Waveguide superconducting single-photon detectors for Integrated Quantum Photonic devices

KOBIT- 1

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Technologiestichting STW

EU-FP7 QUANTIP

TU/e Technische Universiteit Eindhoven University of Technolog

Where innovation starts

PICQUE

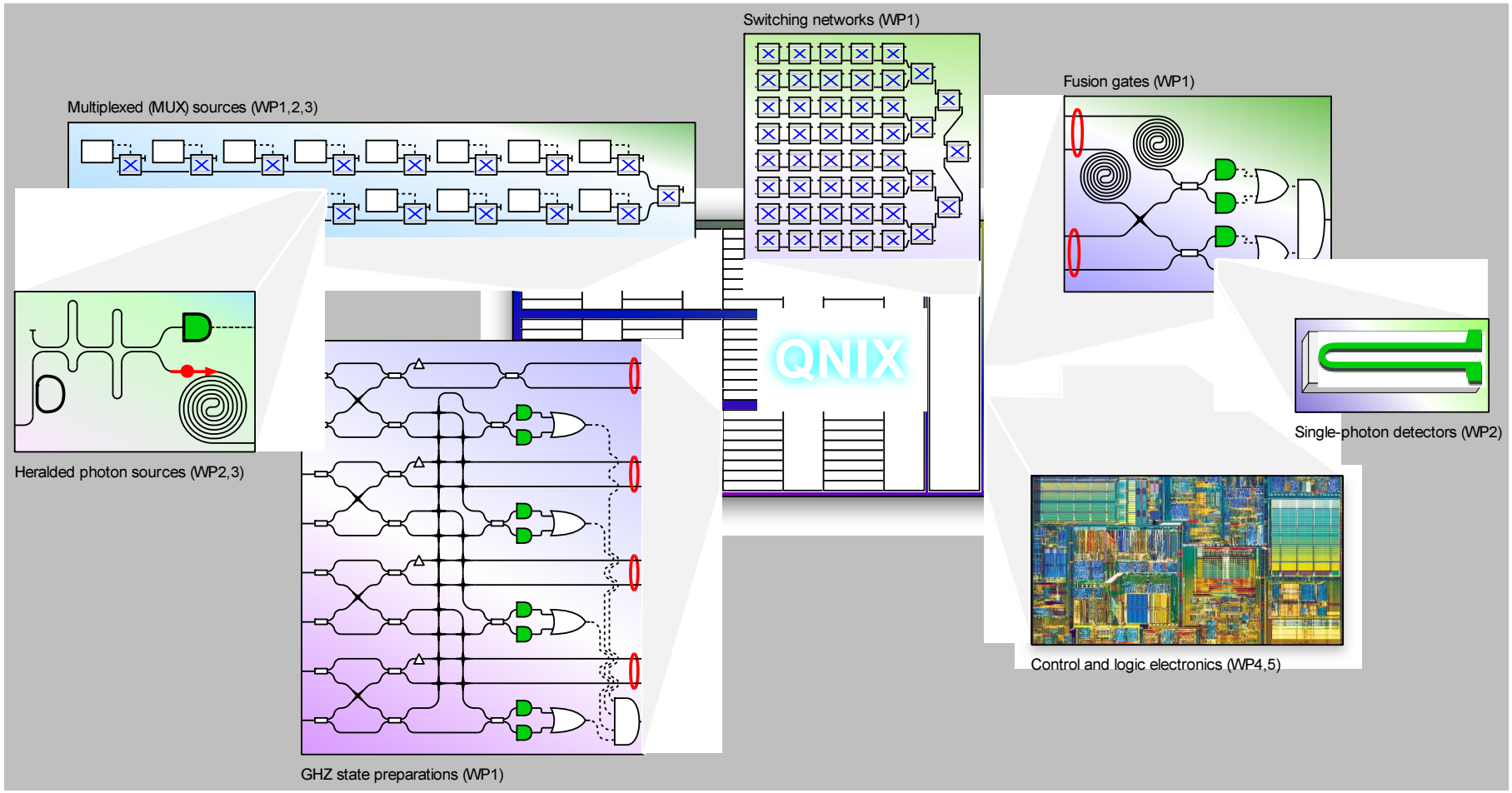
EPSRC

Engineering and Physical Sciences Research Council

MARIE CURIE ACTIONS

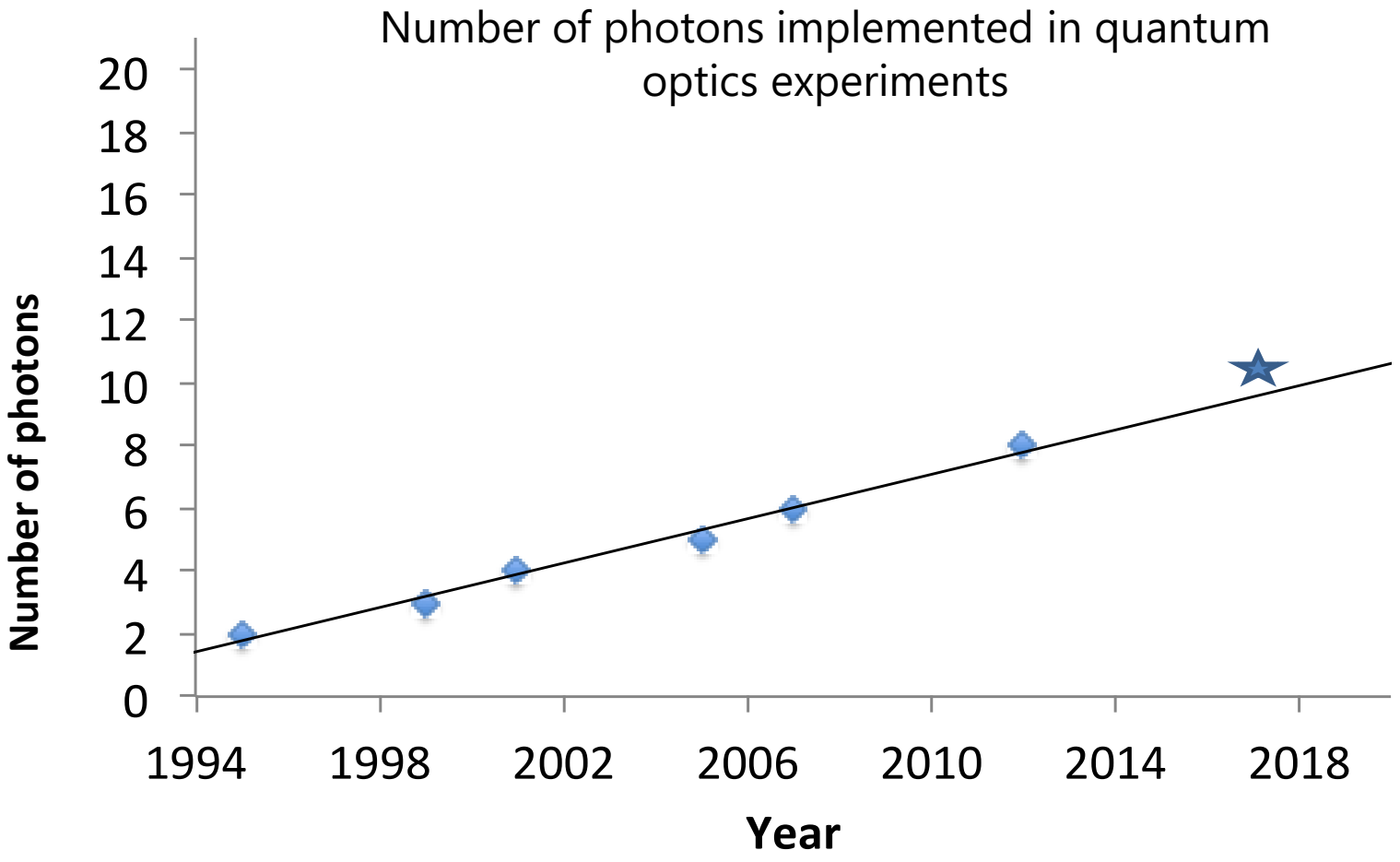
PEOPLE

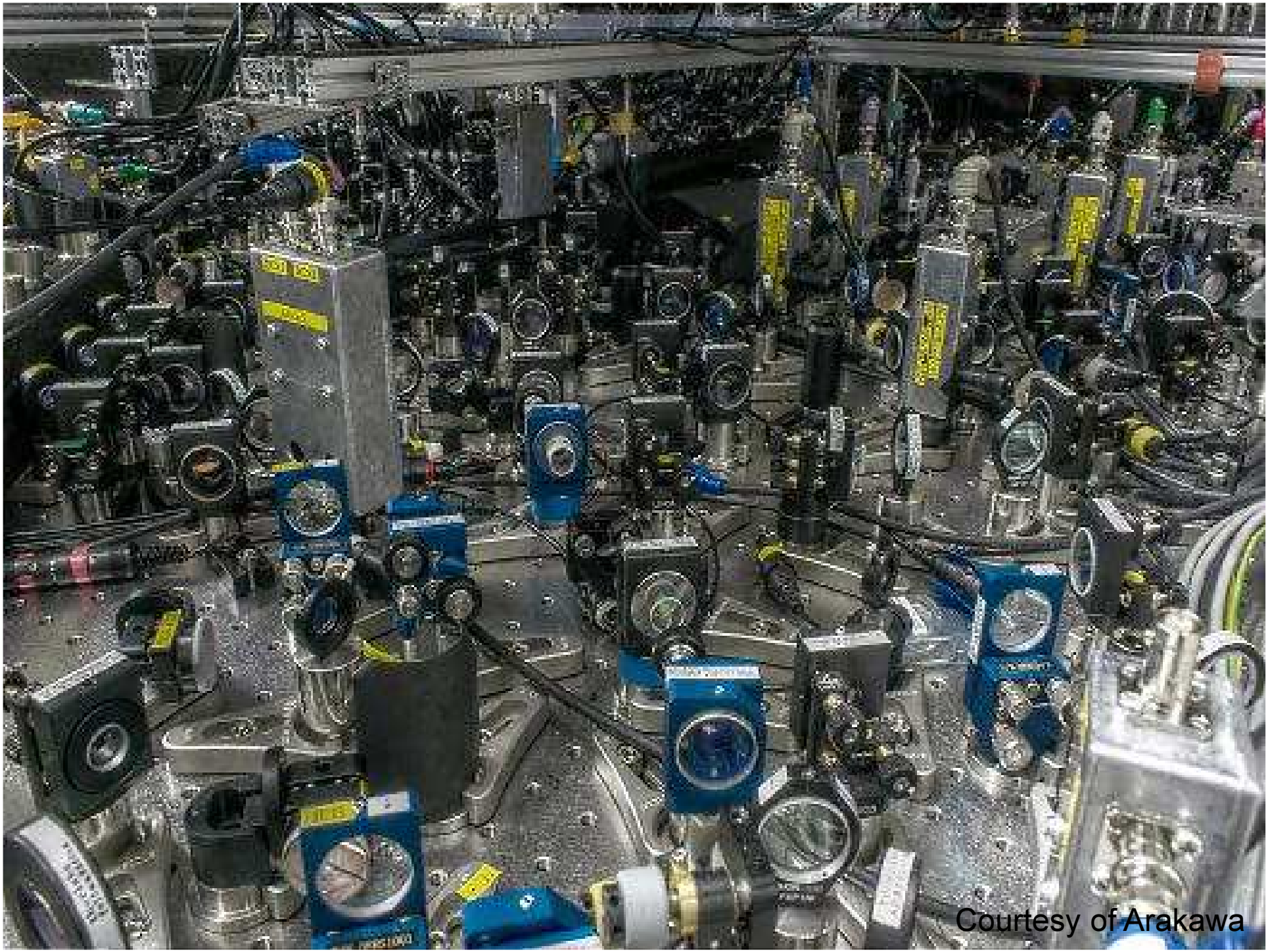
Implementing QNIX on Si

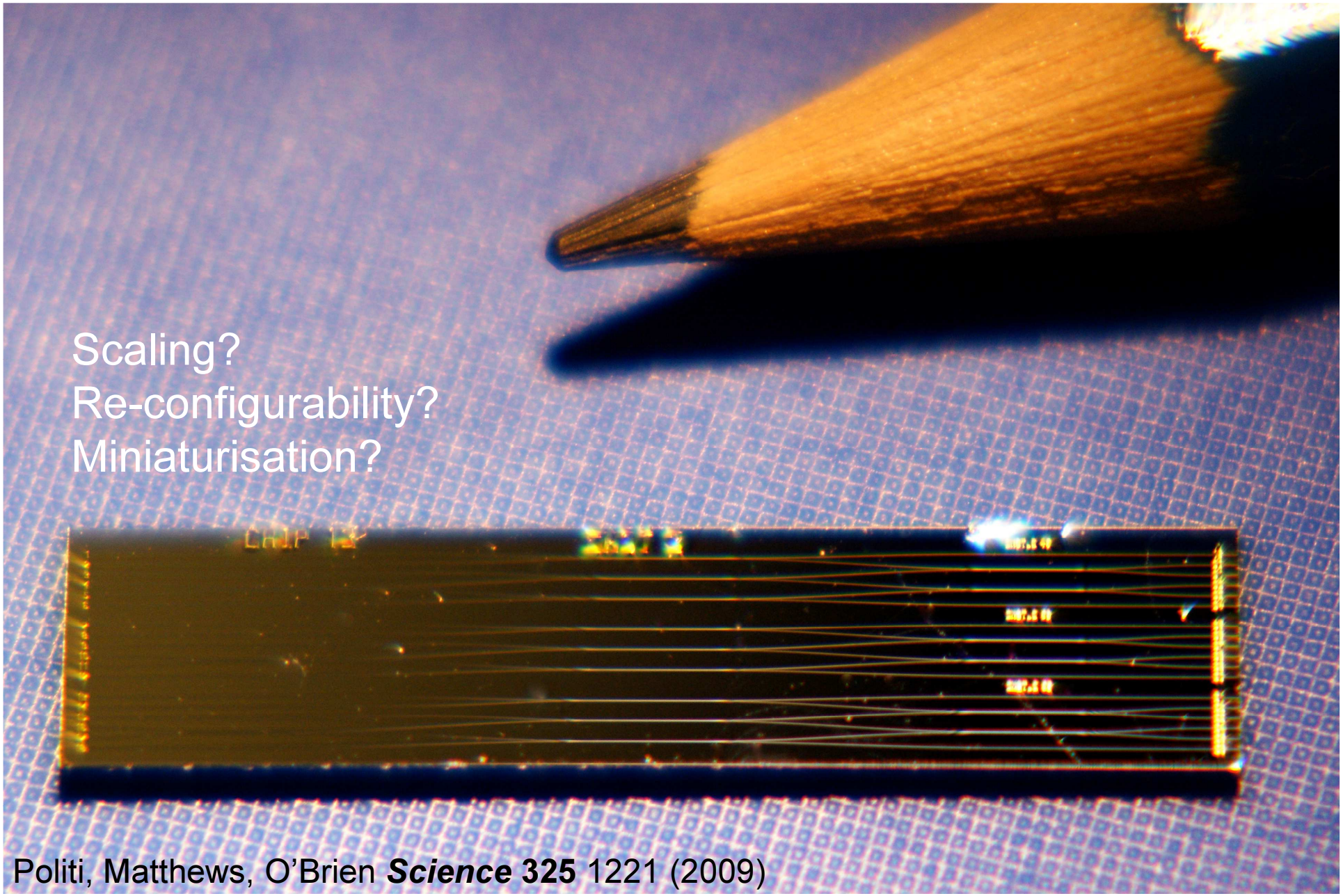


Bristol QET Labs, > 100 people

Quantum photonic Moore's Law



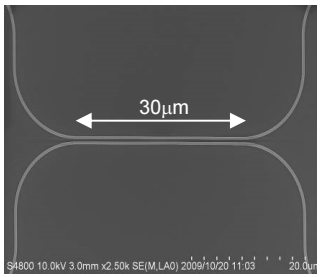

Courtesy of Arakawa



