Narrow-band photon sources for quantum repeaters

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Abstract

The main elements of quantum repeater protocols are entanglement swapping between independent photon sources and storage of photons in quantum memories. These two processes demand a high rate generation of highly coherent photons whose bandwidth can match atomic linewidths. For their practical application narrow-band sources are necessary. Waveguide resonators, i.e. waveguides with lateral mirror coatings, represent a practical solution for the generation, in a cavity-enhanced way, of high coherent photons at specific narrow-band frequencies.

Introduction

Nowadays, the most widely applied method to create photonic entanglement is spontaneous parametric down conversion (SPDC) in non linear crystals. These sources, even if easy to control, produce rather broad output spectra with widths of the order of THz, turning out to be unsuitable for long distance quantum communication applications.

In processes requiring interference of photons coming from different sources, such as entanglement swapping[1], if the coherence time of the photons exceeds the temporal resolution of the detectors, photon timing can be set by detection times and not by synchronization of the sources. This allows the use of continuous-wave really autonomous sources instead of pulsed sources, a fundamental step towards the practical realization of a quantum repeater. Anyway, with simple SPDC sources photons' coherence time is of the order of 10 - 10^2 fs, much smaller than resolution times of existing detectors. Moreover, atomic – based quantum memories need to store at high rate photons with frequency bandwidth comparable with atomic linewidth (≈ MHz). Thus, for the realization of real-world quantum networks with independent and distant nodes, the realization of bright narrow-band sources is highly required.

In last years, to overcome this problem, there have been several attempts consisting in placing the non linear crystal inside an optical cavity, in such a way to realize the so called optical parametric oscillator (OPO)[2,3,4]. In this way it is possible to limit the bandwidth of the output to that of the cavity and, at the same time, to enhance the down conversion process: the system acts as an "active filter", without drastically reducing the count rate as passive filters do.

Waveguide resonators

Some examples of cavity-enhanced based systems realised so far are particularly bright and produce high narrow-band photons[2,3,4], but they are fundamentally lacking in stability and handling.

At the moment we are performing studies concerning periodically poled lithium niobate (PPLN) waveguide resonators, which consist in Ti-diffused waveguides, with a length of 3.2 cm and some μm of thickness, confined between mirror coatings with a reflectivity of about 84% for telecom wavelength and very low for the pump wavelength (780 nm). Thus, a waveguide resonator acts as an OPO system for telecom wavelength: it selects only specific frequencies and at the same time it allows a cavity-enhancement of the generated signal. In Figure 1 the transmission spectrum of one resonator around 1550 nm is shown. It is obtained by scanning of about 40 pm the frequency of the injected light. Peaks have different widths because of a not good acquisition of the transmitted signal by a photodiode. They show a finesse of about 10 and a full width at half maximum (FWHM) of about 170 MHz (about 1.5 pm).

By SPDC we can generate pairs of photons only at

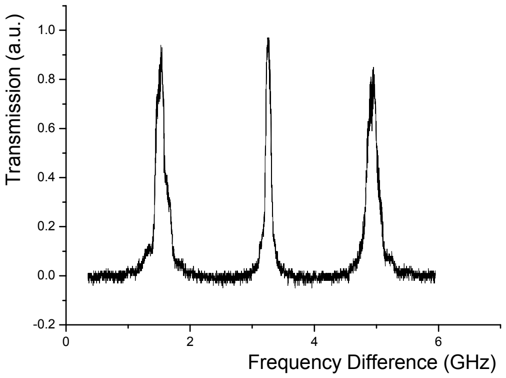

Figure 1: Transmission spectrum of a waveguide resonator around 1550 nm.

the frequencies which satisfy the energy conservation and are selected by a resonator. By proper filtering of the photons (in our case 10 pm, less than the free spectral range of the cavities) we just select one frequency mode for each of them.

The frequency tunability of this source is offered by the fact that changing the temperature of the sample we change its length L by a factor $\Delta L/L \approx 2{,}72\ 10^{-5}$ /°C, sufficient for having a change in frequency of about 23 pm / °C (2.2 GHz / °C). Therefore, in such a way, the stabilization of the frequency transmitted by a resonator doesn't need complicated and not practical methods[2,3,4], but it is related only to the temperature control of the sample.

In order to characterize our narrow-band photon source, we make a time correlation measurement. We measure coincidences between the pairs of photons produced by a waveguide resonator and filtered by 10-pm Bragg filters[6]. We use two InGaAs single photon avalanche diode (APD) detectors connected to a time-to-digital converter (TDC). For a preliminary measurement on a waveguide resonator of finesse about 4, we observed the peak shown in Figure 2. By the deconvolution of the contribution given to the peak by the resolution of the detection system, we obtained a coherence time of about 1 ns, larger than the one obtainable by simple waveguides and 10 pm-filtering[6].

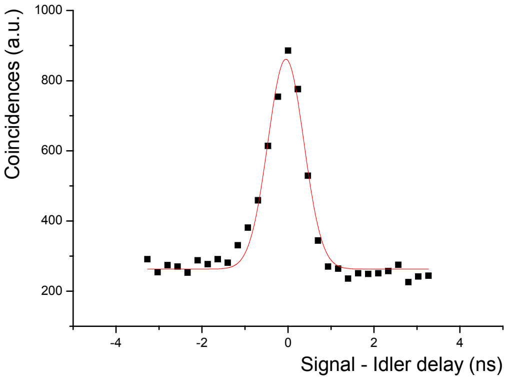

Figure 2: Time correlation measurement between idler and signal photons produced by a waveuide resonator and filtered by 10 pm-Bragg filters.

Conclusions

For long-distance communication applications narrow-band, bright, stable and tunable sources are necessary. Waveguide resonators, a special kind of OPO systems, could offer compactness, good handling and frequency stability for the production of narrow-band and high coherent photons.

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