Waveguide-Coupled Superconducting Nanowire Single-Photon Detectors

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Abstract: We have demonstrated WSi-based superconducting nanowire single-photon detectors coupled to SiN_x waveguides with integrated ring resonators. This photonics platform enables the implementation of robust and efficient photon-counting detectors with fine spectral resolution near 1550 nm.

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Superconducting nanowire single-photon detectors (SNSPDs) based on amorphous WSi are excellent single-photon detectors at near-infrared wavelengths, with demonstrated system detection efficiency up to 93% at 1550 nm, jitter as low as 150 ps, dark count rates of ~1 cps, and reset times of ~40 ns [1]. Fiber-coupled SNSPDs have become widely used in quantum optics and in free space optical communication demonstrations [2,3]. Here, we report our efforts to integrate SNSPDs with low-stress silicon nitride (SiN_x) waveguides and ring resonators in order to develop a platform combining on-chip spectral filtering with photon counting capability. Waveguide-coupled SNSPDs can ultimately enable wavelength-division multiplexing for optical communication in photon-starved applications, and can also be used for near-infrared on-chip spectrometers and repeaters for optical quantum communication [4,5].

A schematic of our device architecture is shown in Fig. 1. Light is coupled into an input waveguide and filtered through a ring resonator. On the resonator drop port, light is evanescently coupled to a WSi-based SNSPD in a hairpin geometry. Simulations indicate lengths on the order of tens of micrometers are necessary for efficient coupling to the SNSPD. We implemented 40-µm-long hairpins, and an additional inductor section in series with the SNSPD absorber prevents latching [6]. Fiber couplers, consisting of self-aligned inverse-taper couplers suspended above etched v-grooves, allow light to be coupled on and off the chip at cryogenic temperatures, as previously demonstrated in Ref. 7. Separate through- and drop-port fiber couplers were fabricated for each SNSPD to allow independent characterization of the resonator and detector.

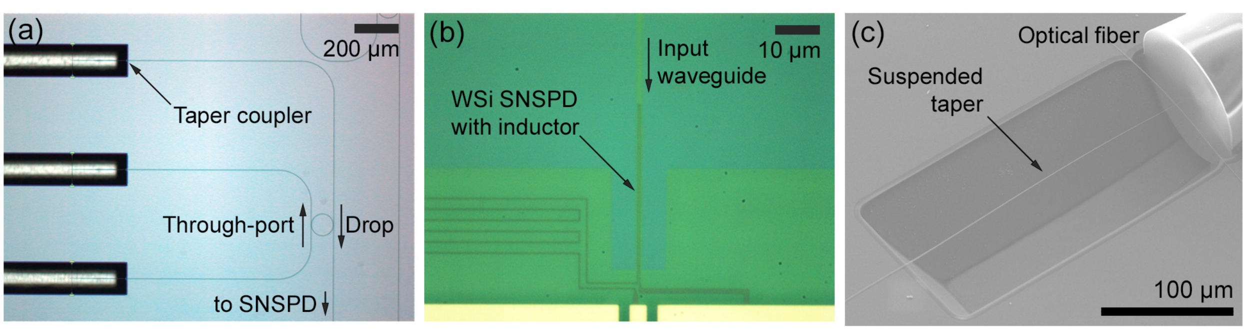

Fig. 1. (a) Optical micrograph of the SiN_x waveguide architecture, showing a ring resonator with through- and drop-port waveguides. (b) Higher-magnification view of a waveguide-coupled WSi-based SNSPD. (c) Scanning electron micrograph of an inverse-taper coupler suspended above an etched v-groove. The depth of the v-groove allows the fiber to be self-aligned to the taper.

Devices were fabricated on Si wafers with 400 nm of low-stress SiN_x deposited by low-pressure chemical vapor deposition on top of 3.5 µm of thermally grown SiO_2. The SiN_x thickness was chosen for optimal confinement of light near 1.5 µm, and low-stress SiN_x was used to avoid cracking. Typical losses in single-mode waveguides were measured to be 5 dB/cm. Amorphous WSi-based SNSPDs and contacts were patterned and protected by sputtered SiO_2, and ridge waveguides were etched into the SiN_x using an SF_6/C_4F_8 plasma etching process. After protecting the SNSPDs with an alkaline-resistant polymer coating, the suspended waveguide tapers were undercut with buffered HF and v-grooves were etched into the Si substrate using KOH.