Politi, Matthews, O'Brien ***Science* 325** 1221 (2009)

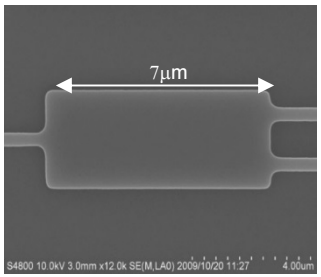
State of the art building blocks on Si

Coupled waveguides



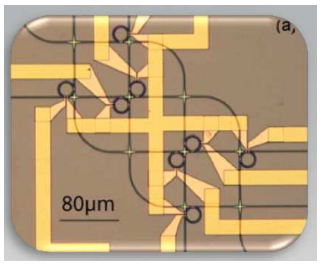
✓ Foundry available

Splitter



✓ Foundry available

Switches



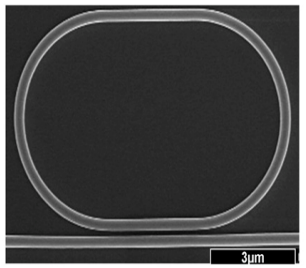
✓ Foundry available

Sources

Non-linearities with external pump

requires

Ring resonator

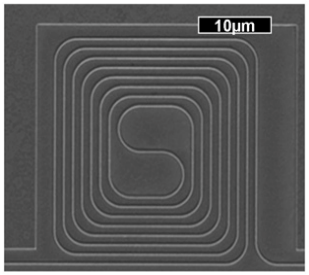


✓ Foundry available

Memory

With specific architecture can be covered by

Delay line



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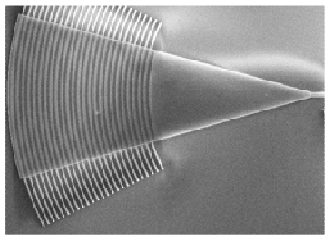
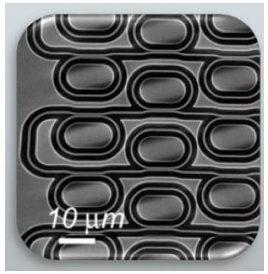
Chip-coupling



