Silicon source providing multi-spectral photon pairs with high-quality entanglement

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ABSTRACT

The silicon photonic platform has the ability of generating and manipulating individual quantum states on single chips. However, a major challenge is the on-chip rejection of the pump without affecting the pairs generated by the non-linear processes. We report the integration on a single substrate a photon-pair generator with a pump-rejection filter. It allowed us to generate photon pairs with near-perfect entanglement on 11 pairs of wavelength channels simultaneously, while achieving 85 dB of rejection of the pump. The frequency comb generated was at telecom wavelengths and compatible with the ITU channels spacing.

Keywords: ring resonator, photonics, SFWM, multimode, Bragg filters.

1 INTRODUCTION

Entanglement is becoming a resource for the quantum networks which requires a large number entangled photons. The Silicon-on-Insulator (SOI) platform provide industry ready photonic circuit that can be tailored for quantum application. Photon pairs can be produced on SOI thanks to ring resonators. They enhances the nonlinear effect of the Silicon by forming a cavity. Thanks to spontaneous four wave mixing (SFWM), signal/idler pairs are generated in the ring, where we showed high visibility and brightness for multiple pairs simultaneously [1]. However, SFWM has the disadvantage of requiring a pump close to the generated photon pairs in terms of wavelength. This makes the pump rejection challenging as it must be applied (>100 dB) on a relatively small bandwidth (∼10 nm). His has been demonstrated using active devices [2], [3] but at the cost of a high complexity, due to the control of all the filters which also brings large coincidence rate losses.

We use instead cascaded Bragg filter to rejection the pump. Such filters avoid saturation by rejecting in a higher order mode the pump and then scattering it with a single mode waveguide. This breaks the coherency between filters. Such strategies allowed us to achieve large rejection of 80 dB [4].

2 SAMPLE & EXPERIMENT

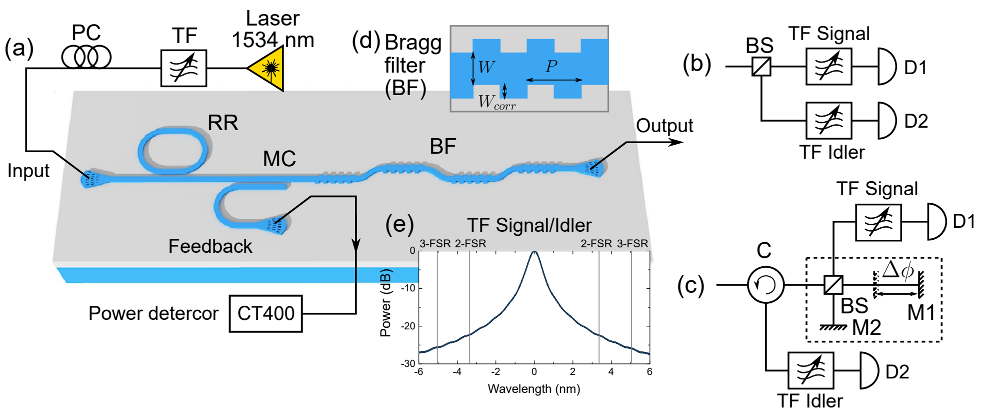

Figure 1. Schematics of the experimental setup. (a) Input laser with filter rejecting the amplified spontaneous emission (anti-ASE) and a polarization controller (PC). The light is injected in the ring resonator (RR), and then propagate to a modal directional coupler (MC) and through the stop-band filter (BF). The output of the chip is connected to either, (b) coincidence configuration with a beam splitter and bandpass filters (BP) to demultiplex signal and idler photon, or to (c) the entanglement qualification in a folded-Franson configuration. (d) Schematic top-view of the filter geometry. (e) Spectrum of the signal and idler filters which exhibit 22 dB and 25 dB rejection for the 2-FSR and 3-FSR configurations, respectively.

A ring resonator was combined with a cascaded filter on a single chip of silicon. This structure can generate pair of photons on all of the ring resonances and can be aligned to the telecom grid channel by carefully choosing the ring free spectral range. The sample was made on SOI with a silicon layer thickness of 220 nm. Electron beam lithography was used to print the pattern. This structure only require a single step of lithographic for fabrication and no active tuning. All filter sections are naturally aligned by the fabrication process, using the cascaded filters strategy (figure 1d) [4].

