# Bandwidth-enhanced Superconducting Nanowire Single Photon Detectors for Telecom Wavelengths

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**Abstract:** We present a single-photon detector providing system detection efficiencies of at least $(86.7 \pm 0.9)$ % from 1450 nm to 1640 nm. It comprises bilayer superconducting WSi nanowires in conjunction with all-dielectric structures for optical impedance matching.

**OCIS codes:** 040.5570 Quantum Detectors, 160.1890 Detector materials, 310.4165 Thin films: Multilayer design.

## Summary

Superconducting nanowire single photon detectors (SNSPDs) have become valuable tools for a variety of experiments and applications in quantum optics, since they combine high detection efficiencies [1], low timing jitter [2], and low intrinsic dark counts [3].

To date, technologies for fabricating SNSPDs have typically aimed for high system detection efficiencies (SDEs) at specific design wavelengths [1, 4], while detectors with broad high-efficiency bandwidths are desirable for a larger variety of experiments and applications in the field and for commercialization.

In this work, we have fabricated and characterized an SNSPD based on bilayer WSi nanowire structures [5] in conjunction with dielectric optical cavity materials. Our bilayer detector exhibits greatly enhanced SDEs in the telecom E-, S-, L-, and U-bands as compared to a single-absorber-layer SNSPD architecture.

The novel SNSPD design comprises a 13-layer dielectric backside mirror, providing double-pass absorption in the WSi bilayer nanowires. By depositing a 4-layer anti-reflection coating, we reduce incoupling losses over a broad spectral range for photons impinging from a self-aligned optical fiber. The meandric nanowires have widths of 110 nm with a pitch of 180 nm.

As a reference, we fabricated a single-absorber-layer SNSPD based on an identical backside mirror design, but with a 3-layer anti-reflection coating. Those nanowires were structured in meanders of 140 nm width and pitch of 210 nm. From a modeling perspective, although not relying on metal-based backside mirrors and using different coating materials, the single-layer device is very similar to the SNSPD with the highest reported SDE to date [1], since both of these were designed and optimized for maximum absorption at 1550 nm.

We characterized both of our devices using strongly attenuated continuous-wave laser light, providing us with a specified photon flux at the fiber input of an adiabatic demagnetization refrigerator (ADR). The SNSPDs were cooled down to around 250 mK to minimize system dark counts. We carefully characterized the properties and uncertainties of the implemented optical components, such as variable optical attenuators and an optical switch routing the laser light either to a calibrated power meter or to the ADR with the devices under test.

After optimizing the photon input polarization we measured the bias-dependent detection rate for both SNSPDs at wavelengths ranging from 1450 nm to 1640 nm. The ratios of the detection rates and the respective input fluxes yield the wavelength-dependent SDEs, which include optical losses at the fiber connection and inside the refrigerator. In Fig. 1 (left) we show the system dark counts as well as the system detection efficiencies at 1550 nm. Both devices exhibit saturated internal detection efficiencies. The average SDEs in the plateau regions are $(91.9 \pm 0.4)$ % for the bilayer device and $(93.1 \pm 0.3)$ % for the single-layer device, while the system dark count rates of both SNSPDs do not exceed 450 cps.

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The wavelength-dependent SDEs at 98 % of the switching bias current are shown in Fig. 1 (right). Therein, the bandwidth enhancement of the novel bilayer SNSPD over its single-layer counterpart becomes clearly visible. We found that, in the range from 1450 to 1640 nm, the bilayer detector's SDE exceeds $(86.7 \pm 0.9)$ %, while for the single-layer detector it drops to about $70-74$% at the edges of the available spectral range. Our results match the theoretical predictions on the optical absorption very well for both devices, when taking about 7.5 % combined optical loss from the fiber connector to the ADR and other possible loss mechanisms into account.

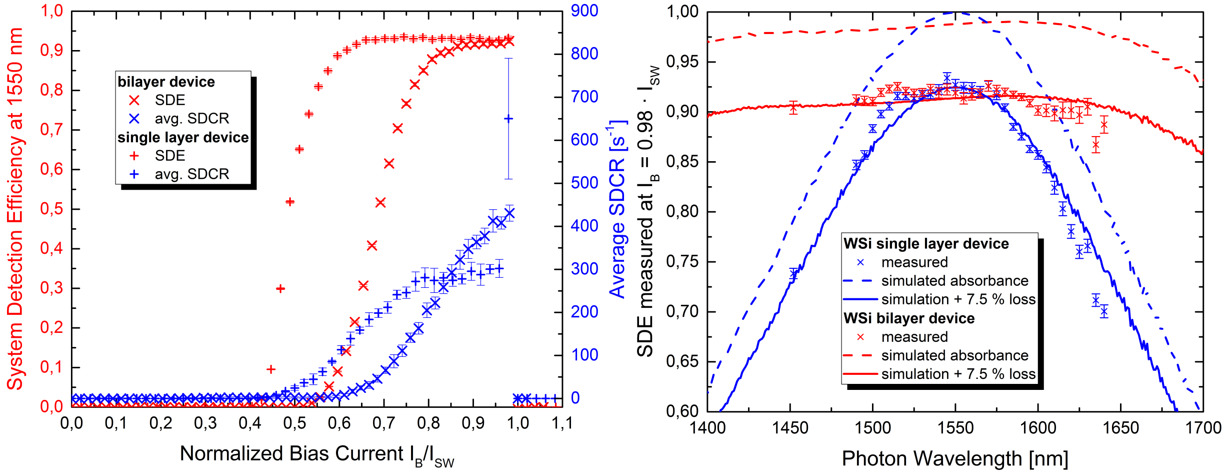

Fig. 1. Comparative measurement results. Both devices show plateauing SDEs, indicating saturated internal detection efficiencies. System dark count rates are below 450 cps (left). The bilayer SNSPD exhbits a strong enhancement of the high-SDE bandwidth as compared to the single-layer device (right).

In conclusion, we have significantly enhanced the bandwidth of high system detection efficiencies in WSi SNSPDs in the infrared, deploying dielectric materials for optical impedance matching in conjunction with bilayer absorber structures. We believe that our technological improvements can be applied to SNSPDs based on other absorber materials, such as MoSi, NbN, and NbTiN. Preliminary simulation results also indicate the feasibility to fabricate tailored high-efficiency dual- or multi-band SNSPDs with our approach, simultaneously covering, for example, wavelength ranges of $(785 \pm 20)$ nm and $(1550 \pm 40)$ nm.

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