Photon pair generation with >600 coincidence-to-accidental ratio in the 4H-SiC-on-insulator platform

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Abstract: We demonstrate efficient photon pair generation via implementing spontaneous four-wave mixing in a compact, high-quality-factor microring resonator in the 4H-silicon-carbide-on-insulator platform. Photon pairs with coincidence-to-accidental ratio up to 600 are measured.

1. Introduction

Entangled photon sources are essential components in quantum optics, especially for communication and networking systems. So far, entangled photon pair sources and quantum interfaces are predominantly based on bulk or waveguide chips made from periodically poled nonlinear optical crystals such as lithium niobate (PPLN) or potassium titanyl phosphate (PPKTP) [1]. Recently, silicon carbide (SiC) emerged as a promising material for quantum applications, as it is compatible with metal-oxide semiconductor (CMOS) foundry processes and has many favorable optical, mechanical, electrical and photonic properties, including optical transparency from approximately 400 nm to 5000 nm, simultaneous second- and third-order nonlinearities, as well as large thermal conductivity [2,3]. In our previous work, we reported the first demonstration of photon pair generation in an integrated SiC platform based on the spontaneous four-wave mixing (SFWM) process [4]. Here, we report a significant improvement in the coincidence-to-accidental ratio (CAR) in the generated photon pairs, which is increased from <5 to up to 600. This two-order-of-magnitude improvement is achieved by choosing a SiC platform with stronger Kerr nonlinearity, suppressing the Raman noise from the fiber, and reducing the overall insertion loss in the characterization setup.

2. Device fabrication and configuration setup

In this work, a compact 36-μm-radius SiC microring resonator is employed for the photon pair generation. The device fabrication starts with depositing 2-μm-thick PECVD oxide on a 4H-SiC (Norstel AB) wafer, which is bonded to a silicon carrier and subsequently polished to a thickness of 500 nm. Note here that the 4H-SiC wafer from Norstel has 2x of Kerr nonlinearity compared to the one employed in our previous work (II-VI) [4, 5], which is a major contributing factor to the improved result in this work. On-chip waveguides and resonators are then patterned using e-beam lithography and transferred to the SiC layer with CHF3/O2 based dry etching. Our optimized nanofabrication has resulted in optical Qs above 1 million for 36-μm-radius SiC microring resonators. In addition, dispersion engineering can be carried out by varying the ring waveguide width, covering the anomalous, zero, and normal dispersions all on the same chip. To couple light to and from the chip, grating couplers are employed which show a facet-to-facet coupling loss on the order of 10 dB. Linear characterization confirms that for ring widths around 1.8 μm, the dispersion of the fundamental TE (transverse-electric) mode is small enough to allow efficient photon pair generation near the pump wavelength.

Our experimental schematic for the photon pair generation in the C band is illustrated in Fig. 1 (a). The pump light, which is a continuous-wave telecom-wavelength tunable diode laser, first goes through a narrow bandpass filter consisting of two cascaded 100-GHz dense wavelength division multiplexers (DWDMs) for selecting the laser line (1550.12 ± 0.11 nm) while rejecting light out of band by up to 60 dB. It is then coupled to the SiC chip through a grating-based coupler with an approximate 5 dB coupling loss. The light coming out of the SiC chip is collected using another grating coupler before being sent to a pump rejection filter consisting of Bragg grating filters and 100-GHz DWDMs. We then employ two 100-GHz channel spacing ITU-channels DWDM to filter the signal and idler photons into the ITU-30 (1553.33 nm) and ITU-38 (1546.92 nm) channels, respectively. For the photon detection, we use two superconducting nanowire single-photon detectors (SNSPDs) with a detection efficiency over 85 % at 1550 nm and a dark count rate less than 500 counts/s. The coincidence measurement is carried out by sending the output from the detectors to a time-to-digital converter (TDC) with a time-bin size of 110 ps.

