Superconducting nanowire single-photon detectors based on amorphous superconductors

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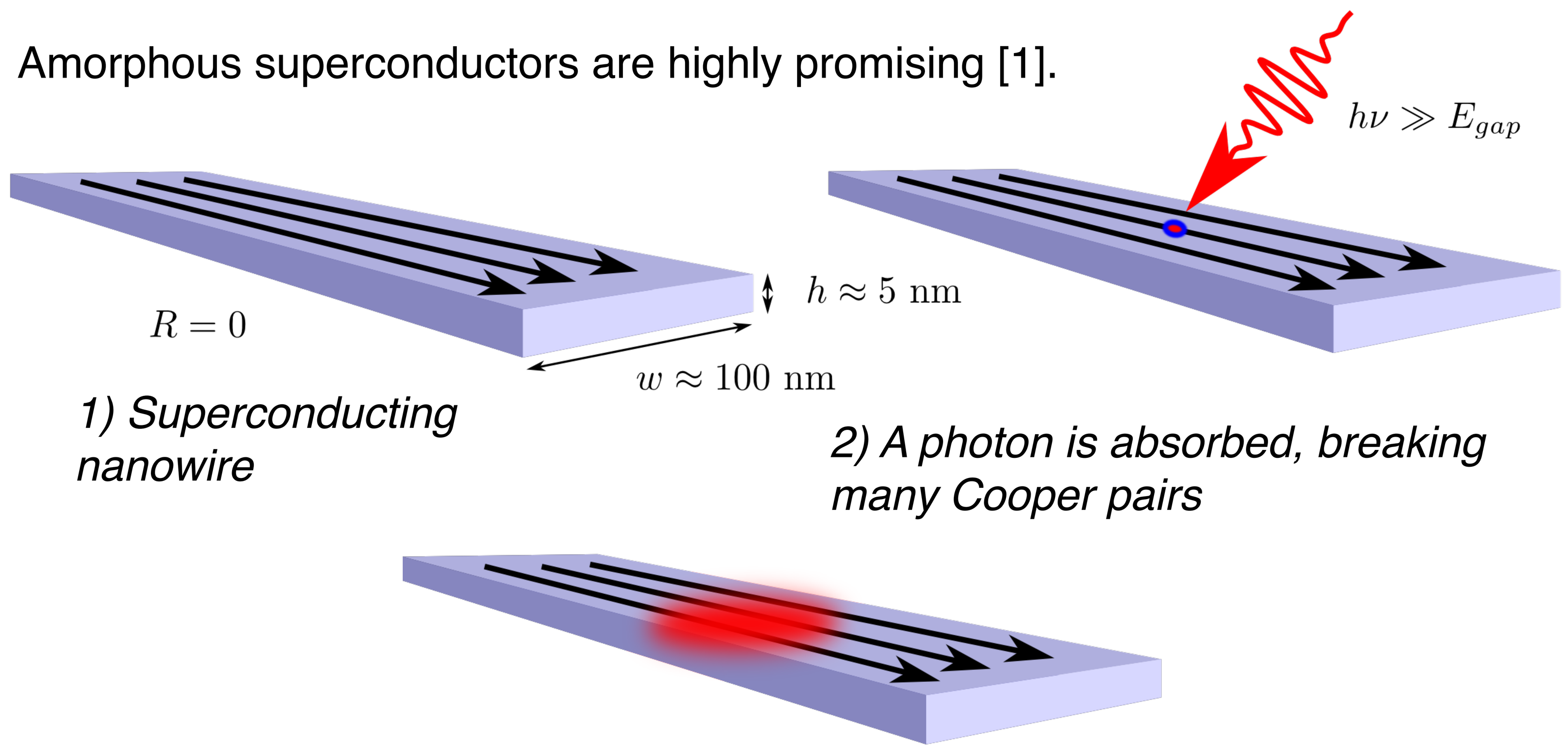
Introduction

Goal: develop SNSPDs with:

- High intrinsic quantum efficiency (e.g. 90% at 1550 nm)
- Low dark count rates (<10 Hz)
- No afterpulsing effects
- High count rates (20 MHz)
- Low intrinsic jitter (<70 ps)

