Integration of Superconducting Nanostripe Single-Photon Detectors with Dielectric Waveguides for Silicon Quantum Photonic Integrated Circuits

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Abstract: We report on design, fabrication, and characterization of superconducting nanostripe single-photon detectors integrated with dielectric optical waveguides, whereby part of the upper cladding is removed to enhance absorption of photons by the superconducting nanostripes.

1. Introduction

The unique behavior of quantum systems, such as coherence, superposition, and entanglement, can be harnessed to process, encode, and transmit information. Each quantum application (communication, computing, metrology, sensing, etc.) places its own set of requirements on the underpinning photonic technology, but many of these requirements are common to all the applications, and they form the basis for the implementation of future silicon quantum photonic integrated circuits (SiQuPICs). These common elements include single- or entangled-pair photon sources, passive optics to coherently mix photonic modes, active optics and delay lines to reconfigure those modes, high extinction ratio filters, and single-photon detectors. In this paper, we focus on two of these common elements, namely single-photon detectors coupled to passive optical waveguides, integrated on a single Si chip.

2. Device Description

We use the concept of NbN superconducting nanostripe single-photon detectors (SNSPDs) integrated with dielectric optical waveguides, whereby part of the upper cladding is removed to enhance absorption of the photons by the superconducting nanostripes. SNSPDs are currently the best detectors for counting and sensing photons over a wide range of wavelengths, from visible light to mid-infrared range. They can reach close to 100% detection efficiency, which is absolutely critical for the successful demonstration of high-performance quantum systems.

The most common SNSPD design consists of large-area (typically $10\times10\ \mu m^2$) square meanders, with photons approaching the device at the direction normal to the detector plane [1]. Such approach is not suitable for SiQuPICs, since the SNSPD sensing element, a superconducting nanostripe, must be in-plane, with the incoming photon flux guided by waveguide. This requires a different, non-meander geometry. For an SNSPD efficiently coupled to a dielectric optical waveguide, the best device geometry is a traveling-wave structure, described for the first time in [2] and more recently reviewed in [3]. In our implementation, the superconducting nanostripe is deposited directly on top of a thinned SiO_2 cladding of the Si_3N_4/SiO_2 optical waveguide, so that the evanescent field outside the waveguide could be absorbed by the stripe. If the interaction distance is long enough, the probability of a photon being absorbed will be close to unity.

3. Device Fabrication

The Si_3N_4/SiO_2 optical waveguides are fabricated on Si substrates using chemical vapor deposition technique, while the NbN nanostripes are created using atomic layer epitaxy. The dimensions of the NbN nanostripe are ~4 nm in thickness and ~50 nm in width. As illustrated in Fig. 1, the nanostripe is deposited as a U-shaped element centered on the waveguide axis. In order to maximize the coupling efficiency between a single-mode optical fiber carrying photons from an external source and the on-chip waveguide, a narrow funnel-like taper is fabricated at the edges of the chip, such that the guided mode profile in the fiber closely overlaps with the mode profile in the straight section of the funnel-taper [4].

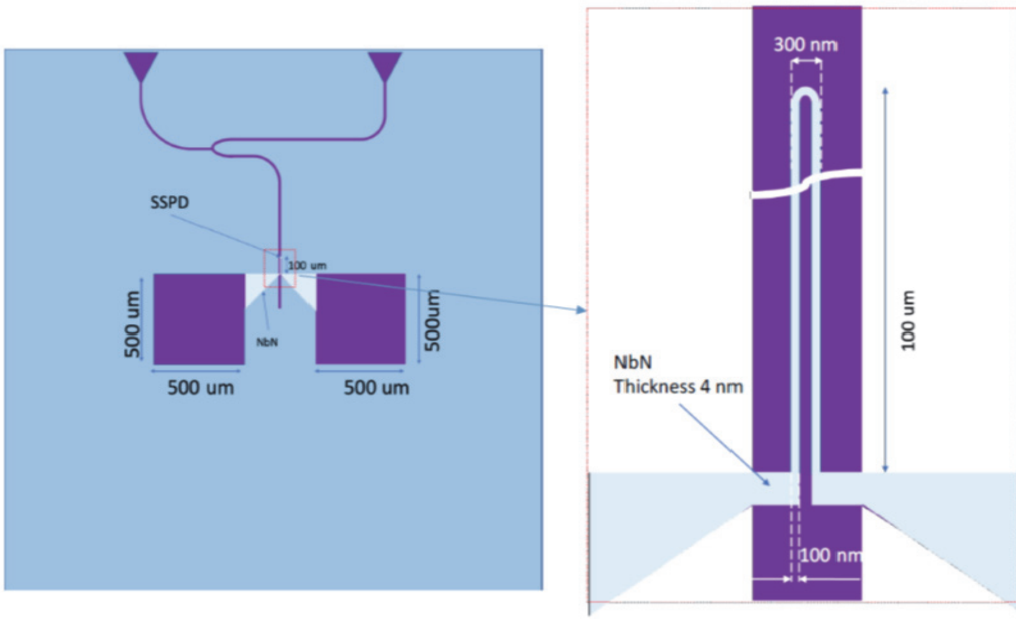

Fig. 1. Design of a travelling-wave SNSPD nanostructure suitable for a direct integration with a quantum information circuit on a single silicon platform. The left panel shows the entire element together with input and reference optical waveguides, while the right panel (inset) presents the travelling-wave SSPD in detail, placed directly on top of a dielectric waveguide.

4. Device Characterization

Cryogenic experiments were performed using a customized HYPRES ICE-T24B cryostat, with inserted Corning ClearCurve ZBL (zero-bend-loss) single-mode fibers for optical signal input and output. An attenuated light from an external 1.55-µm semiconductor laser was coupled to the fiber butt-coupled to the chip. The light was then sent to a 50-50 splitter, with one arm redirecting the photons to an output fiber for monitoring purposes, and the other arm connected to the SNSPD. Measured parameters, such as dark count rate, detector efficiency, recovery time, timing jitter, etc. will be reported at the conference.

4. Conclusion

Our results confirm that the waveguide-coupled SNSPD is, in general, a very promising detector scheme for SiQuPICs, ideally suited for cryogenic quantum information processing demonstrations.

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6. References

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