

**Ultra-high system detection efficiency superconducting nanowire single-photon detectors for quantum photonics and life sciences**

Rodriguez, Bruno Lopez; Chang, Jin; Los, Johannes W.N.; Steinhauer, Stephan; Zwiller, Val; Zadeh, Iman Esmaeil

**DOI**

[10.1364/CLEO\\_AT.2022.AW5P.2](https://doi.org/10.1364/CLEO_AT.2022.AW5P.2)

**Publication date**

2022

**Document Version**

Final published version

**Published in**

CLEO

**Citation (APA)**

Rodriguez, B. L., Chang, J., Los, J. W. N., Steinhauer, S., Zwiller, V., & Zadeh, I. E. (2022). Ultra-high system detection efficiency superconducting nanowire single-photon detectors for quantum photonics and life sciences. In *CLEO: Applications and Technology, A and T 2022* Article AW5P.2 (Optics InfoBase Conference Papers). Optica Publishing Group (formerly OSA).  
[https://doi.org/10.1364/CLEO\\_AT.2022.AW5P.2](https://doi.org/10.1364/CLEO_AT.2022.AW5P.2)

**Important note**

To cite this publication, please use the final published version (if applicable).  
Please check the document version above.

**Copyright**

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

**Takedown policy**

Please contact us and provide details if you believe this document breaches copyrights.  
We will remove access to the work immediately and investigate your claim.

***Green Open Access added to TU Delft Institutional Repository***

***'You share, we take care!' - Taverne project***

**<https://www.openaccess.nl/en/you-share-we-take-care>**

Otherwise as indicated in the copyright section: the publisher is the copyright holder of this work and the author uses the Dutch legislation to make this work public.

# Ultra-high system detection efficiency superconducting nanowire single-photon detectors for quantum photonics and life sciences

Bruno Lopez Rodriguez<sup>1</sup>, Jin Chang<sup>2</sup>, Johannes W. N. Los<sup>3</sup>, Stephan Steinhauer<sup>4</sup>, Val Zwiller<sup>4</sup>, Iman Esmail Zadeh<sup>1</sup>

*1) Optics Research Group, ImPhys Department, Faculty of Applied Sciences, Delft University of Technology, Delft 2628 CJ, The Netherlands.*

*2) Kavli Institute of Nanoscience, Department of Quantum Nanoscience, Delft University of Technology, Delft 2628 CJ, The Netherlands.*

*3) Single Quantum B.V., 2628 CH Delft, The Netherlands*

*4) Department of Applied Physics, Royal Institute of Technology, Albanova University Centre, 106 91 Stockholm, Sweden  
b.lopezrodriguez@tudelft.nl*

**Abstract:** Ultra-high system detection efficiency (SDE) superconducting nanowire single-photon detectors are demonstrated for a broad range of wavelengths, from UV to mid-infrared, opening novel possibilities in the fields of quantum photonics, neuroimaging and astronomy. © 2022 The Author(s)

## 1. Background

Superconducting single-photon detectors (SNSPDs) are among the best single-photon detection technologies with promising applications in space optics, optical communications, biophotonics, light detection and ranging (Lidar) and quantum key distribution. SNSPDs have been fabricated and used in many material platforms, among these, NbTiN based SNSPDs can operate at higher temperatures (e.g. 7K operation has been demonstrated [1]) and simultaneously achieve high time resolution, ultrahigh efficiency and low dark count rates [1].

High performance SNSPDs are exceedingly desired for characterizing bright single-photon sources. A promising class of such emitters are III-V quantum dots which typically emit at 800-1000 nm wavelength range. Increasing the collection efficiency of quantum dots and the system detection efficiency of detectors are major challenges in current quantum photonic technologies.

Due to the increasing demand on single-photon detectors in communication applications, the highest efficiencies also have been reported for telecom detectors, between the O-band (1310 nm) and the C-band (1550 nm). In recent works, over 98 % SDEs have been demonstrated on different platforms [2–4]. Meanwhile, efforts were made to extend the working wavelengths of SNSPDs into the mid-infrared range. In 2019, Hui Zhou et al. [5] demonstrated 63% SDE at 2000 nm with 102 ps time resolution using NbN films and Verma et al demonstrated WSi SNSPDs with sensitivity up to 10  $\mu\text{m}$  [6].

## 2. Our works

### 2.1. UV and visible range: 350 nm - 800 nm

For the lower part of this wavelength range, our work has been focused on the use of superconducting single-photon detectors in conjunction with scintillators for gamma ray detection. For the visible and near infrared (500-800 nm) range, multimode fiber coupled detectors were developed [7]. The high detection efficiencies, between 405 nm and 650 nm that were achieved (70 – 80% for 550-650nm range and > 60% for 405nm) and the demonstrated high timing resolution (< 20 ps for a multimode fiber coupled detector) can improve the performance of experiments in quantum optics, bio-imaging and space optics.

### 2.2. Near infrared: 800 nm - 1000 nm

Our current work is focusing on combining fiber-coupled semiconducting quantum dots, with emission at 800-950 nm wavelength range, and high SDE SNSPDs that are specially tuned (by tuning the design of their distributed bragg reflectors) for corresponding wavelengths. The fiber-detector airgap was controlled by employing non-deformable metal spacers to maximize the absorption in the desired wavelengths. Fig. 1a shows a detector with a maximum system detection efficiency of > 95% at the wavelength of 940 nm, which is, to the best of our knowledge, the highest reported single-photon detection efficiency for a non-telecom detector. Inset of Fig. 1a, shows a time resolution of 10.5 ps for another high performance device in similar wavelength range. Typical jitter values were in the range of 10-18 ps for the majority of the detectors.