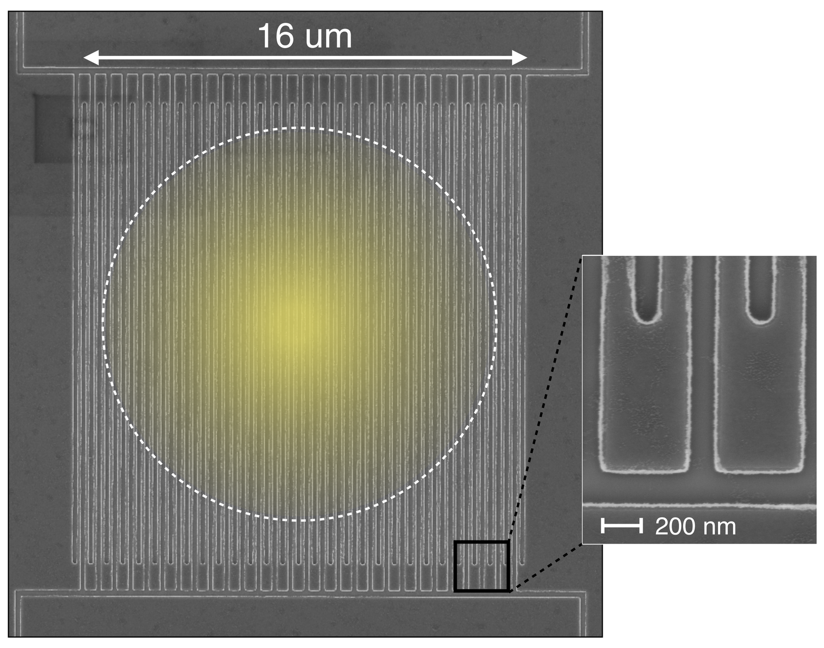
Amorphous superconductors are highly promising [1].



1) Superconducting nanowire

2) A photon is absorbed, breaking many Cooper pairs

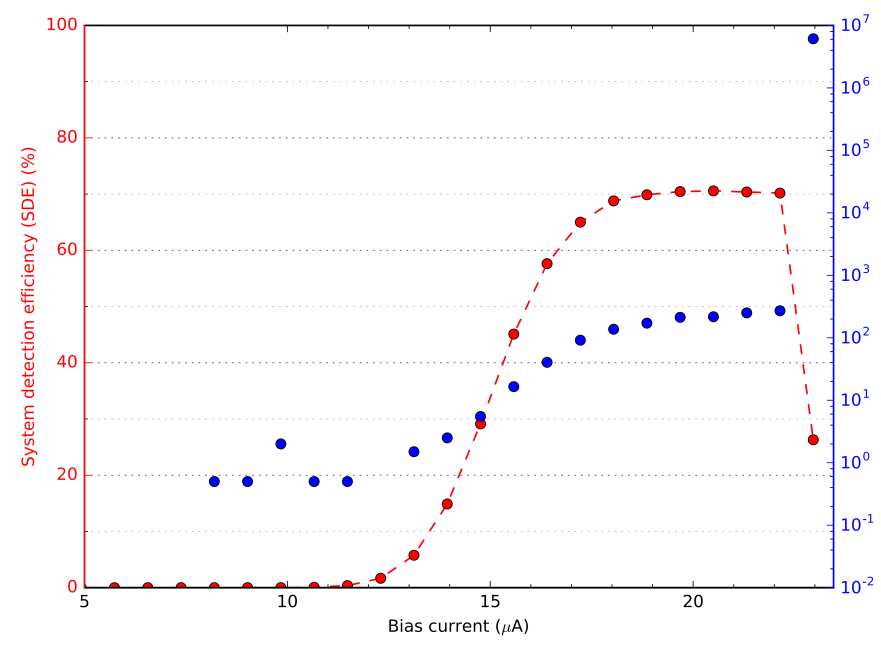
3) The superconductivity is broken —> electric signal