Waveguide-coupled detectors were tested in a closed-cycle He-3 cryostat at 0.5 K. A single-mode laser with a tuning range of 1510 to 1620 nm was used to measure system detection efficiency (SDE) and spectral response. Figures 2(a) and (b) show the SDE and background count rate (BCR) observed for a fixed input wavelength of 1615.5 nm. SDE of ~2.5 % was observed with a detector bias current greater than 1.5 µA, where the saturated internal efficiency indicates that nearly all the evanescently coupled light was collected by the SNSPD. The BCR is nearly indistinguishable with the input fiber either blanked or connected to fiber outside of the cryostat, implying negligible dark counts from the fiber. Figure 2(c) shows the spectral response of a SNSPD coupled to the drop-port of a ring-resonator filter with a diameter of 50 µm. The resonance shown in Fig. 2(d) indicates a typical linewidth of ~100 pm, corresponding to an intrinsic resonator quality factor of approximately 30,000.

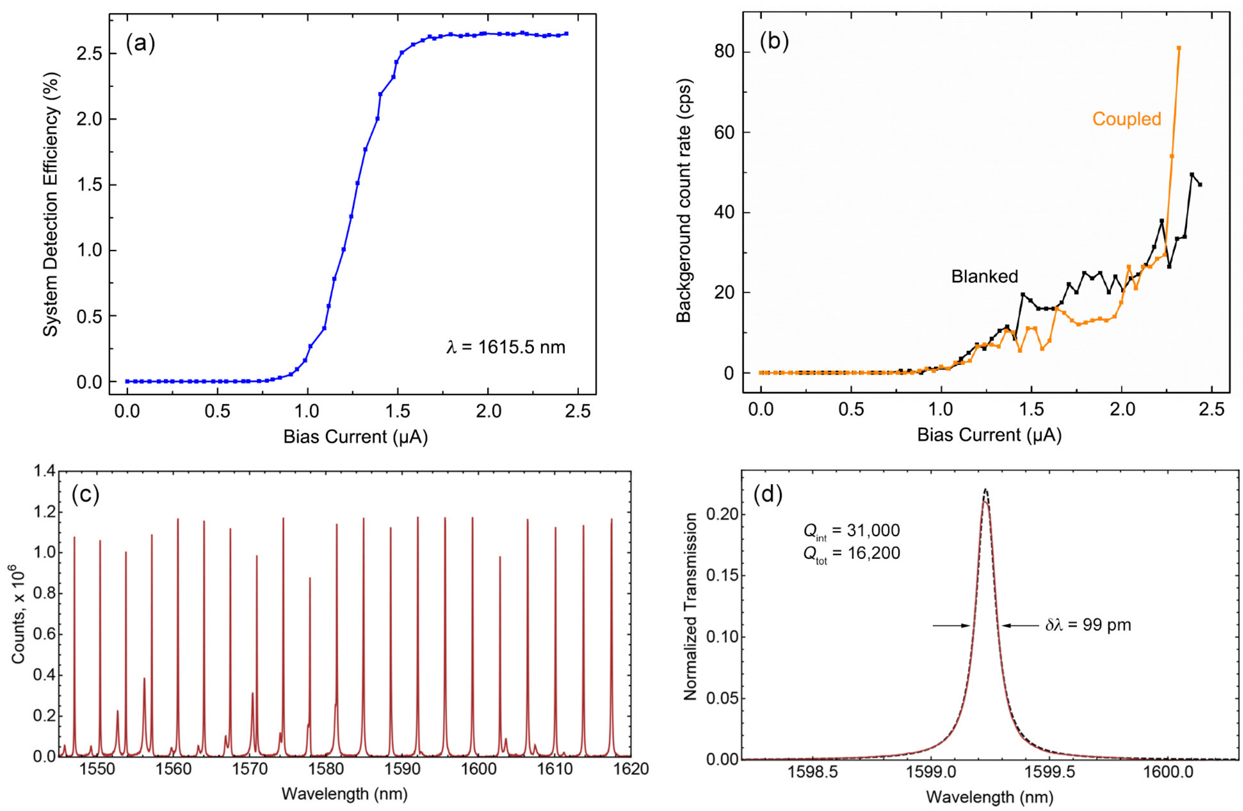

Fig. 2. (a) System detection efficiency versus bias current measured for a waveguide-coupled SNSPD at a fixed input wavelength of 1615.5 nm. (b) Background count rate measured for the same device with the input fiber connected and blanked. (c) Detector count rate versus wavelength for a SNSPD coupled to the drop-port of an integrated ring resonator, and (d) the detector spectral response measured near 1600 nm.

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