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Silicon nitride nanophotonic circuit for on-chip spontaneous four-wave mixing

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Abstract. Here we present an integrated nanophotonic circuit for on-chip spontaneous four-wave mixing. The fabricated device includes an O-ring resonator, a Bragg noch-filter as well as a nine-channel arrayed waveguide gratings (AWG) operated in the C-band wavelength range (1550 nm). The measured optical losses of the device (-6.8 dB) as well as a high Q-factor ($> 1.2\times10^5$) shows a good potential for realizing the spontaneous four-wave mixing on the silicon nitride chip.

1. Introduction

Quantum photonics integrated circuits (QPICs) is the one of the most promising approach for realization of long term quantum computation processing [1]. QPICs combine several advantages over table-top schemes: small size, high performance, and no need of alignment, high temperature stability as well as the possibility of integration with electronic circuits on the same platform. Quantum processing applications would require to fully integrating single-photon sources, logical elements and single-photon detectors onto the same platform. Because of its large optical bandwidth, thermal and mechanical properties, silicon nitride (Si3N4 has) been demonstrated to be a promising platform [2]. In this paper we present the design and characterization of a nanophotonic circuitry which can be used for single photons generation and on-chip spectral demultiplexing.

2. Device design and fabrication

Block diagram of the nanophotonic devices for nonlinear pair generation and filtering is shown in Figure 1. Such circuit consists of three main elements: Bragg waveguide [4, 5] as a notch wavelength filter, O-ring resonator [6] as a biphoton field source and the arrayed waveguide grating (AWG) as an optical demultiplexer [7]. Biphoton field is generated by optical pumping the integrated O-ring resonator. The pump light is filtered out by the Bragg waveguide and photons are distributed to different waveguide channels for a further correlated detection. The Figure 4(e) shows the expected transmission spectra of the nanophotonic device and its individual components. The dashed line indicates the transmission spectrum of the O-ring resonator, the solid black line shows the Bragg pumping filter, and the individual channels of the AWG are shown as colored semi-ovals. The channels labels correspond to the one shown in Figure 4(a). For the correct device operations, all the spectral channels of the AWG, as well as the pumping filtration, should be aligned with O-ring resonances.

The main fabrication steps are shown in Figure 2. The integrated circuit is realized on commercially available silicon wafers Si (350–400 µm) with a thermal silicon oxide of SiO_2 (2600 nm) and silicon nitride Si_3N_4 (450 nm) grown on top. A spin coated high resolution ZEP 520A

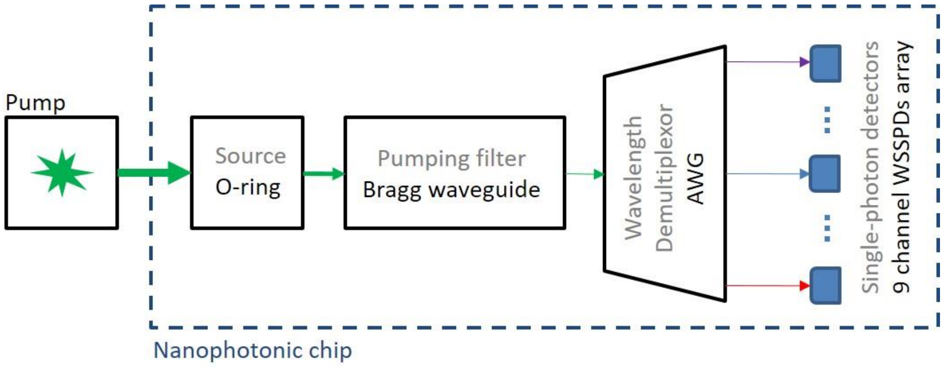

Figure 1. Block diagram of a nanophotonic circuit utilizing nonlinear photon-pair sources includes. The blue color shows schematically waveguide integrated superconducting single-photon detectors, the realization of which is planned in the future work.

resist was used for providing e-beam lithography. The chip exposure of a waveguide pattern was made by e-beam lithographer system Cable 9000C. For waveguide formation the method of plasma-chemical etching of Si_3N_4 layer in the atmosphere of Ar and CHF_3 was used. By cleaning the residual resist in the oxygen plasma, nanophotonic chip was finalized.

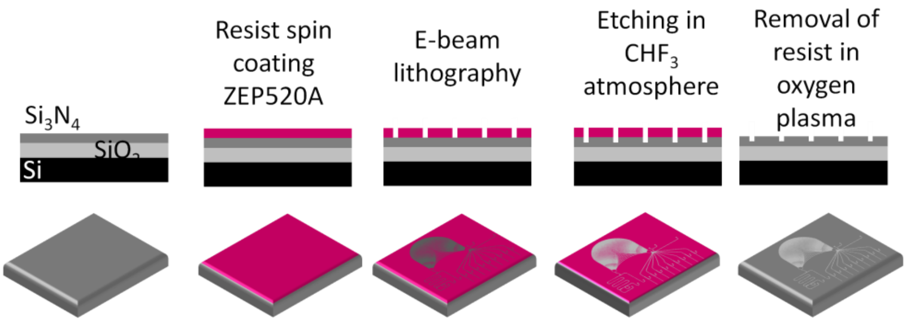

Figure 2. Technological route of manufacturing the device

Fabricated nanophotonic circuit is shown in Figure 4(a) and includes the SEM images of the main integrated components: Bragg waveguide (Figure 4 (b)), O-ring resonator (Figure 4 (c)), the star coupler of the arrayed waveguide grating (Figure 4 (d)).

3. Experimental setup and results

At this stage, the transmission spectrum of the circuit and found optical losses is tested.

