High speed SNSPD with four interleaved nanowires

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For applications that require high-speed or photon-number resolution multipixel superconducting nanowire single-photon detectors (SNSPDs) in the telecom range are very attractive.
Single Quantum has developed a type of multipixel detector that allows for very fast detection. This four-pixelated device demonstrates full efficiency recovery after 6.5 ns and 3dB efficiency-point above one billion counts per second with an outstanding timing detection accuracy, just above 10 ps.

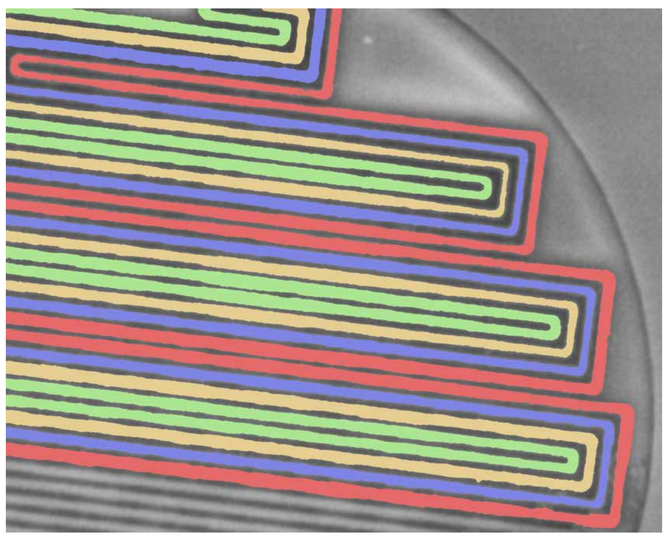


Figure 1: SEM image of a 4 interleaved nanowire SNSPDs. Blue is the outer wire and yellow is inner one.

Interleaved design

Short pixels, low kinetic inductance, high speed, low dead time

- Homogenous count rate on all pixels
- All pixels have same critical current
- Each pixel is controlled independently
- Very large dynamic range:
  1 GHz count rate @ 1550 nm
- Excellent jitter: 13.0 ps FWHM

SNSPD Pulse Efficiency Recovery

- After 5 ns the height of the pulse is reduced by 1/e.
- Each pixel can detect a new photon even before this time frame, although the current is not fully restored.
- The Efficiency Recovery Histogram (likelihood of detection events vs time) shows at least 50% chance of detecting an incoming photon after 5 ns
- after 7 ns the chance is 100% (system efficiency fully restored).

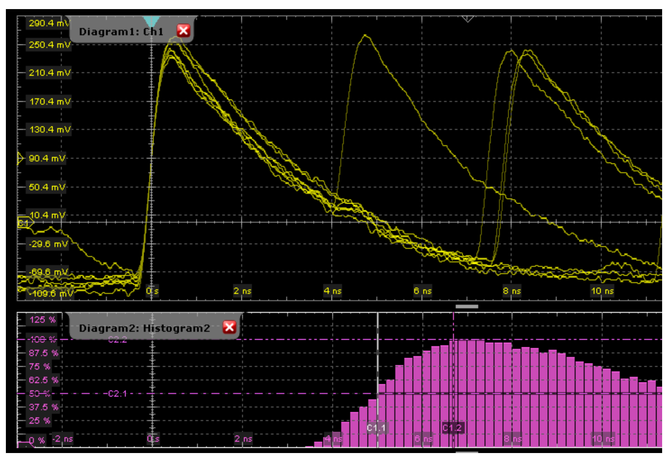


Figure 2: (Top) SNSPD pulse taken with a 4 GHz Bandwidth oscilloscope. (Bottom) Efficiency Recovery Histogram, cursors are placed at 50% and 100% detection likelihood. The histogram was acquired under CW illumination with a flux of 1 billion counts per second.

Why 4 pixels?

SDE 70 %	4-Pixels	8-Pixels	16-Pixels
1 photon	70 %	70 %	70 %
2 photons	37 %	43 %	46 %
3 photons	13 %	23 %	28 %
4 photons	2 %	10 %	16 %
5 photons		3 %	8 %
6 photons		1 %	4 %
7 photons		0 %	2 %
8 photons		0 %	1 %

- Good balance between system complexity and performance
- Up to six 4-pixels detectors in one single cryostat
  (price benefit/upgradable)
- More than 4-pixels don't offer a competitive advantage in the detection of 2 photon events

$$P(k) = \prod_{k=1}^{4} \eta^k * \left[\frac{Pixels - (k-1)}{Pixels}\right]$$

High Count Rate Characterization

- Device tested under CW illumination @ 1550 nm
- Total flux varied from 10^6 to over a 10^9 photons per second.
- Detection efficiency drops by 10% at 10^8 and by 50% at 10^9 photon flux. Here, the dead time impacts the efficiency

