

Low-jitter single-photon detector arrays integrated with silicon and aluminum nitride photonic chips

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Abstract: We present progress on a scalable scheme for integration of single-photon detectors with silicon and aluminum nitride photonic circuits. We assemble arrays of low-jitter waveguide-integrated single-photon detectors and show up to 24% system detection efficiency.

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Superconducting nanowire single-photon detectors (SNSPDs [1]) offer high speed [2], low timing jitter [3] and high efficiency [4] in the near-infrared, making them promising candidates for integration with on-chip quantum photonic circuits [5]. We have developed a micron-scale flip-chip approach that allowed us to assemble large arrays of waveguide-integrated single photon detectors (Fig. 1(a)). Instead of directly fabricating the detectors onto the photonic chip, which results in low yield for low-jitter SNSPDs [6], we fabricated hundreds of SNSPDs on top of membranes, shown in Fig. 1(c), on a dedicated chip. Each detector was tested and only high-performance detectors were selected and transferred onto the photonic chip using the membranes as carriers. The assembled detector arrays showed sub-60-ps timing jitter (Fig. 1(b)) for single-photon detection events [7].

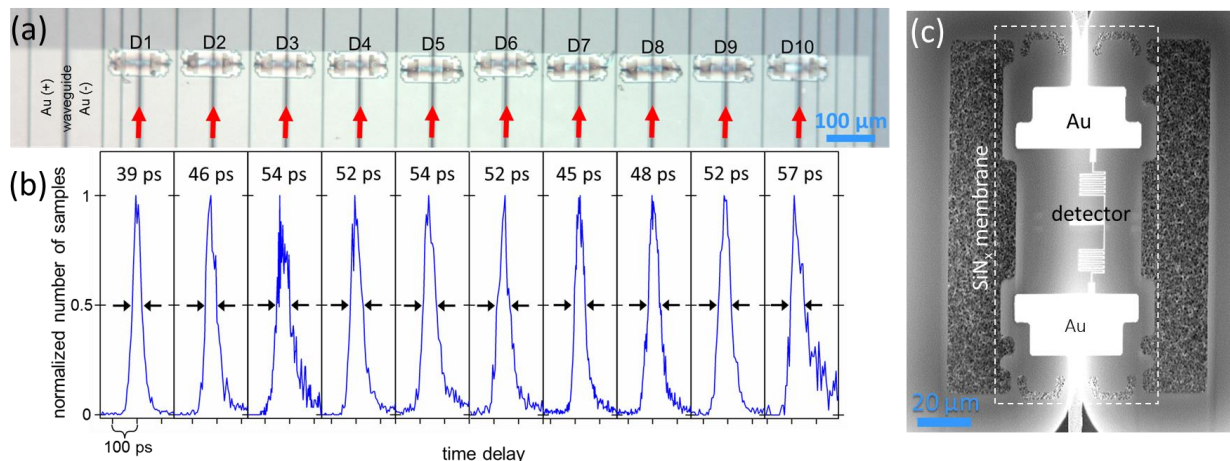


Fig. 1. (a) Optical micrograph of ten adjacent waveguide-integrated single-photon detectors D1-10. The detectors were transferred onto the photonic chip on top of ~ 200 -nm-thick rectangular membranes [7]. The red arrows denote single-mode silicon waveguides (~ 1550 nm center wavelength). The photodetection signal is measured through on-chip gold pads that make electrical contact with the detectors. (b) Top-illuminated photodetection delay histogram of D1-10 measured in a cryogenic probe station at 2.8 K base temperature. The timing jitter, defined as the full-width at half-maximum of the histogram, is listed above each histogram. (c) Scanning-electron micrograph of a detector fabricated on top of a suspended SiN_x membrane.

Figure 2 (a) shows a close-up scanning-electron micrograph (SEM) of a single-photon detector on top of a silicon waveguide. The detector has a long rectangular shape [5]. Given sub-100-nm proximity between the detector and the waveguide, light travelling in the waveguide is gradually absorbed by the detector, resulting in system detection efficiencies up to 24% including fiber-to-waveguide coupling losses.