3. Result

When the microring is pumped at the resonance wavelength with mW-level power, photon pairs are efficiently generated based on the SFWM process in the high-Q microring resonator. Using two SNSPDs detectors and a time-to-digital converter, we measured a clear coincidence peak with a CAR peak of up to 600 at approximately 0.5 mW on-chip pump power without **any** background subtraction (see Fig. 1 (c) and (d)). The photon rate of one channel (signal) is plotted as a function of pump power for both on-resonance and off-resonance pumping in Fig. 1(b). The on-resonance measured points are fitted by a quadratic function (blue curve) that gives reasonable agreement. The signal registered over 1M counts/s - limited by the maximum count rate of SNSPD - indicating a photon rate of >10M photons/s on the chip after accounting for all the insertion losses (approximately 5 dB from grating and 5 dB from off-chip filters) and detector efficiency. The off-resonance photons are basically generated by the Raman scattering in the fiber-based filters used in our experimental setup, the measured points are fitted by a linear function that gives reasonable agreement (see inset of Fig. 1(b)).

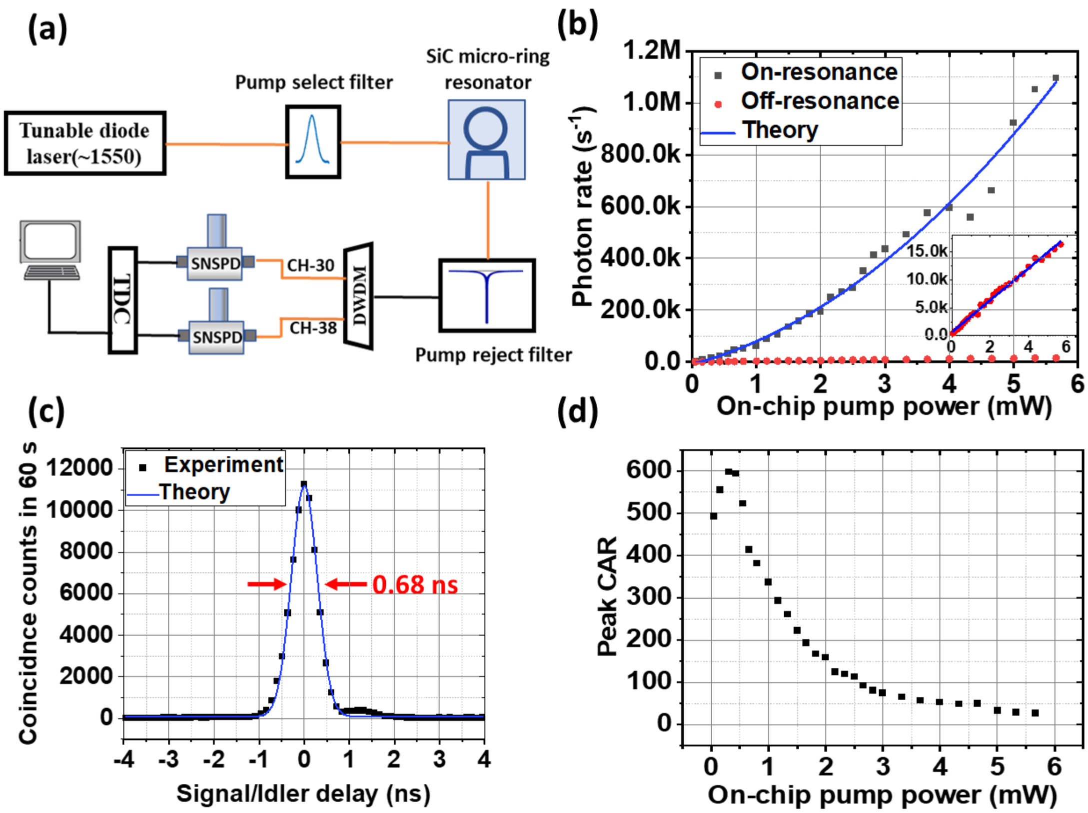

Figure 1: (a) experimental setup for the photon pair generation in SiC. (b) photon rate of one channel (signal) as a function of estimated pump power for both on-resonance and off-resonance pumping, with the on-resonance measured points fitted by a quadratic curve. Inset: off-resonance measured points fitted by a linear curve. (c) measured coincidence count rates between signal and idler in 60 second under 0.5 mW estimated on-chip pump power, the FWHM of the coincidence counts calculated from the fitted coincidence curve is 0.68 ns. (d) raw CAR peak obtained for varied estimated on-chip pump powers from 0.05 mW to 5.6 mW, the maximum CAR peak value obtained is 600 at approximately 0.5 mW estimated on-chip pump power.

DISCLAIMER: Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

4. References

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