### 2.3. Single-photon detection at 1300 nm - 1900 nm for deep tissue imaging:

Beside demonstrating > 98% detection efficiency at telecom wavelength [4] we also investigated the potentials of high performance SNSPDs for neuroimaging. Two available, less explored, high transmission windows for deep mouse brain imaging are around 1300 nm and 1700 nm. Within this range, we show > 90% efficiency at 1500 nm (fig. 1b). Our SNSPDs were used to experimentally demonstrate, in a single-photon microscopy setup, deep imaging of mouse brains [8]. Non-invasive confocal fluorescence imaging can also benefit from high performance detectors at longer wavelength e.g. > 1880nm. Our detectors were recently used in a non-invasive neuroimaging experiment [9] in the wavelength range of 1600-1900 nm.

### 2.4. Single-photon detection at 2 $\mu$ m and beyond

One of the most important aspects about this wavelength range is the presence of unique molecular fingerprints of many chemicals and greenhouse gasses such as carbon dioxide and methane among others. High SDE mid-infrared detectors could give birth to new technologies to monitor harmful gases on Earth using Lidar or provide space telescopes with power instruments for applications such as exoplanet spectroscopy. On the other hand, low scattering in the human skull and biological tissue in parts of the mid-IR range, make this area appealing for next generation brain imaging technologies. In our recent work [10], SNSPDs with different nanowire widths (40/60/80 nm) and diameters (8/9/10  $\mu$ m) were fabricated on NbTiN films and achieved high performance for the wavelength range of 2 – 4  $\mu$ m. An example is shown in Fig.1c together with its low jitter (inset).

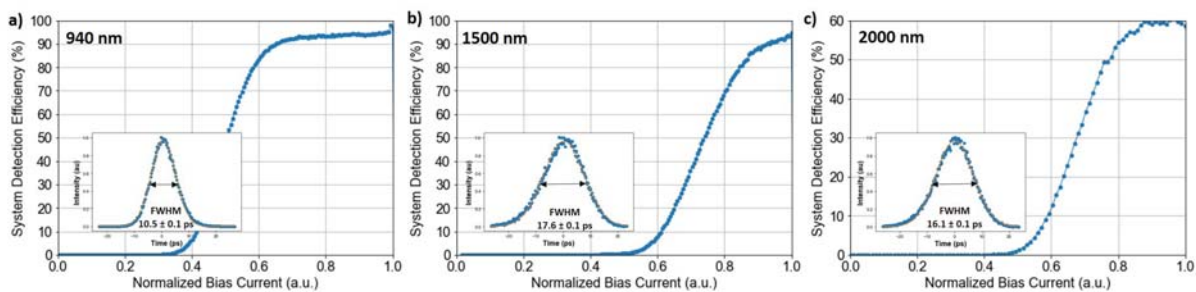


Fig. 1. SDE of SNSPDs at a) 940 nm, b) 1500 nm and c) 2000 nm.

## References

1. Iman Esmail Zadeh, Johannes W. N. Los, Ronan B. M. Gourgues, and Jin Chang et al. Efficient single-photon detection with 7.7 ps time resolution for photon-correlation measurements. *ACS Photonics*, 7(7):1780–1787, 2020.
2. Dileep V. Reddy, Robert R. Nerem, Sae Woo Nam, Richard P. Mirin, and Varun B. Verma. Superconducting nanowire single-photon detectors with 98% system detection efficiency at 1550 nm. *Optica*, 7(12):1649–1653, Dec 2020.
3. Peng Hu, Hao Li, Lixing You, and Heqing Wang et al. Detecting single infrared photons toward optimal system detection efficiency. *Optics Express*, 28(24):36884–36891, 2020.
4. J Chang, JWN Los, JO Tenorio-Pearl, and Niels Noordzij et al. Detecting telecom single photons with 99.5- 2.07+ 0.5% system detection efficiency and high time resolution. *APL Photonics*, 6(3):036114, 2021.
5. Hui Zhou, Yiming Pan, Lixing You, and Hao Li et al. Superconducting nanowire single photon detector with efficiency over 60% for 2  $\mu$ m wavelength. *IEEE Photonics Journal*, 11(6):1–7, 2019.
6. VB Verma, B Korzh, AB Walter, and AE Lita et al. Single-photon detection in the mid-infrared up to 10  $\mu$  m wavelength using tungsten silicide superconducting nanowire detectors. *APL Photonics*, 6(5):056101, 2021.
7. Jin Chang, Iman Esmail Zadeh, Johannes W. N. Los, and Julien Zichi et al. Multimode-fiber-coupled superconducting nanowire single-photon detectors with high detection efficiency and time resolution. *Appl. Opt.*, 58(36):9803–9807, Dec 2019.
8. Fei Xia, Monique Gevers, Andreas Fognini, and Aaron T. Mok et al. Short-wave infrared confocal fluorescence imaging of deep mouse brain with a superconducting nanowire single-photon detector. *ACS Photonics*, 8(9):2800–2810, 2021.
9. Feifei Wang, Fuqiang Ren, Zhuoran Ma, and Liangqiong Qu et al. Non-invasive confocal fluorescence imaging of mice beyond 1700 nm using superconducting nanowire single-photon detectors. *bioRxiv*, 2021.
10. Jin Chang, Johannes WN Los, Ronan Gourgues, and Stephan Steinhauer et al. Mid-infrared single-photon detection using superconducting nbtin nanowires with sub-15 ps time resolution in a gifford-mcmahon cryocooler. *arXiv preprint arXiv:2107.06354*, 2021.