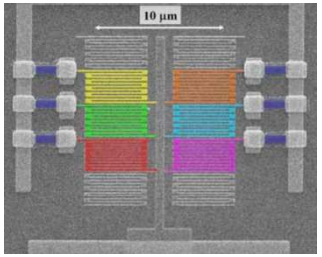
✓ Foundry available

Filters



✓ Foundry available

Detectors

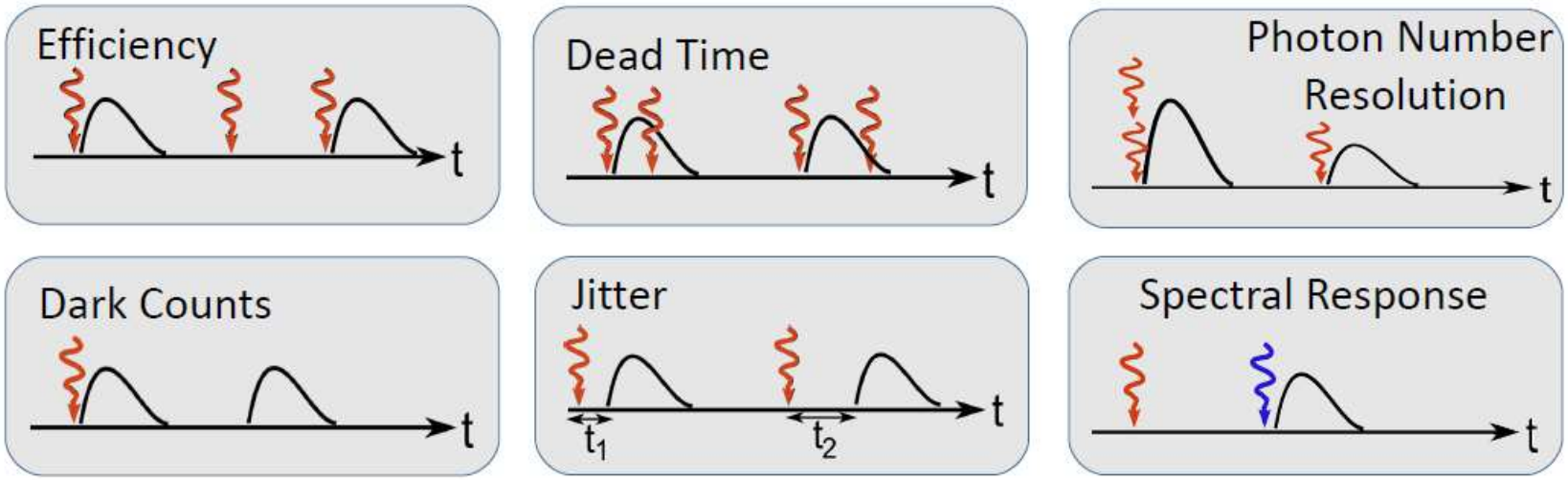


Foundry NOT available

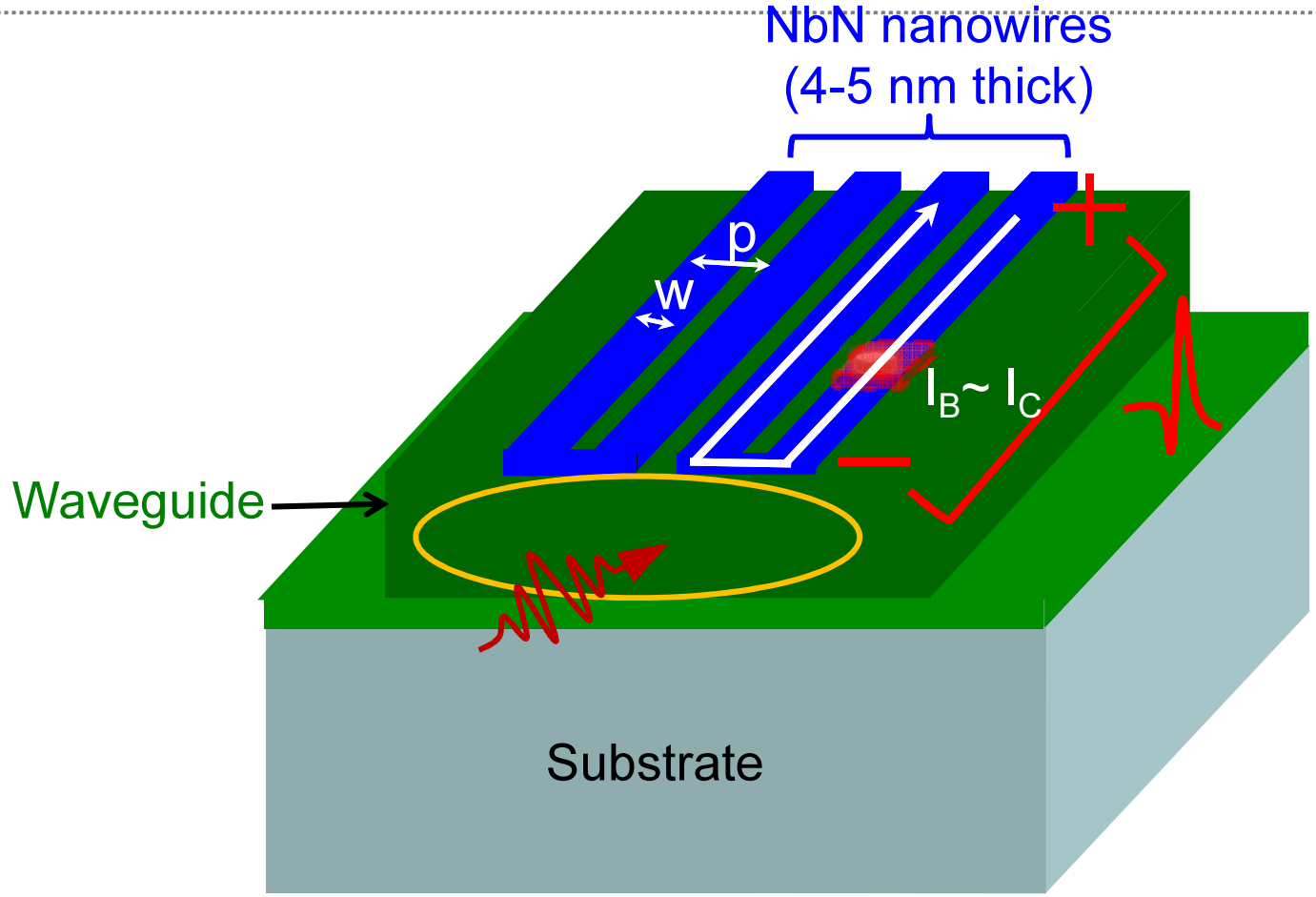
Appl. Phys. Lett. 106, 111116

Why SNSPDs ?