The sample was pumped with a tunable laser which is cleaned from the amplified spontaneous emission. The ring resonator (RR) has Q-factor of 30 000 which converts the pump into an frequency comb of entangled-photon pairs, see figure 1. Then the Bragg filter (BF) cleans the comb from the pump (-85 dB attenuation). The pump rejection filter has a 3-dB bandwidth of 5.5 nm which does not allow to access the closest resonances (1-FSR) from the pumped resonance. A modal coupler is placed between the ring and the filter to collect the rejected light [5]. This allowed us to make sure that we are pumping the cavity at the right wavelength and control the alignment of the input fiber. The generated comb is demultiplexed and the pairs are sent to a coincidence measurement (figure 1b) to ensure the quantum nature of the light. Then they are sent to a two-photon interference measurement experiment (figure 1c), to measurement the entanglement between the pairs.

3 RESULTS

Entanglement is analyzed using a folded Franson arrangement consisting of a single unbalanced fiber Michelson interferometer. The integrated filter combined with a ring yields a rate of 480 pairs per seconds in the first available resonance (2-FSR from the pumped resonance). These photons are sent in the interferometer where the phase is changed. This reveals the two photon interferences as a sinusoidal oscillation of the coincidence rate. By fitting the oscillations with $\sim N_0(1 - V\cos(2\varphi))$, we can extract the visibility V. The closer it is to one, the more entangled the pair is.

We proceeded to test the entanglement over 11 pairs of resonances over 40 nm. We measured an raw visibility higher than >90 % (Fig. 2) for all the quantum channel tested with a high internal rate of >2 MHz. This was achieved by adding only a 20dB-crosstalk de-multiplexing after the chip, see figure 1e. On top of the integrated filter which uses multi-mode effects to break the coherence between filters.

This all passive system was made by a single lithographic step with large dimensions (>75 nm), which can be fabricated using industrial deep-UV lithography. Thanks to its simplicity and low loss [4], it does not increase the fabrication process while keeping the rate of generated pairs high. Moreover, there are already many de-multiplexing strategies on-chip, it is not a limitation.

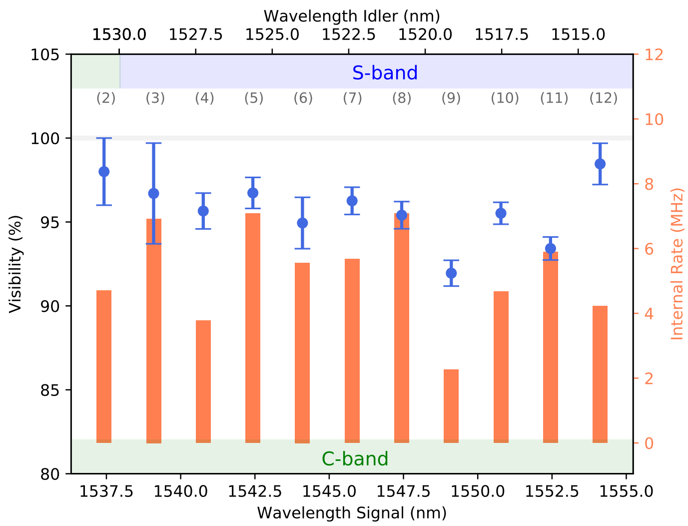

Figure 2. Raw visibilities and internal rate plotted as a function of the signal and idler wavelengths. For sake of clarity, we associate signal and idler wavelengths to their corresponding telecom band. The visibility was fitted using a time coincidence window of 200 ps centered around the maximum of the central coincidence peak.

4 CONCLUSION

We have demonstrated that using a new strategy of cascaded filters, we could make a source of entangled pairs of photons. This all-passive photon-pair source is an important step towards the integrated resource of telecom entangled photons. The low loss [4] and simplicity of the proposed approach allows the implementation of photon-pair sources with a high generation rate, based on a single lithography step. The pair generated yield a near unity visibility. This system directly can be used on quantum key distribution network to as a cheap source of entangled photon pair.

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