The experimental setup is shown in Figure 3. We used a tunable laser source (TLB-6600) to generate light in a wavelength range of 1510-1620 nm, a polarization controller (Thorlabs FPC032) to adjust the polarization of the fiber mode which is coupled onto the input of focusing grating coupler (FGC). Using an optical fiber array, connected via FGCs we collected light that passed through all of the components, including the O-ring resonator and the Bragg waveguide (output 1) as well as the O-ring resonator, the Bragg waveguide and the AWG (outputs 2-10). The light was detected using a infrared photodiode Hamamatsu G9801.

The transmission spectrum of the nanophotonic circuit is shown in Figure 4(f). We analyzed the data and extracted the coupling losses (-7.8 dB), the filtering losses (-2.7 dB) and also the losses for a wavelength demultiplexer (-6.8 dB) separately.

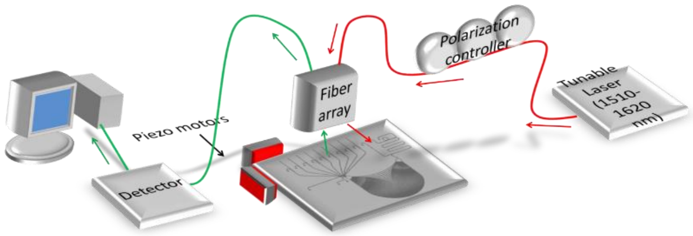

Figure 3. The scheme of the experimental setup including the tunable laser source, polarization controller, fiber array, room-temperature detectors as well as nanophotonic chip placed on a piezo stage.

Although the transmission spectrum is qualitatively similar to the one that was incorporated in the design of the nanophotonic device, the position of the spectral channels, as well as their spectral alignment, is still not sufficient to provide the generation of the biphoton field and its detection. This is due to the lack of optimized technology for the fabrication of nanophotonic devices. In the future, the work will be aimed at optimizing the fabrication technology by the increasing a resolution and improving the star coupler to minimize cross talk as well as combining with superconducting nanowire single-photon detectors.

4. Conclusion

In conclusion, we proposed nanophotonic architecture for on-chip single-photon emission through spontaneous four-wave mixing process. The measured optical losses of the device (-6.8 dB) as well as a high Q-factor (> 1.2×10^5) is demonstrated. Further work will be based on improving the optical losses of the circuit by optimize the reflow process and the etching process to achieve spontaneous four-wave mixing as well as integration with on-chip superconducting nanowire single-photon detectors (SNSPDs) [8].

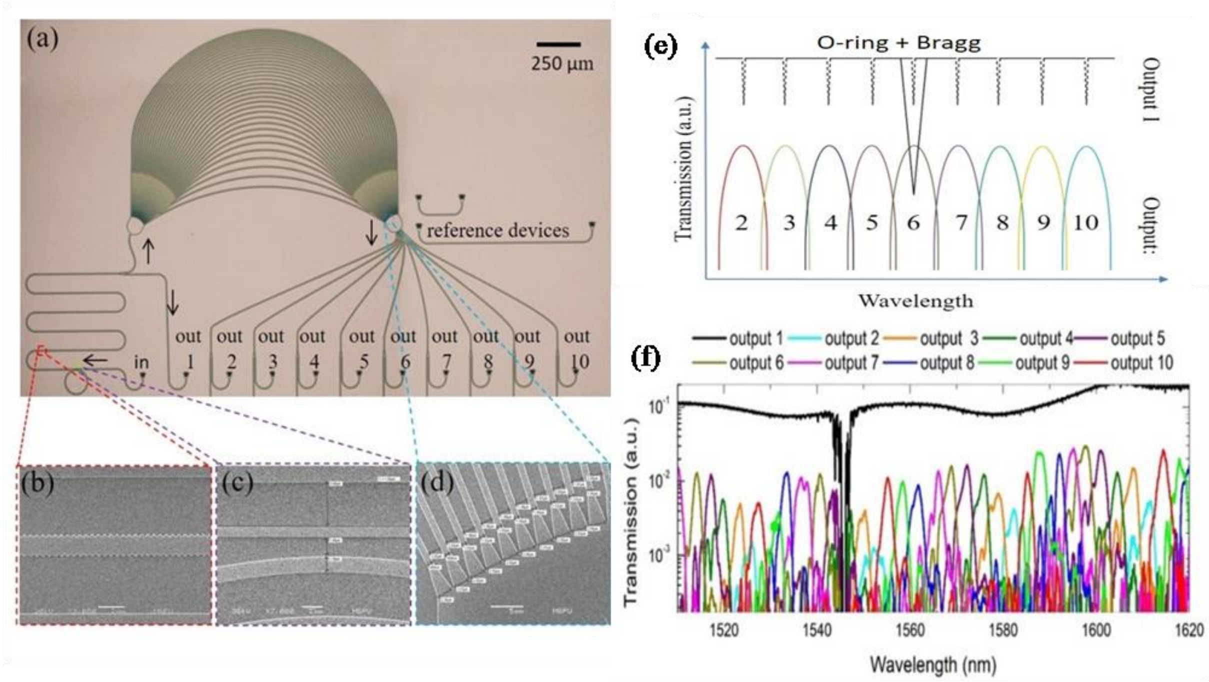

Figure 4 (a-f). (a) Optical image of the fabricated nanophotonic device; **(b)** A SEM image of the Bragg waveguide; **(c)** A SEM image of the gap between the waveguide and the O-ring; **(d)** A SEM image of the star coupler in AWG; **(e)** A schematic representation of the transmitted spectrum via device; **(f)** Measured transmitted spectrum via device.

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