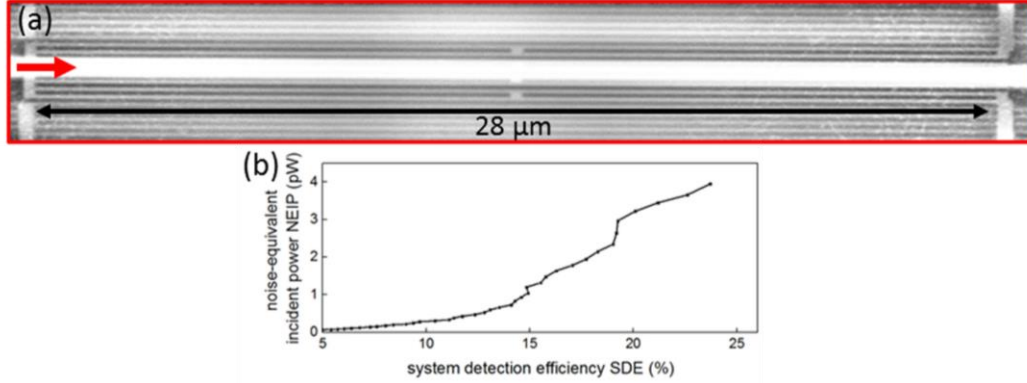


Fig. 2. (a) Top-down SEM of a detector integrated with a Si waveguide. The length of the detector is $\sim 28 \mu\text{m}$. (b) System detection efficiency (SDE) vs. noise-equivalent incident power for a directional coupler integrated with two large-coupling-length detectors as shown in (a).

The SNSPD integration method presented here can be applied to different substrates. Fig. 3(a) shows an SNSPD integrated with an AlN-on-sapphire waveguide, also showing sub-60-ps jitter performance (Fig. 3(c)). The AlN-on-sapphire material system has several distinguishing properties from silicon, including a wide transparency window and high piezoelectric transduction efficiency. The ease of SNSPD integration on silicon and AlN waveguides suggests that our method would also apply to other photonic chip material systems.

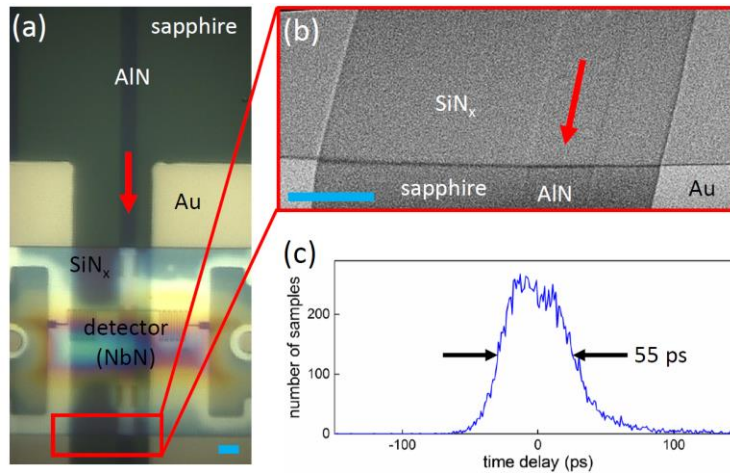


Fig. 3. Single-photon detector integrated with a multi-mode AlN-on-sapphire waveguide. The equivalent length of the scale bar (blue) is $5 \mu\text{m}$. (b) Angled SEM showing the membrane conforming to waveguide and Au pad surfaces. The equivalent length of the scale bar (blue) is $5 \mu\text{m}$. (c) Top-illuminated photodetection delay histogram of the detector shown in (a,b).

We are currently applying the detector pick-and-place transfer process to photonic circuits with integrated single-photon sources and quantum memories in diamond [8] in order to assemble a full single-photon circuit on-chip. We would like to thank J. Daley, M. Mondol, I. Bayn, K. Sunter, Y. Ivry, R. Hobbs, Q. Zhao, AttoCube and Montana Instruments for technical support.

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