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Hybrid Quantum Photonics

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Abstract: We deterministically integrate nanowire quantum-emitters in SiN photonic circuits. We generate single-photons, suppress excitation-laser, and isolate specific transitions in the quantum-emitter all on-chip with electrically-tunable filter. Finally, we demonstrate a novel Quantum-WDM channel on-chip.

OCIS codes: 230.5590 Quantum-well, -wire and -dot devices; 250.5300 Photonic integrated circuits

1. Introduction

Quantum communication applications require a scalable approach to integrate bright and deterministic quantum emitters in complex on-chip quantum circuits. Currently, one of the most promising quantum sources are based on III/V semiconductor quantum dots (QD)[1]. However, complex photonic circuitry is mainly achieved in silicon photonics due to the tremendous technological challenges in circuit fabrication of III/V semiconductors[2]. We take the best of both worlds by developing a new hybrid on-chip nanofabrication approach[3, 4]. We demonstrate for the first time on-chip generation, spectral filtering, and routing of single-photons from selected single and multiple III/V semiconductor nanowire quantum emitters all deterministically integrated in a CMOS compatible silicon nitride (SiN) photonic circuit. Our new approach eliminates the need for off-chip components, opening up new possibilities for integrated quantum photonic systems with on-chip single- and entangled-photon sources.

2. Hybrid integration of quantum emitters

We transfer nanowire QDs on silicon chip using a nanomanipulator. The tool is capable of positioning and aligning nano-sized objects with high position and orientation precision of 200nm and 0.5 degrees, respectively. In the process, a pre-characterized nanowire is detached at its base from the growth chip and then transferred at a preselected position on the photonic circuit chip comprising of a silicon substrate capped with a 2.4 µm of thermal silicon oxide. After the transfer, we encapsulate the nanowire in pressure enhanced chemical vapor deposited SiN, which serves as the core of the photonic channel. The photonic circuits are patterned and etched with respect to alignment features. Electrical contacts are fabricated to tune the on-chip ring resonator filters. Finally, the devices are cladded with PMMA for symmetric optical mode confinement. Figure 1(a-c) show the fabrication steps to realize the hybrid quantum photonic devices. Figure.1(d) shows an artistic representation of the fabricated single-photon sifter on-chip. Figure.1(e-g) show microscope image of a nanowire quantum dot integrated in a photonic channel in addition to its forward and backward emission collected from waveguides facets. We confirmed that the nanowire QDs retain high quality emission properties in terms of linewidth and vanishing probability of multi-photon emission despite going through several fabrication steps.

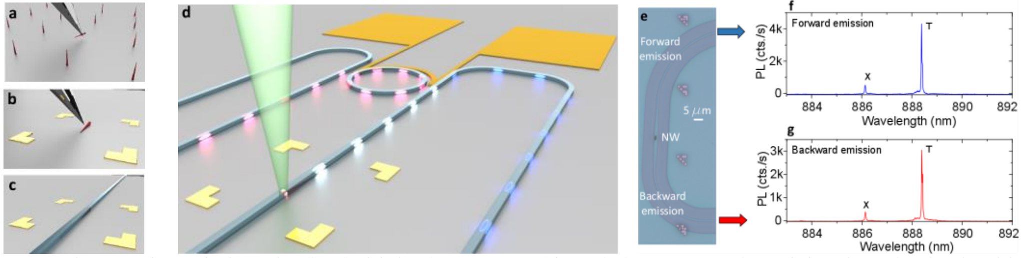

Figure.1 (a-c) Nanowire transfer and photonic circuit fabrication process. (d) Artistic representation of the photonic circuit with tunable ring resonator filter and integrated nanowire quantum source. The nanowire QDs can be either excited out-of-plane (shown here) or in-plane through the waveguide. (e) Microscope image of integrated nanowire in SiN photonic waveguide. (f) and (g) show the QD emission in the forward and backward directions respectively.