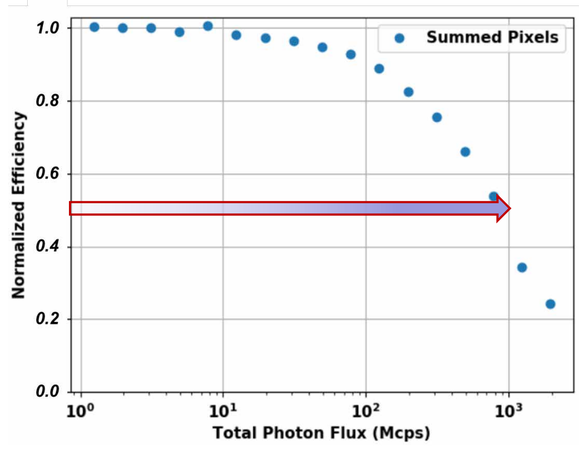
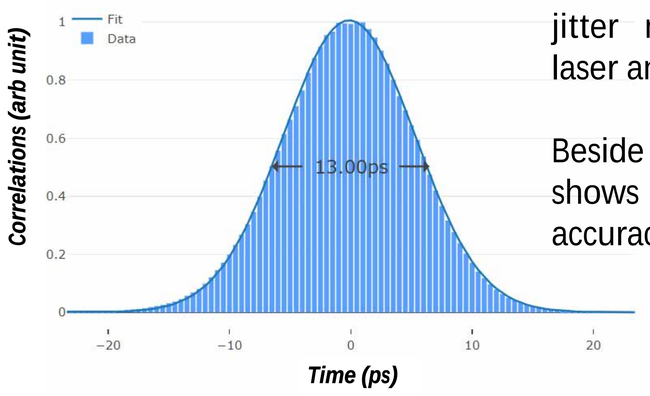


Figure 3: HCR measurement with CW illumination. The arrow highlights the 3 dB point where the detection efficiency drops by 50%

Timing accuracy



jitter measured with a pulsed laser and cryogenic amplification.

Beside being fast, such device shows an outstanding timing accuracy of 13 ps

Figure 4: Timing jitter of one single pixel

PNR performance Interleaved SNSPDs

- PNR of the 4-pixel SNSPD shown by combining the signal outputs.
- Persistence map recorded with an oscilloscope shows 4 distinct pulse heights during pulsed illumination
- The Histogram estimates the ***coincidence probability*** of detecting simultaneous photons.

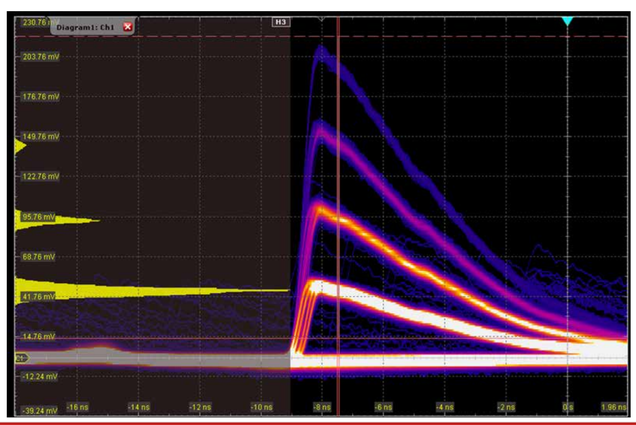
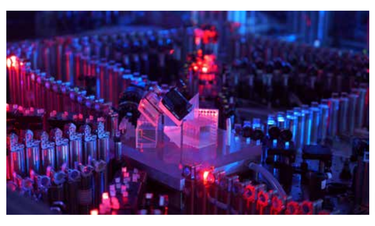


Figure 5: Persistence map.
Mean photon number per pulse is 2.

Applications



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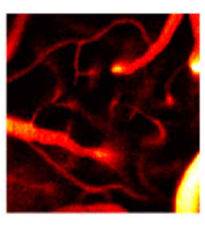
Quantum optics

- Photon correlation with one detector
- Faster measurements
- Photon-number resolution



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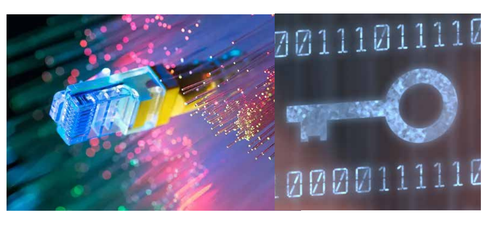
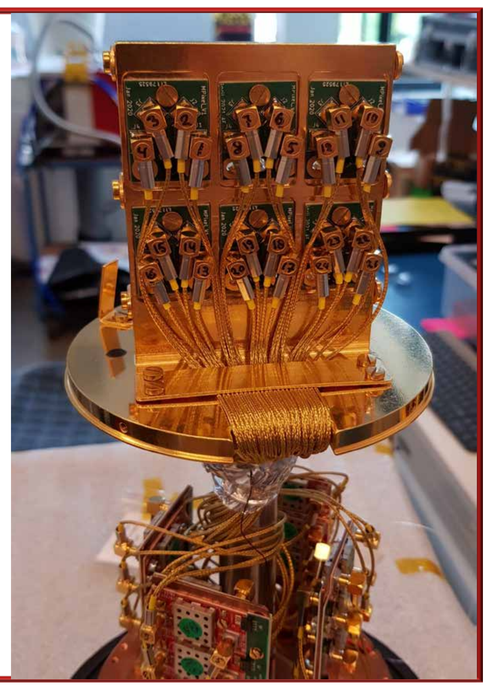
Bio-Imaging

- High dynamic range
- Long penetration depth
- Outstanding Signal-to-Background ratio



QKD

- Attack detection
- Fast key generation
- Photon number resolution



[1] F. Xia, et. al. "Short-Wave Infrared Confocal Fluorescence Imaging of Deep Mouse Brain with a Superconducting Nanowire Single Photon Detector". ACS Photonics 2021, 8, 9, 2800–2810 (2021).
[2] Han-Sen Zhong et al. "Phase-Programmable Gaussian Boson Sampling Using Stimulated Squeezed Light". Phys. Rev. Lett. 127, 180502 – (2021)