- Efficiency (as high as possible, maximum 100 %) ☺
- Dead time (detector cannot register any photon) ☺
- Dark count (false counts) ☺
- Jitter (uncertainty in detection) ☺
- Spectral response (visible up to 5 μm) ☺



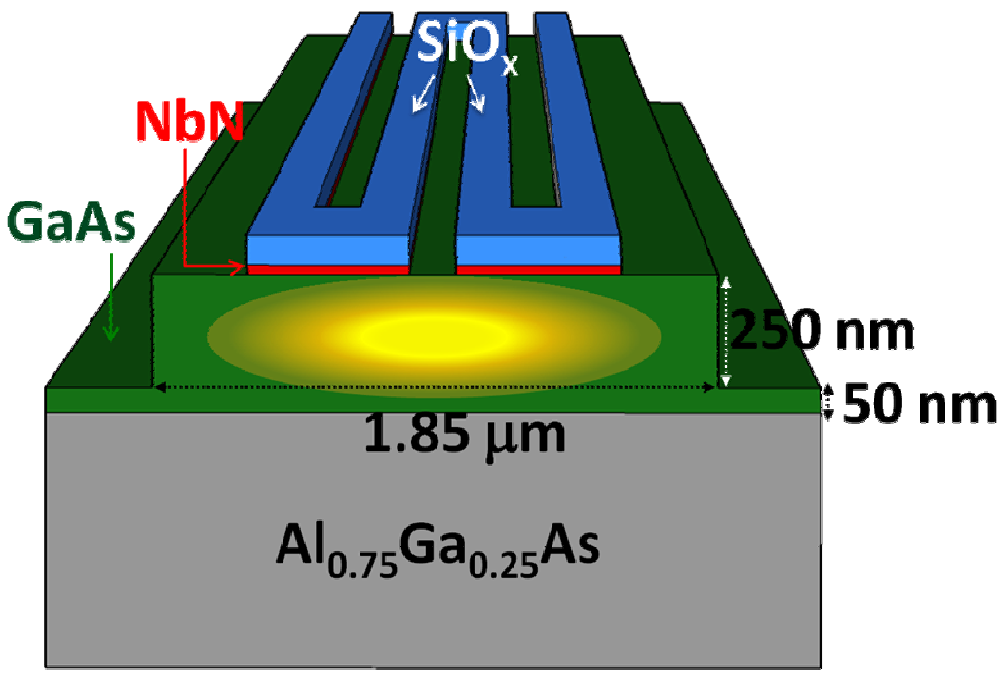
Photon detection principle

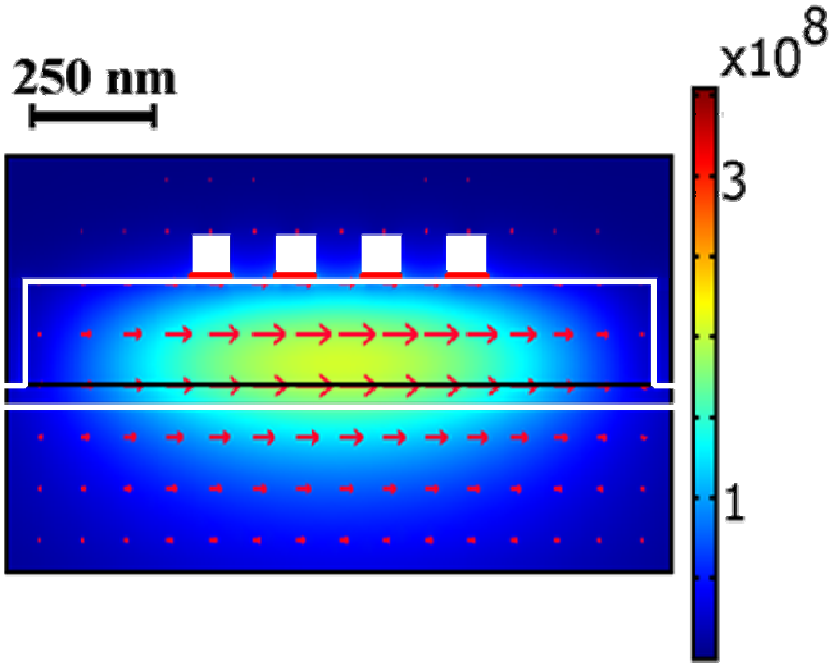


w= 100 nm and p= 250 nm

Golts'man et al., APL (2001)

Design of waveguide single-photon detector (WSPD)

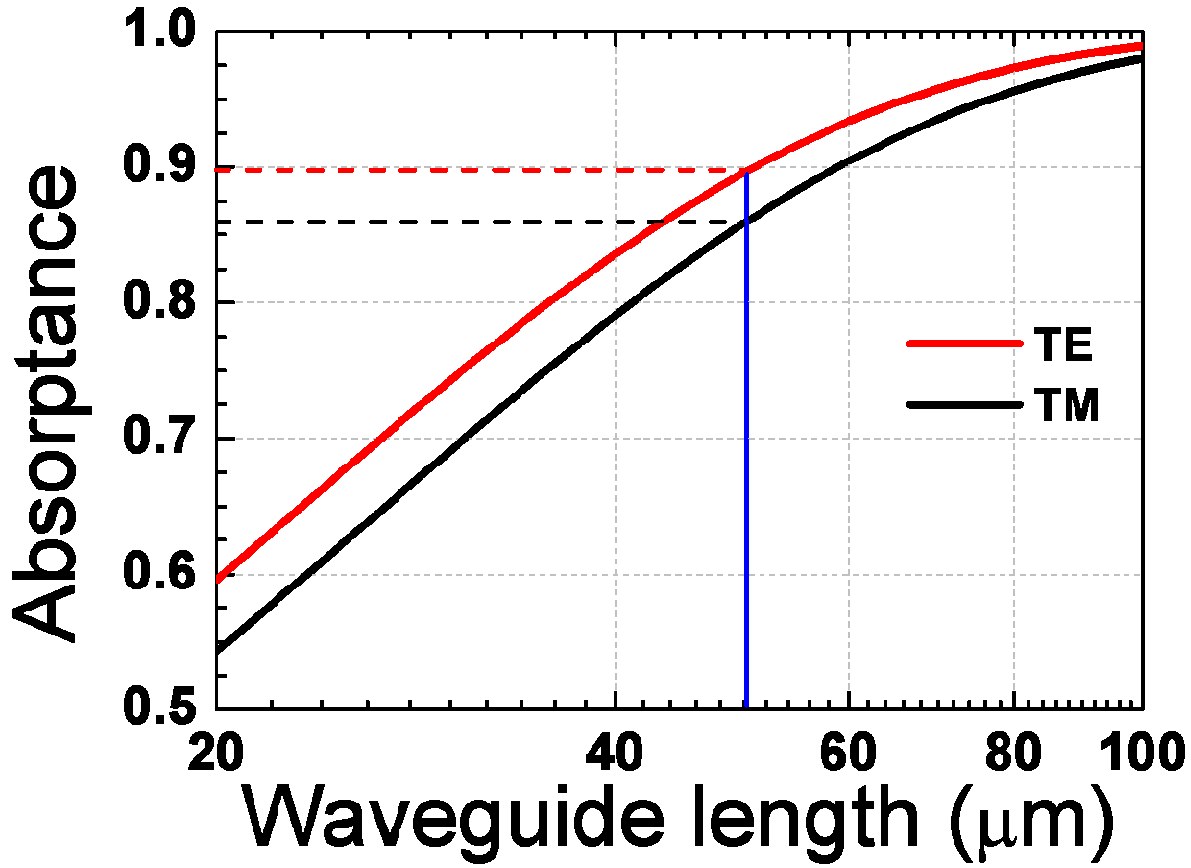




Finite-element simulation

JP Sprengers et al. Appl. Phys. Lett. 99, 181110 (2011)
Book: Optical waveguide Theory by A.W. Snyder & J. Love or any other books

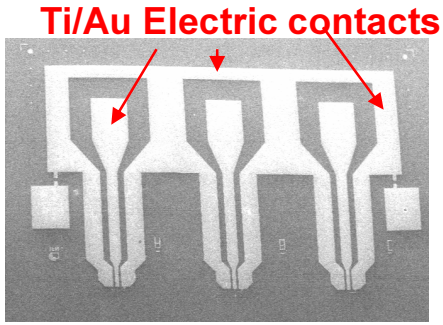
Absorptance of WSPD



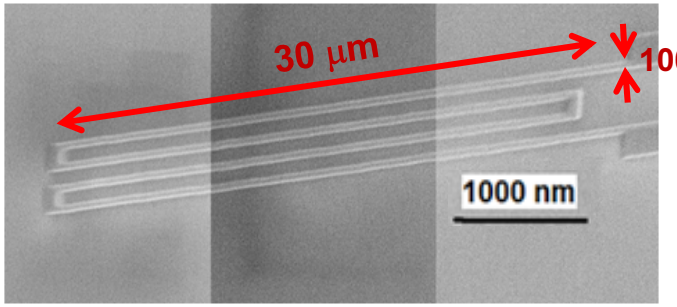
JP Sprengers et al. Appl. Phys. Lett. 99, 181110 (2011)

