes (TM) of light are a promising resource for quantum information as they span a discrete infinite dimensional encoding basis [1]. Additionally, TM are compatible with standard fibered communication as they share the same polarization, carrier frequency and transverse spatial mode properties. Single photons in specific TM can be obtained by Spontaneous Parametric Down Conversion (SPDC) and Spontaneous Four-Wave-Mixing (SFWM) sources. The Joint Spectral Amplitude (JSA), derived from energy and momentum conservation constraints describes the two-photon state and the signal and idler spectral distribution. The Schmidt decomposition of the JSA function : $F = \sum_n \sqrt{\lambda_n} S_n(\omega_s) I_n(\omega_i)$ where the ($\{S_n\}$) and ($\{I_n\}$) are the TM basis of the signal and idler photons is sometimes reduced to one non zero term [2] where both signal and idler photons are generated in a single TM, giving rise to a factorable state of the pair. This can be achieved if a group velocity matching condition is satisfied (either $\beta_1(\omega_p) = \beta_1(\omega_s)$ or $\beta_1(\omega_p) = \beta_1(\omega_i)$ or $2\,\beta_1(\omega_p) = \beta_1(\omega_s) + \beta_1(\omega_i)$ in the case of SFWM with β_1 the inverse group velocity). Such single TM states are very useful for scalable heralded photon sources [3]. On the contrary, having several non-zero terms in the Schmidt decomposition depicts spectral correlations between the signal and idler which can also be required for others applications. Here we show experimentally in a stimulated regime how the shape of the JSA can be changed for photon pairs produced by FWM in a gas-filled inhibited-coupling (IC) fiber.

IC fibers exhibit a discontinuous multiband dispersion where the position of the discontinuities are dictated by the silica strut thickness [4]. Such exotic dispersion opens new possibilities for the FWM phase matching fulfillment, and thus for tailoring the JSA. With the ability to have the pump and the generated signal and idler photons lying in different dispersion band, group-velocity matching can be easily obtained. We use stimulated emission tomography [5], which consists in seeding the FWM process with a tunable continuous wave laser, to reconstruct the 2D JSI ($= |\mathrm{JSA}|^2$) as a function of signal and idler wavelengths. With a femtosecond pulsed pump at 1030 nm and a seed laser at telecom wavelength, we chose two optimized fibers denoted A and B with struts thickness t=600 nm and inner-core diameter d=40 μm and t=1250 nm; d=49 μm (Fig 2). These two fiber designs allow a multiband FWM. Indeed the idler (fiber A), or both the signal and idler (fiber B) are generated in a different band from the pump. Xenon gas has been chosen because i) no Raman-Scattering can take place in a noble gas, which eliminates the usual main source of noise in fibered photon-pair generation and ii) it exhibits high non-linearity (in the order of 10^{-21}m^2/W at 10 bar).

For a given fiber design, pump wavelength, gas pressure and fiber length are three adjustable parameters that can be tuned to access various JSA shapes as can be seen on the simulations in Fig.1. Both single TM or, opposingly, multi-TM can be obtained. Changing the gas pressure impacts the medium dispersion, which results in shifting the JSA and modifying its shape (Fig 1). As a first experimental demonstration in such gas-filled IC fibers, we experimentally reconstruct the JSI for two different fibers (Fig 2) with signal and idler wavelength respectively in the 771 nm and 1550 nm ranges. It shows that two very different Schmidt decompositions can be obtained: a quasi factorable state and a correlated state.

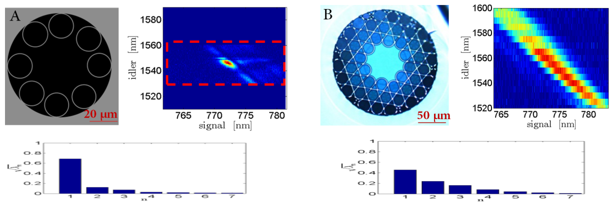

Figure 2: Fiber cross-section, experimental JSI and corresponding Schmidt decomposition for a 8 tubes IC fiber and a kagome IC fiber denoted A and B. In JSI of A the red dashed-lines define the measurement range. The pixelated structure of the JSI of B is due to an insufficient number of measures and will be improved.

We have made a new proposal of using multi-dispersion band medium in order to engineer photon-pair time-frequency correlations. For the first time to our knowledge, we implement this technique using gas-filled inhibited-coupling fiber. More configurations are currently being investigated in order to demonstrate the real time tuning possibility in such a medium.

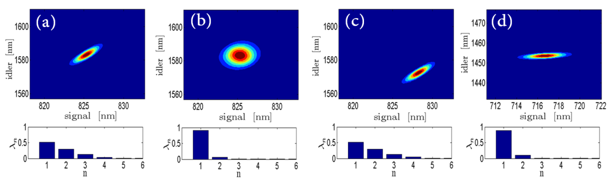

Figure 1: Simulated JSI for different configurations of length, gas pressure and pump wavelength. Starting from the conditions of (a) P =3bar λ_p =1085 nm L = 1m, (b-d) correspond to the change of one parameter (b) L = 30 cm (c) P = 2.6 bar (d) λ_p =985 nm

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