Hybrid Quantum Photonic Circuits

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Quantum optical applications require a scalable approach combining bright on-demand quantum emitters and complex integrated photonic circuits. Currently, one of the most promising quantum sources are based on III/V semiconductor quantum dots (QD)[1]. However, demonstrating complex photonic circuitry based on III-V semiconductors faces tremendous technological challenges in circuit fabrication and deterministic integration of single photon sources[2]. On the other hand, silicon and silicon nitride based photonic circuits are CMOS compatible and well-developed for large scale and complex integration. We take the best of both worlds by developing a new hybrid on-chip nanofabrication approach[3, 4]. We demonstrate 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. We performed measurements confirming 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.

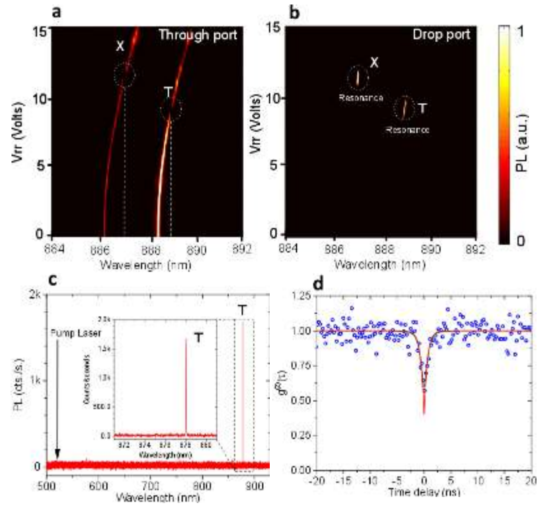

Figure.1 (a) and (b) selective routing of QD excitonic transitions between the drop-port and through-port of the ring resonator. (c) By tuning the resonator, a single QD transition is routed to the drop-port. (d) Second-order correlation measurement ($g^2(0) = 0.41\pm0.05$)

A major problem 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 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.1 (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.1 (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).

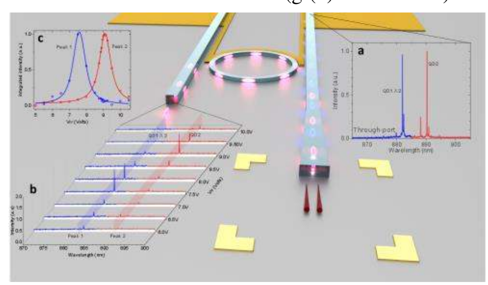

Figure 2: Schematic of the integrated photonic circuit. (a) Collected emission from the through-port waveguide. (b) Drop-port emission as a function of ring resonator voltage Vrr. (c) Integrated intensity of QD1 and QD2 at the drop-port as a function of V_{rr}.

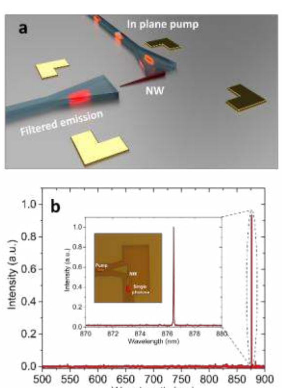

Figure.3 (a) In-plane excitation schematic. (b) emission spectra showing only QD emission

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 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.2. 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.

Finally, we implemented a scalable in-plane pumping scheme shown in Figure.3 which decouples the excitation laser from the QD emission. The broadband nature of the pump suppression and the absence of resonant photonic structures makes it attractive for performing resonant excitation of QDs on-chip.

References

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