Ultra-fast Photon Pair Sources for Quantum Networking

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Abstract: We report on the realization of ultra-fast photon pair source, capable of delivering high-quality single photon pairs, guaranteeing efficient operational condition for advanced quantum networking by taking advantage of high-performance telecom components and integrated optics.

The role of entanglement, which was initially categorized as a theoretical ground in quantum physics, is now considered as a resource for enabling various implementations of complex quantum information science (QIS) protocols. Taking advantage of strong correlations between entangled photons allows QIS protocols to reach their fullest potential in term of long operational distances. One of the most investigated protocols for quantum networking, involving entanglement as a genuine resource, is the quantum relay configuration.[1, 2] With that being said, the success rates of complex protocols such as QR, are highly affected by the non-deterministic nature of spontaneous parametric down conversion (SPDC), usually exploited for photon pairs generation. In favor of achieving higher success rates, we exploit here high-speed performance offered by state-of-the-art telecom laser technology and guided-wave optics.

Generating photon pairs at telecom wavelength by SPDC requires pumping any suitable non-linear crystals at visible wavelength. To achieve this, most of the demonstrated QIS protocols adopt solid-state, mode-locked lasers producing optical pulses around 780 nm as the pump beam whose repetition rate is inherently limited to a few hundreds of MHz. In contrast, state-of-the-art, ultra-fast fiber laser is readily available in the 1550 nm telecom band exhibiting picoseconds pulses whose repetition rate is adjustable up to 10 GHz. On the other hand, the very high efficiency of periodically poled lithium niobate (PPLN) waveguides has led to the investigation of sequential non-linear processes *i.e.* two PPLN waveguides are arranged in a cascade manner for which each particular waveguide plays a specific designated role. In such configuration, the non-linear interaction of second harmonic generation (SHG) up-converts the incident lights from 1560 nm to 780 nm, then through SPDC in the second PPLN waveguide, photon pairs back in the 1560 nm band are created.[3] What we propose here is to use such fast laser pulses at 10 GHz rate, feeding the cascaded PPLN waveguides to generate photon pairs at telecom wavelength at ultra-high repetition rate.

In this paper, we demonstrate the realization of ultra-fast photon pair sources and their characterization in terms of coincidence-to-accidental ratio, as well as the spectral "purity" which are essential for efficient quantum networking.[4] For that purpose, a standard arrangement of Hanbury Brown and Twiss (HBT) experiment is implemented and this conveniently gives access to *P1,* the probability of registering a "heralded" photon given the other counterpart "heralding" photon is detected, and to $g^{(2)}(0)$, the second order auto-correlation function which quantifies the "singleness" of the emitted photon pairs. On the other hand, the picosecond laser regime has been identified to be optimal for generating "pure" photon states in the spectral domain, *i.e.* Fourier-transform limited within the duration of the pump pulses, since suitable spectral filtering in standard telecom channels can be achieved using competitive off-the-shelves, high-performance, low-loss and relatively inexpensive fiber components.[5] We have further tested the indistinguishability of the produced photons using a Hong-Ou-Mandel (HOM) type setup.[6]

As illustrated in Fig.1, using ultra-fast, 10 GHz picosecond pulses, the figures of merit *P1* and $g^{(2)}(0)$ are measured. Pairs of photons are generated in a PPLN waveguide, using frequency-doubled 10 GHz laser (1540 nm → 770 nm). The slightly non-degenerate, energy-matched photon pairs are deterministically separated thanks to a combination of a wavelength division multiplexor (DWDM) and a fiber Bragg grating (FBG) filter, in predefined ITU 42 and ITU 50 telecom channels, respectively. Through the employed HBT setup, the correlation in terms of coincidences between the

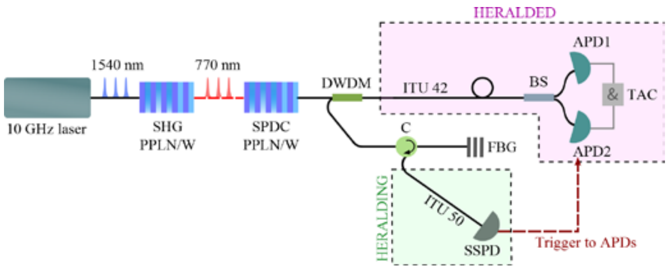

Fig. 1: The multi-pair contributions is characterized using a HBT

two heralded avalanche photodiode (APD) detectors is registered. For the moment, our source exhibits a *P1* of 0.385 and a $g^{(2)}(0)$ of 0.09 at a heralding rate about 2.3 MHz. Moreover, high purity of the photons has been demonstrated with the arrangements shown in Fig. 2. At this stage, we simply used a much slower, solid-state, Coherent MIRA 900 laser (770 nm, 76 MHz, 1 ps temporal duration pulses). By adjusting the temporal overlap of interfering photons at the beam splitter (BS), we reveal a raw dipping signature during the acquisition of four-fold coincidences of 98.6% visibility. This indicates the high degree of indistinguishability of our single photon preparation stage, making it suitable for quantum networking. In addition, the measured false four-fold coincidence rates are closed to the estimated, pure APD dark counts contribution which suggests negligible presence of photonic noise in the setup. This is achieved by implementing better filtering scheme with optimum rejection and also by employing high-performance telecom fiber components.

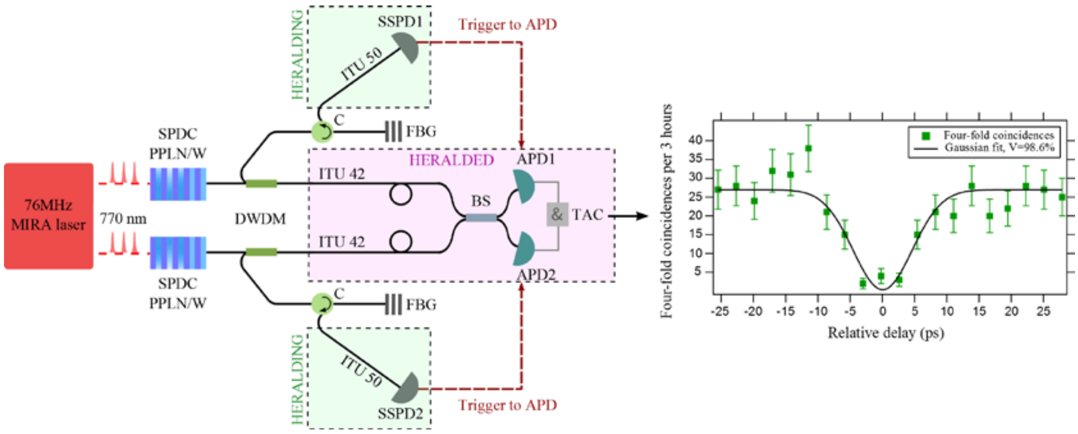

Fig. 2: The accumulated four-fold coincidences are registered for single photon indistinguishability measurement using a much slower MIRA laser.

So far, promising results have been obtained, gauging the quality of our experimental approaches. The next step is to perform a two-photon interference experiment at 10GHz repetition rate. We therefore expect achieving better results, namely, high four-fold coincidence rates, up to 1000 coincidences per an hour of measurement, while keeping an excellent visibility for the HOM dip. This should demonstrate the effectiveness of our high-speed photon pair sources for quantum networking.

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