Processing of WSPDs

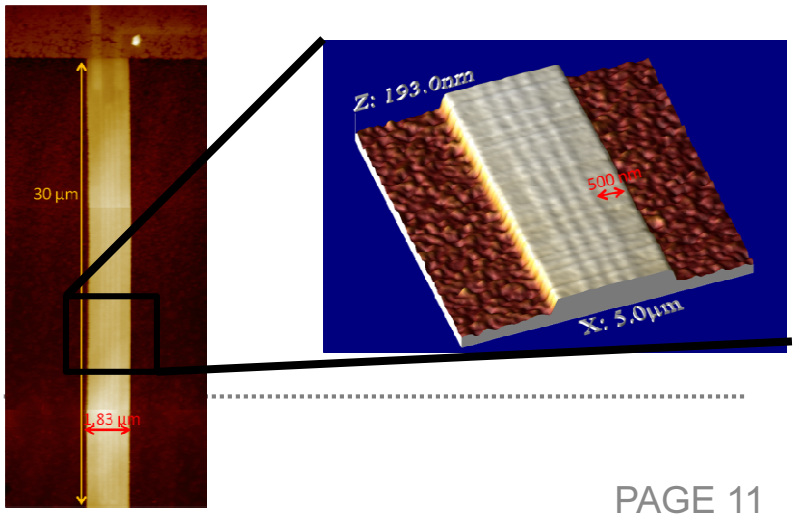
1. Deposition of NbN films (DC magnetron sputtering technique)



2. Definition of contact pads (e-beam lithography and lift-off)

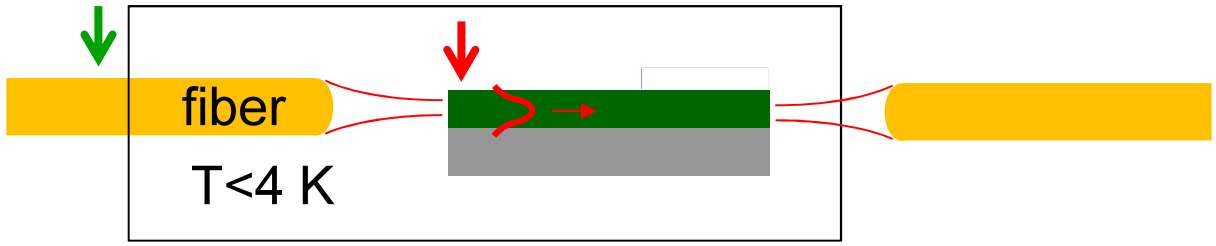


3. Definition and etching of nanowires (e-beam lithography and RIE etching)



4. Definition and etching of waveguides aligned to nanowires (e-beam lithography and RIE

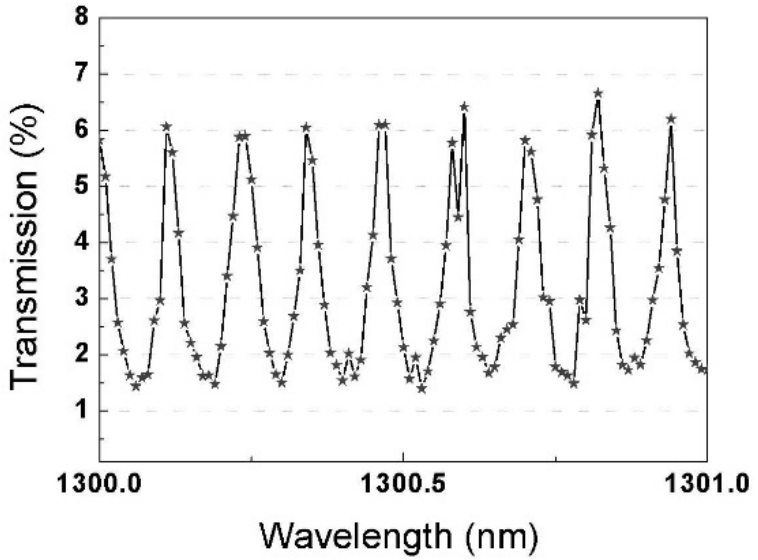
Measurement set-up & efficiency calculations



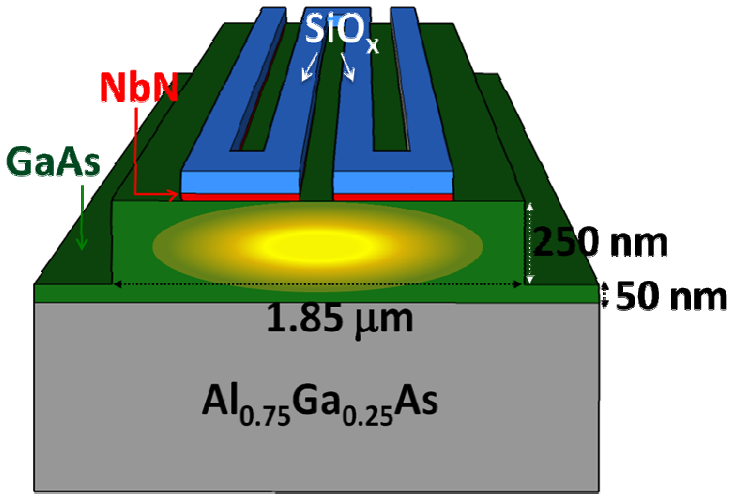
System quantum efficiency (SQE) = Numb of counts/ Numb of photons coupled

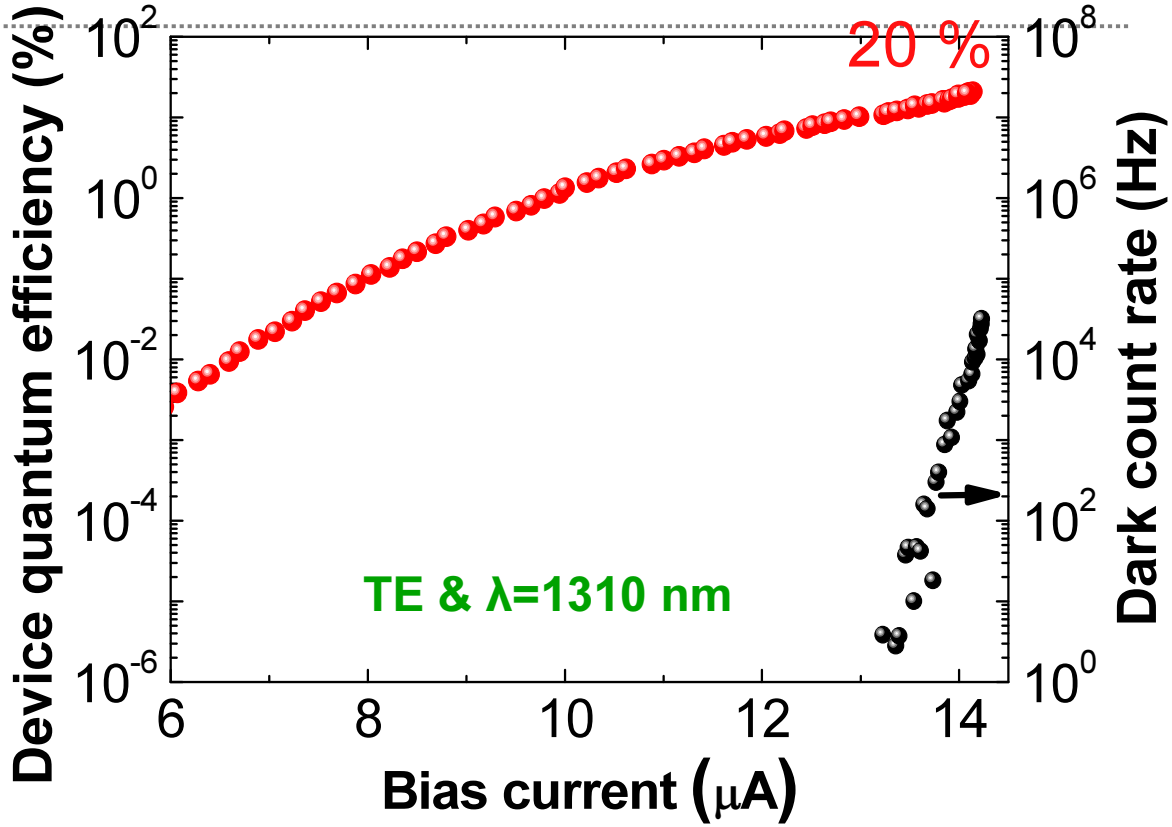
(Device) Quantum efficiency (QE) = SQE / η_c

$$T = \eta_c^2 \frac{e^{-\alpha L}}{1 + R^2 e^{-2\alpha L} - 2Re^{-\alpha L}\cos(2kL)}$$