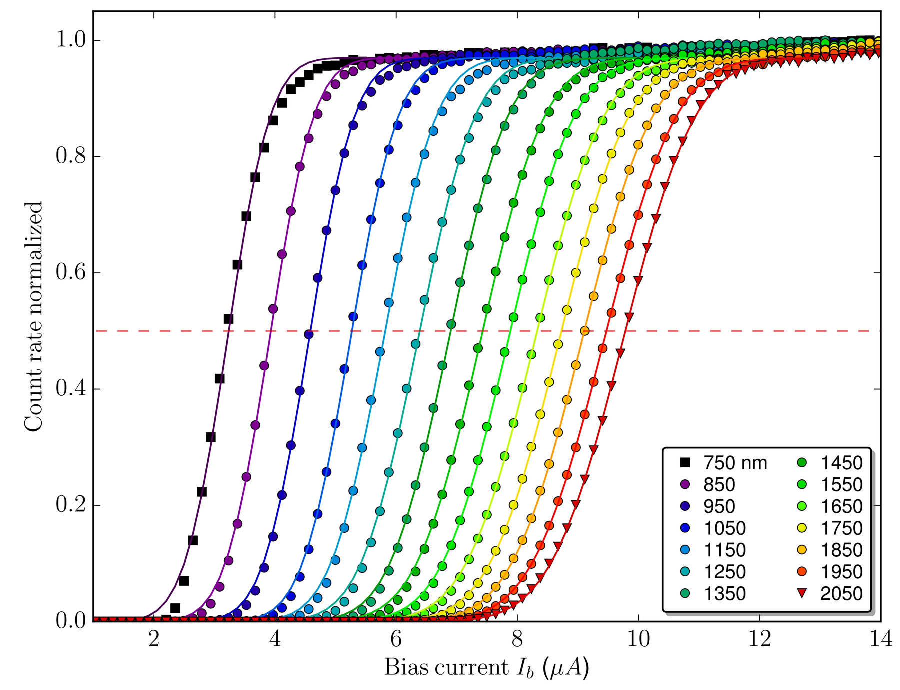
- The devices are made of amorphous superconducting MoSi
- The photons coming from the optical fibre are mainly absorbed in the center of the meander shape nanowire
- Packaging uses self-aligned fibre coupling which ensures a precision of ±3 μm
- Nano-fabrication carried out in EPFL's Centre of MicroNanoFabrication (CMi)
- > 100 devices per 4" wafer