3. On-chip filtering and routing of single-photons

One of the major problems with integrated quantum photonics is the suppression of excitation lasers and elimination of unwanted emission lines. This proved to be a considerably difficult task, which hindered the demonstration of on-chip single-photons without the use of external bulky filters. Here, we have overcome this

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hurdle and realized single-photons generation and filtering on-chip. The emission from a nanowire embedded in a SiN waveguide is filtered with the tunable ring resonator filter. Figure.2 (a) and (b) show the collected emission from the ring resonator through-port and drop-port for different tuning voltage V_{rr}. Exciton and Trion lines from the QD are filtered and routed at specific ring-resonator voltage settings. Figure.2 (c) shows filtered Trion line in the drop port with suppression of the excitation pump (at wavelength 532 nm), nanowire bulk emission (at wavelength 830 nm), and all additional emission lines from the QD. To verify the successful filtering, we measured the second-order correlation function ($g^2(0) = 0.41\pm0.05$) directly on the drop-port revealing single-photon emission, as shown in Figure.2(d).

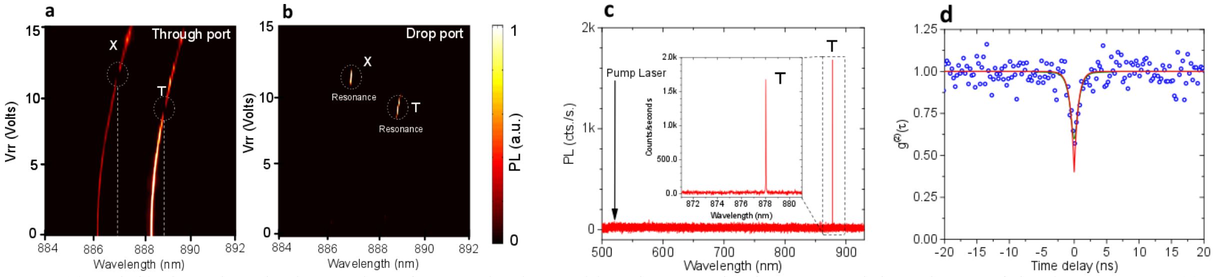

Figure.2 (a) and (b) show the selective routing of QD excitonic transitions between the drop-port and through-port of the ring resonator. (c) By tuning the resonator, a single QD transition is routed to the drop-port. The inset focuses on the Trion emission at ~878 nm. (d) Second- order correlation measurement ($g^2(0) = 0.41\pm0.05$) of the QD trion line at the drop-port of the ring resonator after directly coupling it to the APDs with no additional external filtering.

4. Quantum-Wavelength Division Multiplexing (QWDM)

Wavelength and polarization filtering is performed using the electrically-controlled integrated ring resonator filter[5]. Taking advantage of our new on-chip single-photon filtering and routing, we are able to perform the first quantum wavelength division multiplexing/demultiplexing of on-demand quantum emitters. We realize a multi-frequency quantum channel comprising two independently selected and deterministically integrated nanowire-QDs as shown in Figure. 3. The two nanowires launch single photon into the waveguide. The through-port emission of both nanowires is depicted in graph a). By tuning the ring resonator voltage V_{rr}, we can sift single-photons from one or the other nanowire into the drop-port (graph b)). Plot c) shows the integrated intensity of QD1 and QD2 as a function of ring resonator voltage V_{rr}, verifying the filtering and routing of single-photons in an integrated circuit.

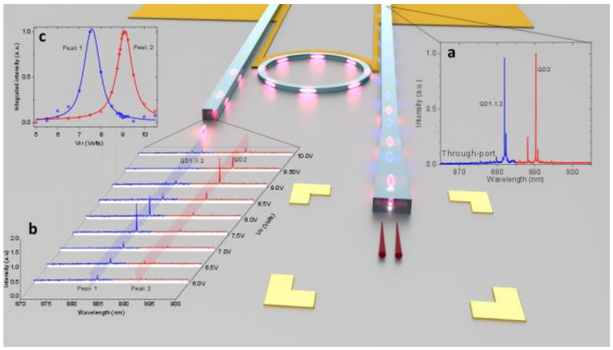

Figure 3: Schematic of the integrated photonic circuit. (a) Collected emission from the through-port waveguide. (b) Drop-port emission as a function of ring resonator voltage Vrr. (c) Integrated intensity of QD1 and QD2 at the drop-port as a function of V_{rr}.

In summary, we have demonstrated controlled integration of single and preselected III/V nanowire quantum emitters in CMOS compatible integrated photonic circuit. Furthermore, we have realized on-chip single-photon tunable-filtering that show ultra-efficient pump rejection. This allowed us to demonstrate a novel reconfigurable 2-source QWDM channel. Our novel techniques of hybrid integration and eliminating the need for off-chip components open up new possibilities for large-scale quantum photonic systems with on-chip single- and entangled- photon sources.

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