WSPD performance

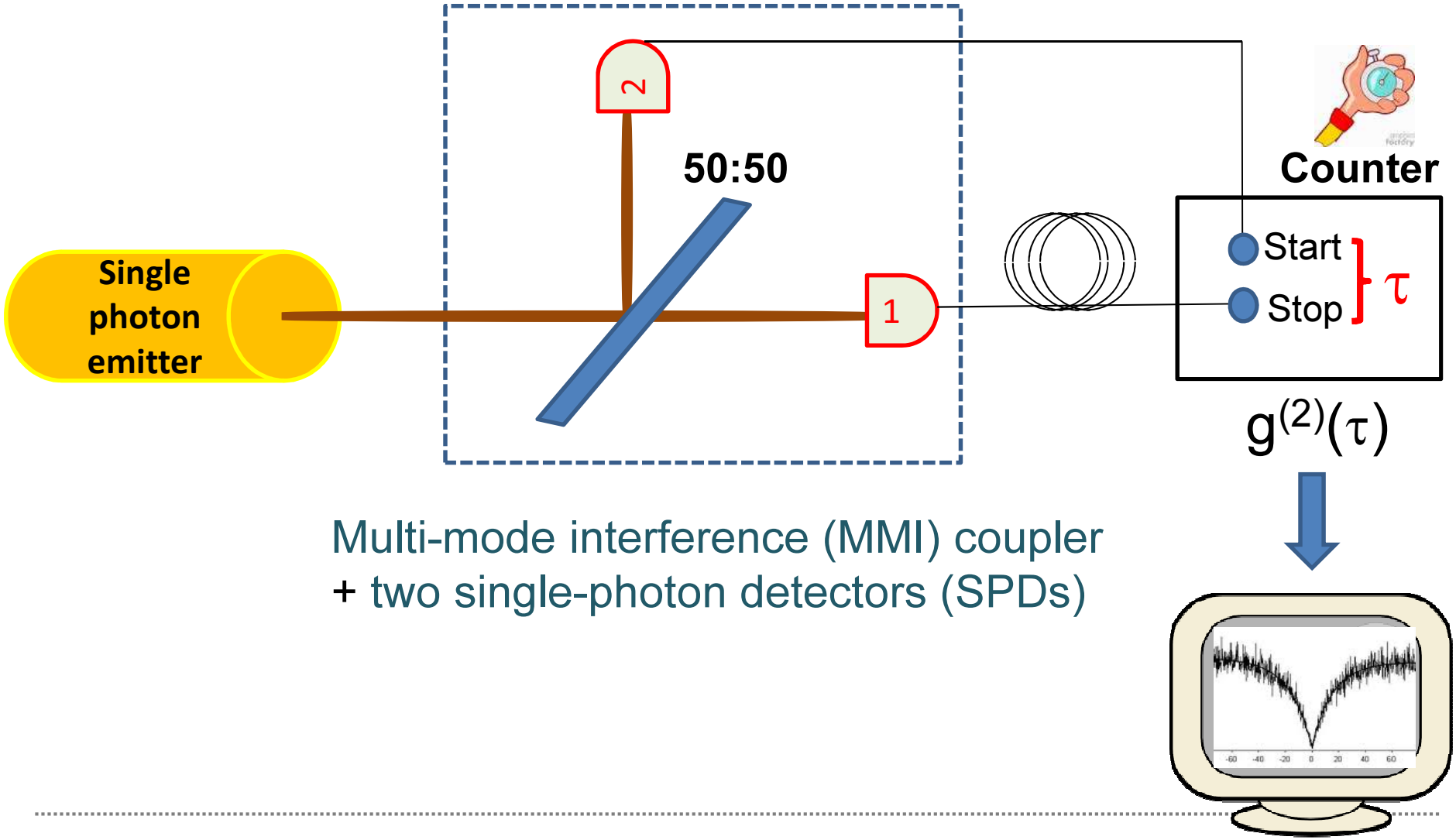




The first demonstration of waveguide SNSPDs on III-V that is compatible with single-photon sources and passive circuit.

Sprengers et al. Appl. Phys. Lett. 99, 181110 (2011)

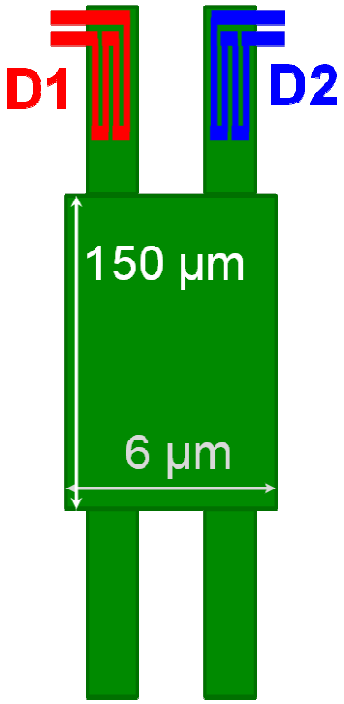
Hanbury-Brown and Twiss interferometer: $g^{(2)}(\tau)$ measurements



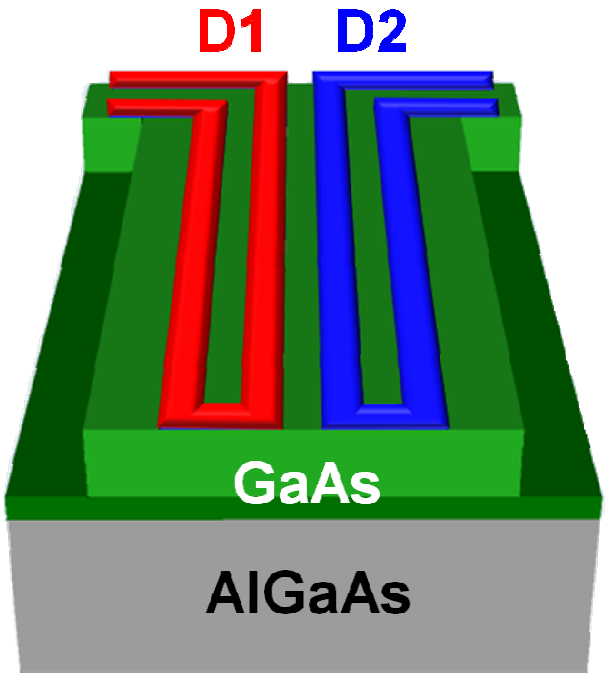
Multi-mode interference (MMI) coupler
+ two single-photon detectors (SPDs)