Devices characterisation

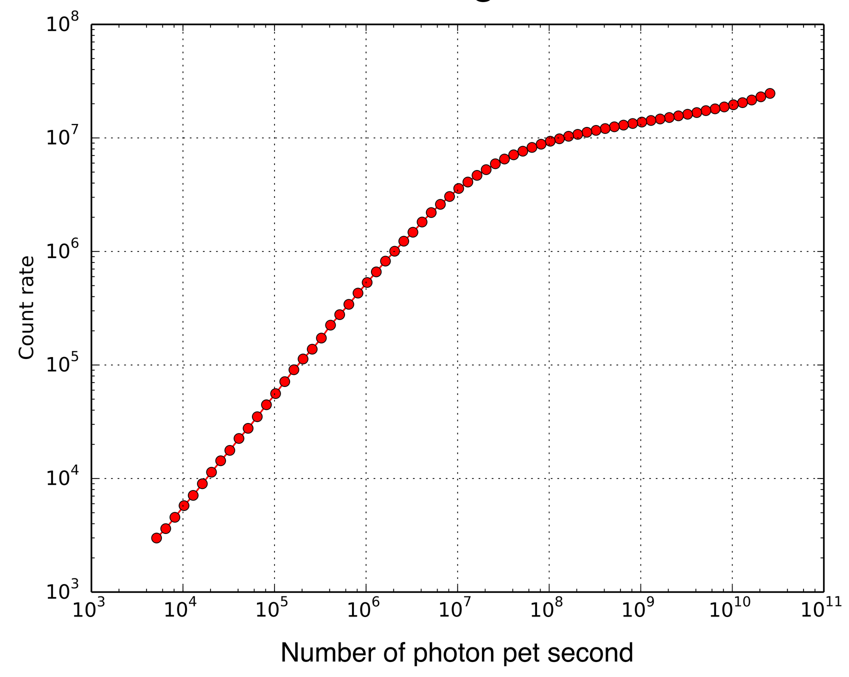
System detection efficiency



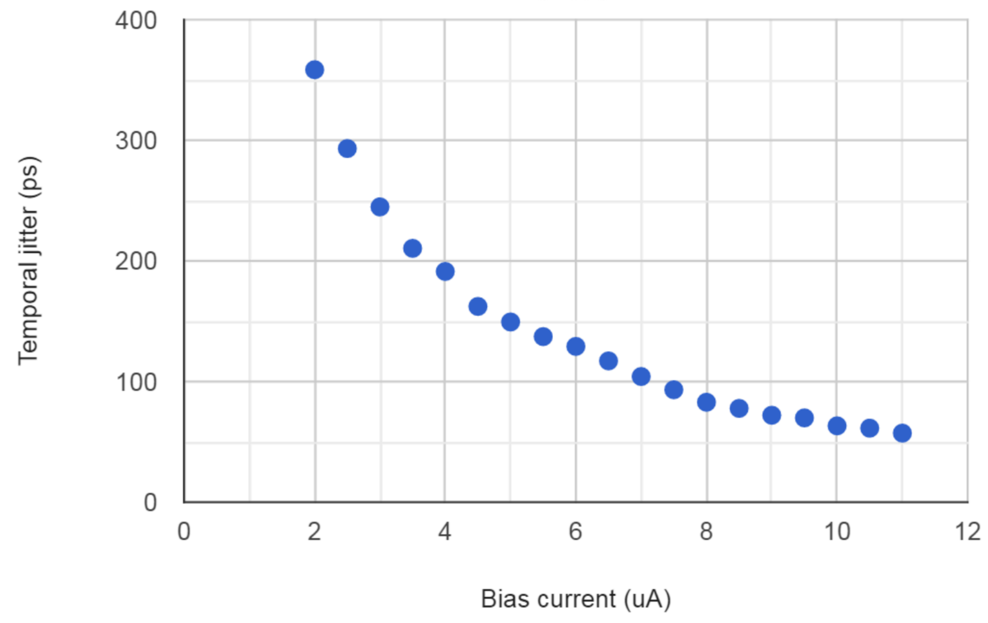
Broadband spectral response



Counting rate



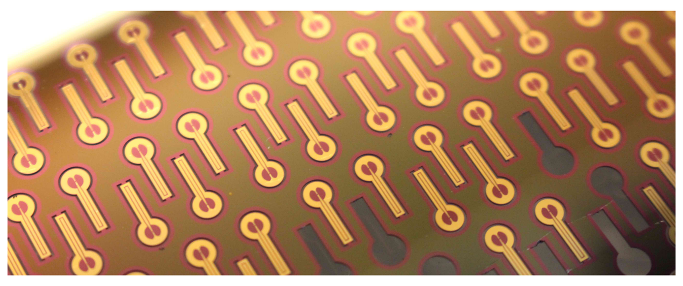
Jitter

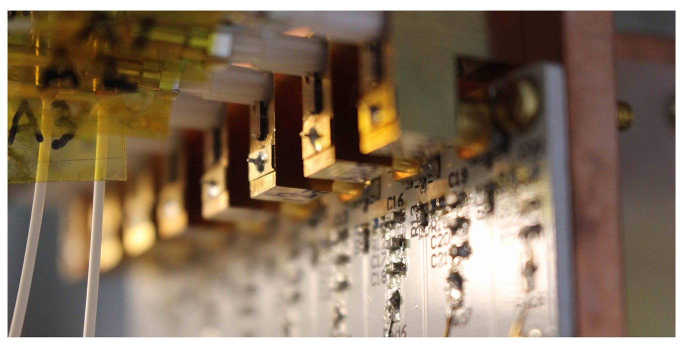


Measurements at 0.8K show:

- >70% maximum system detection efficiency
- Large spectral response [2]
- 50 ns deadtime
- Jitter as low as 55 ps
- Saturated efficiency, which is the first requirement for high overall system efficiency and higher temperature usability
- Dark count rate can be reduced to few counts per second using filters