Waveguide single photon autocorrelators

Waveguide HBT

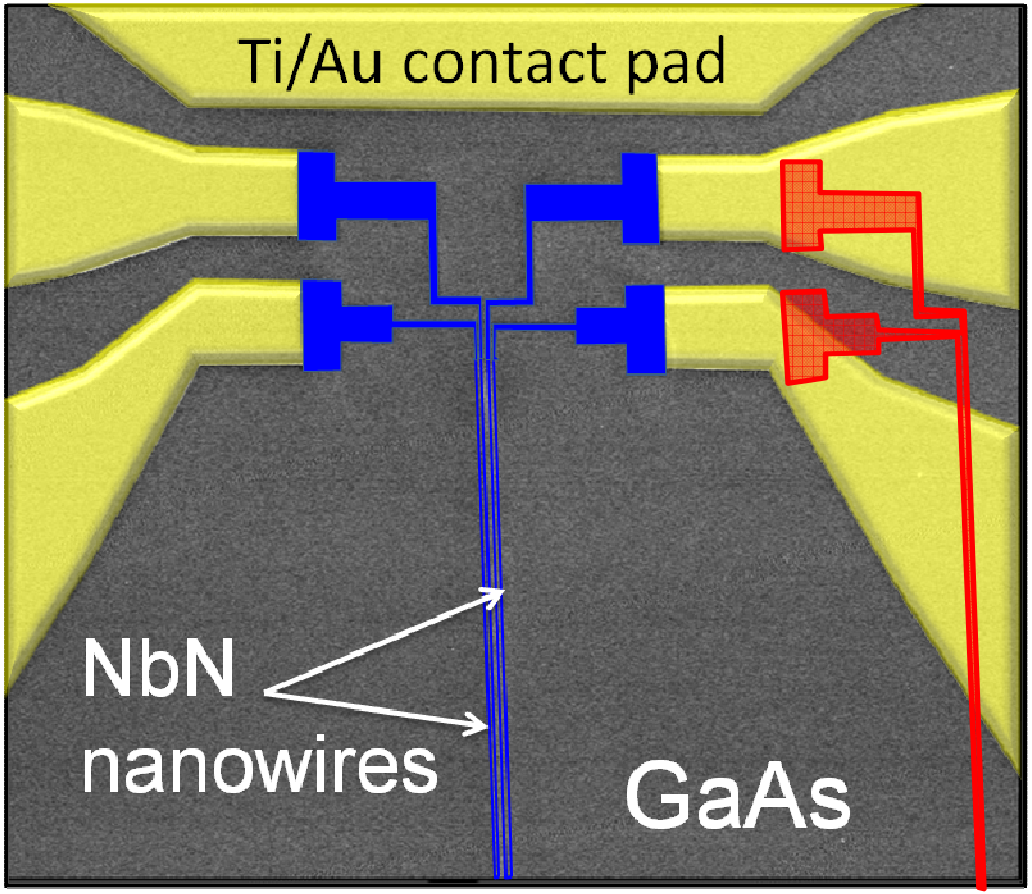


Waveguide autocorrelator



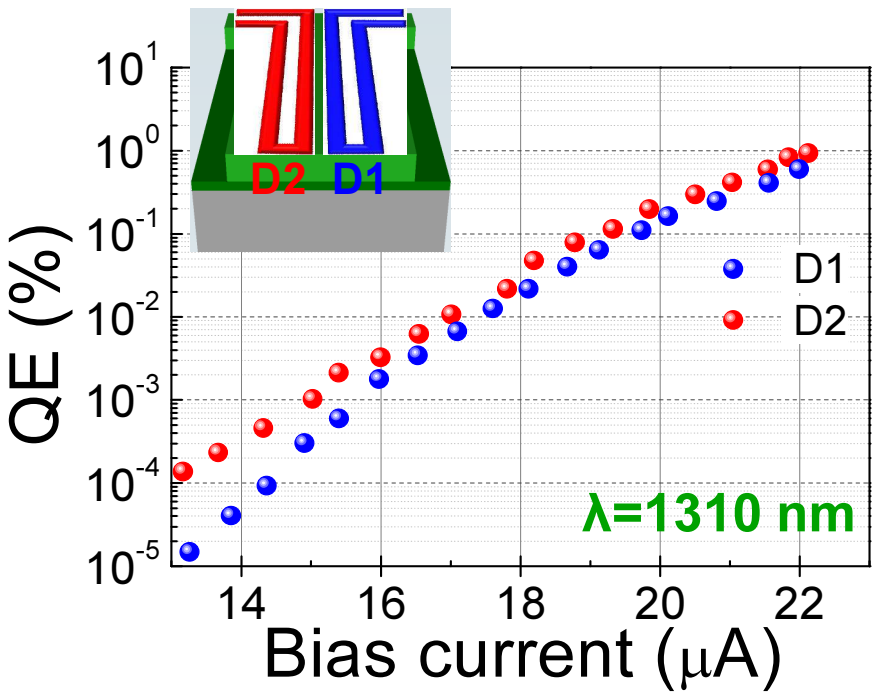
h_{ridge} = 300 nm
w_{ridge} = 1.85 µm
t_{NbN} = 5.9 nm