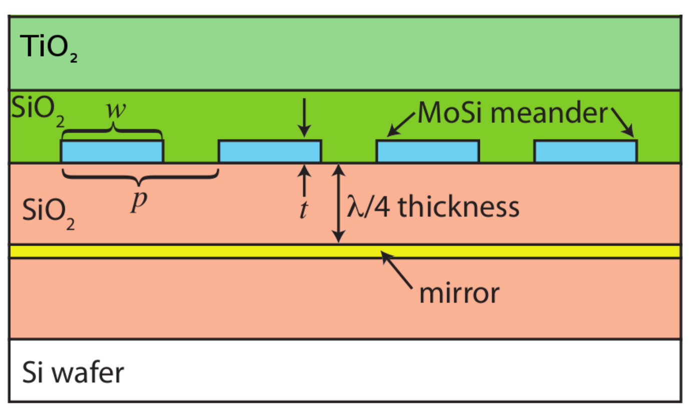
Operation and optimisation





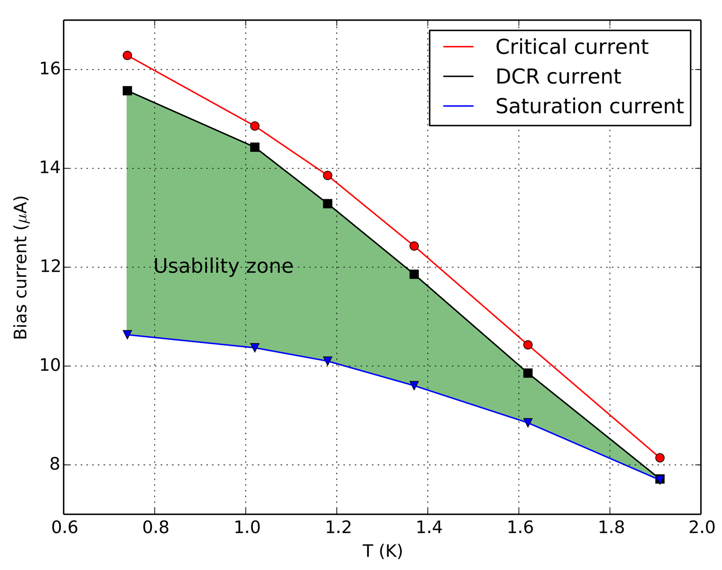
Optical coupling to optical fibre

- Devices are detached from the wafer and aligned in a zircon mating sleeve
- An optical fibre in a ferrule is automatically aligned with the sensitive area of the detector
- Any kind of fibre can be used



Efficiency optimisation

- Optical stack to optimise absorption in the nanowire, from UV to Mid-IR



Temperature behaviour

- Plateaued efficiency up to 1.9 K
- Further optimisation of thickness and critical current can lead to operation at 2.3 K [4]

Amorphous SNSPDs for space quantum communication

Optical coupling to large telescopes : requires a large collection area

- Free-space coupling in fixed cryostat with **Coudé path** (best overall efficiency, but more noisy)
- **Large core optical fibres** (eg. 200 μm-core multimode fibres) from focus of telescope to SNSPD detector

Large collection area using a 2D array of detectors

- Up to 64 pixels was demonstrated using WSi (320 μm diameter area) [3]
- A large yield of the fabrication process is essential to create large arrays. We currently have a **yield higher than 80%** (working detectors) with our MoSi process. Higher yield is within reach.

Readout strategy

- A readout strategy is needed to read all the pixels simultaneously.
- Flex coaxes can be used to connect to all pixels, from 0.8K to room temperature
- We have implemented **cryogenic amplification at 40K**
- A multiplexing scheme can be implemented on the array itself, with some compromise on the fill factor and the efficiency per pixel. [3]

Time tagging

- WSi arrays have been shown to count up to 1.2 Gcounts per second [3]
- Tests with a new time tagger from IDQ (25 MHz counting rate per channel, 4 channels) are planned

[1] Marsili F. et al, Detecting single infrared photons with 93% system efficiency, *Nat Photon 7*, 210-214 (2013).
[2] Caloz M. et al, Optically probing the detection mechanism in a molybdenum silicide superconducting nanowire single-photon detector, APL 110, 083106 (2017).
[3] M. S. Allman et al., A near-infrared 64-pixel superconducting nanowire single photon detector array with integrated multiplexed readout, APL 106, 192601 (2015).
[4] V. B. Verma et al, High-efficiency superconducting nanowire single-photon detectors fabricated from MoSi thin-films, Opt. Expr. 23 33792 (2015)

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