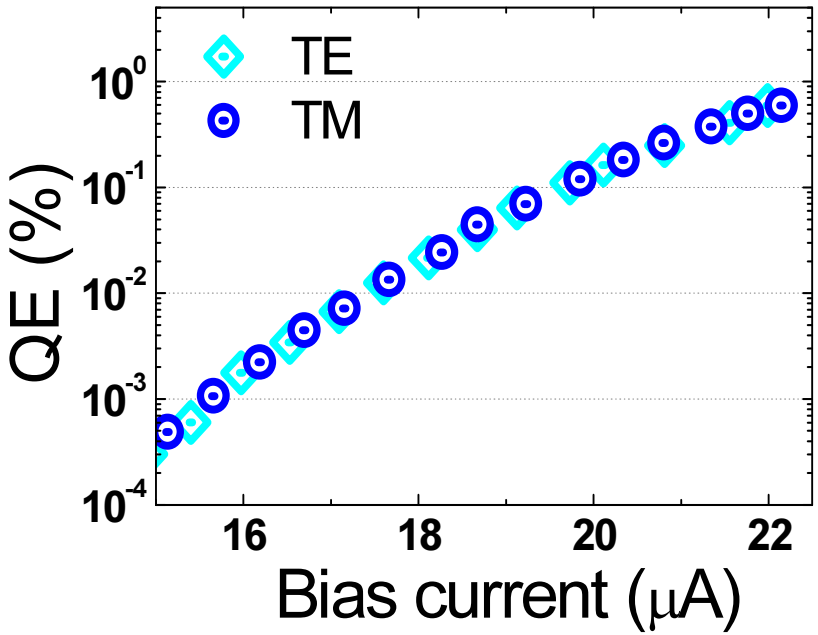
Waveguide single photon autocorrelators



D. Sahin et al. OpEx 21, 11162 (2013)

Efficiency and polarization response

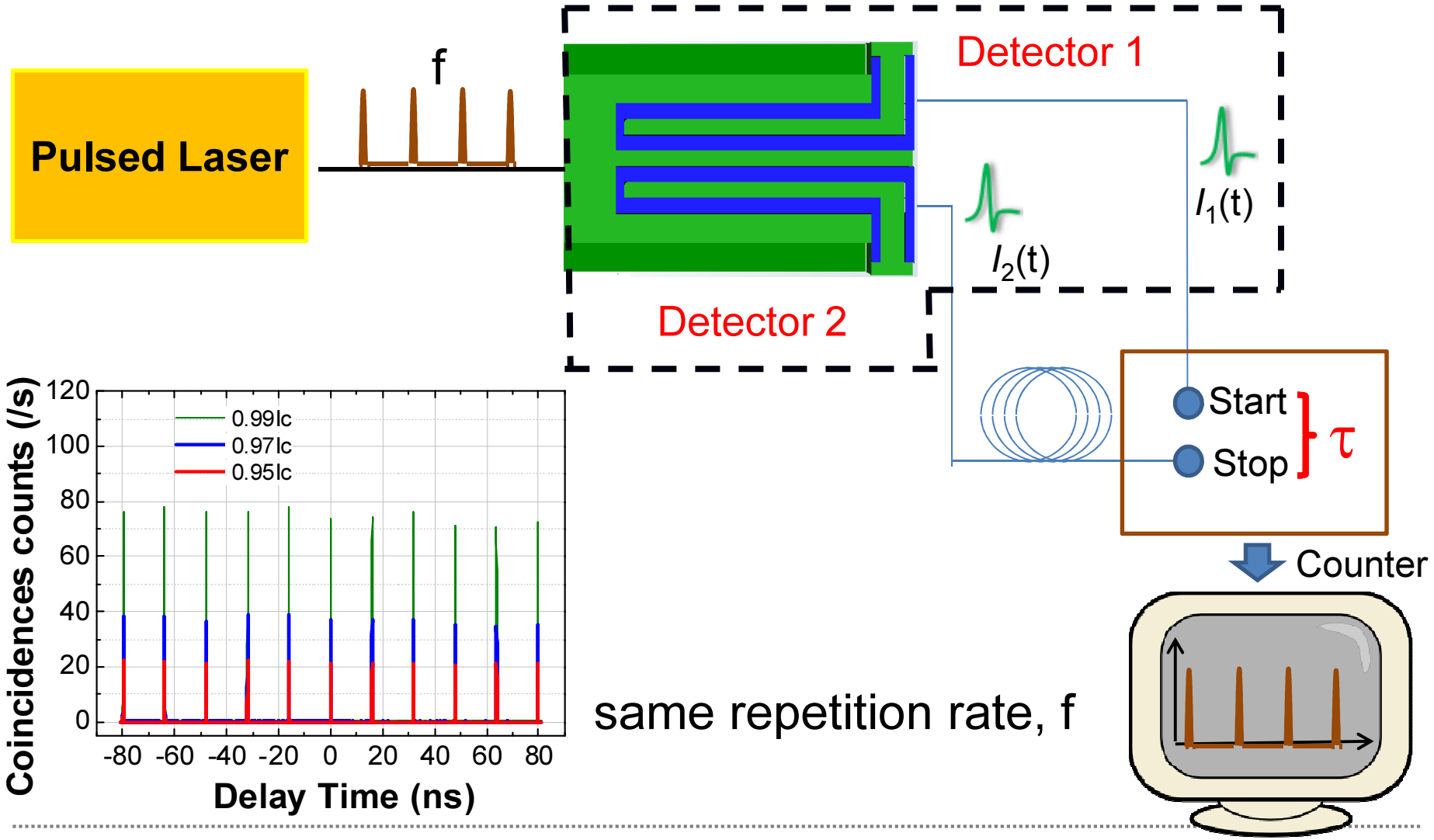




Very high absorptance (>90% for both TE&TM)
of 50 μm long waveguide

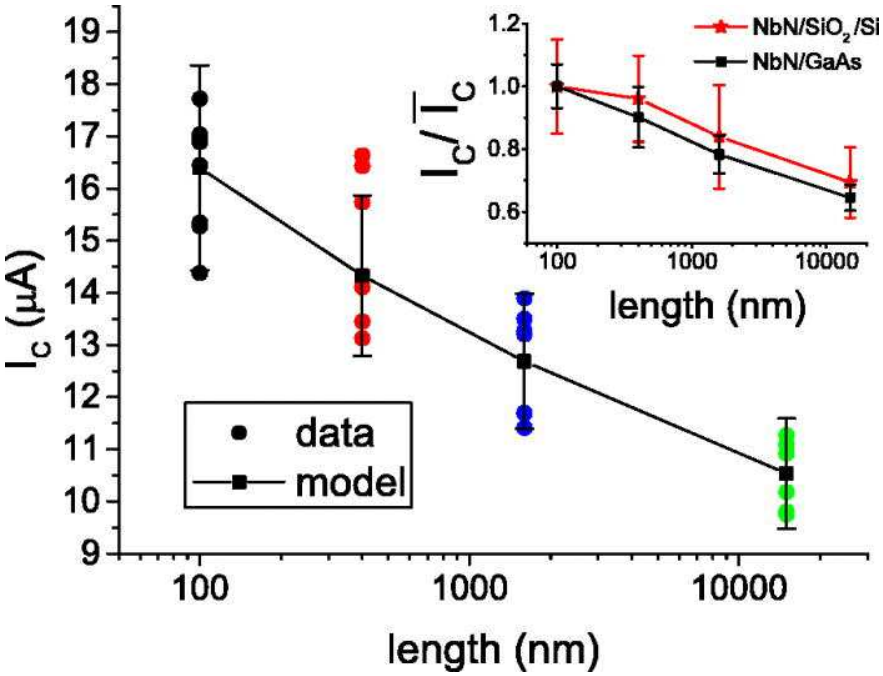
D. Sahin et al. OpEx 21, 11162 (2013)

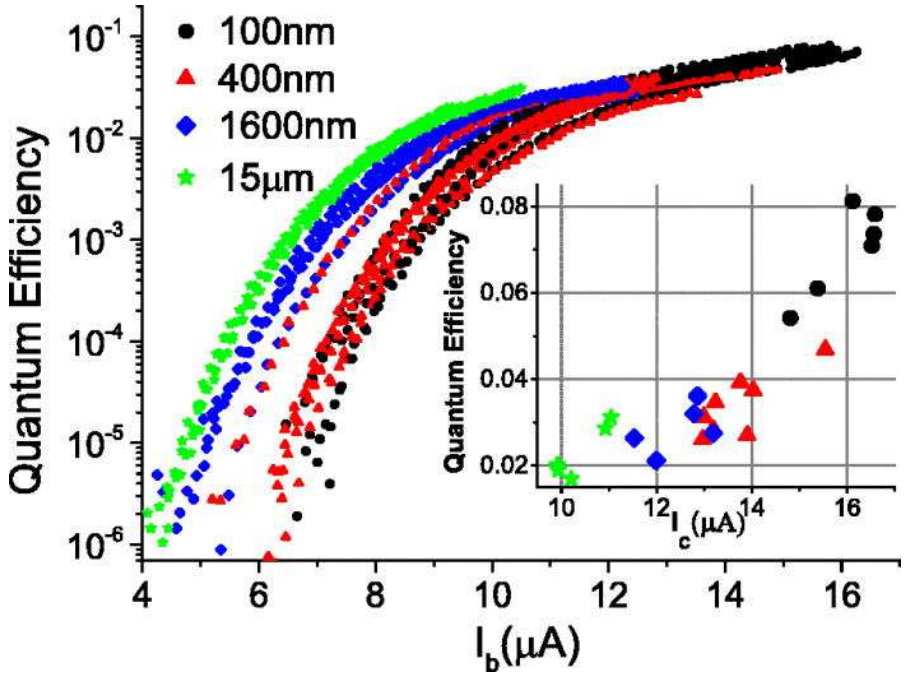
$g^{(2)}(\tau)$ measurements



D. Sahin et al. Opt. Express 21, 11162 (2013)

Inhomegeneity of NbN SNSPDs

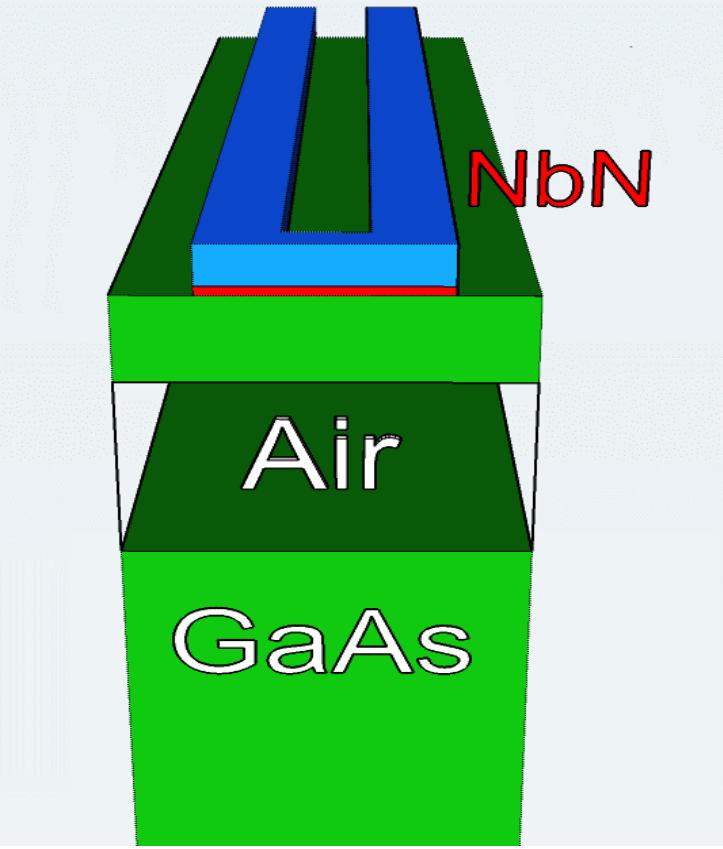


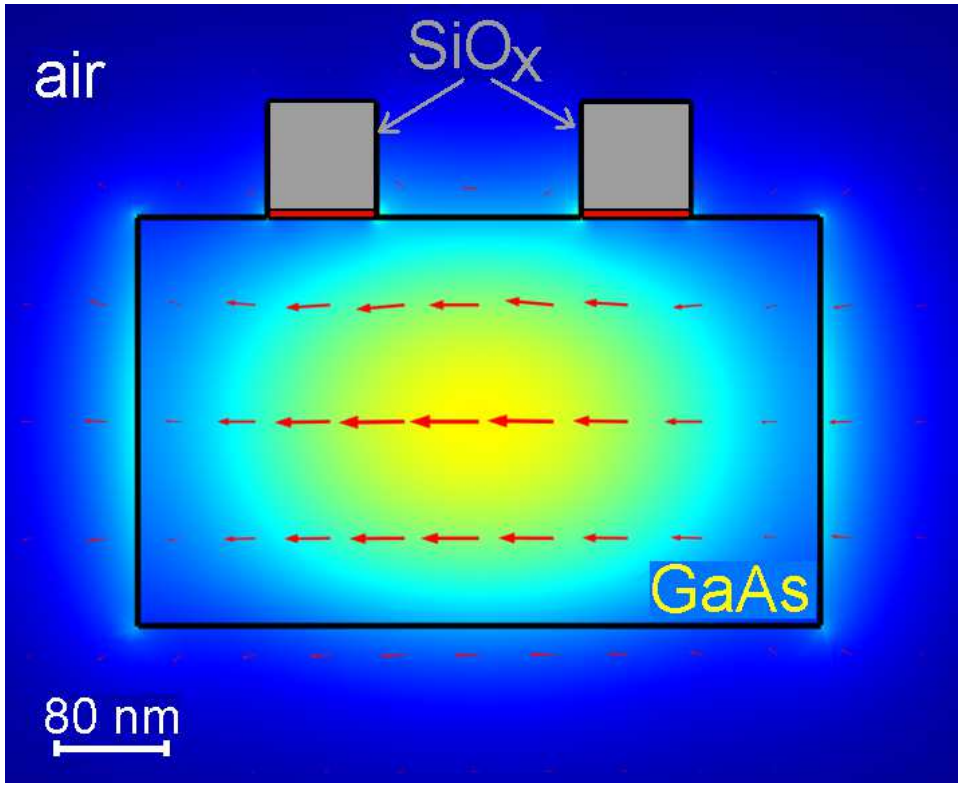


R Gaudio et al., APL **105**, 222602 (2014)

SNSPD on Nanobeam

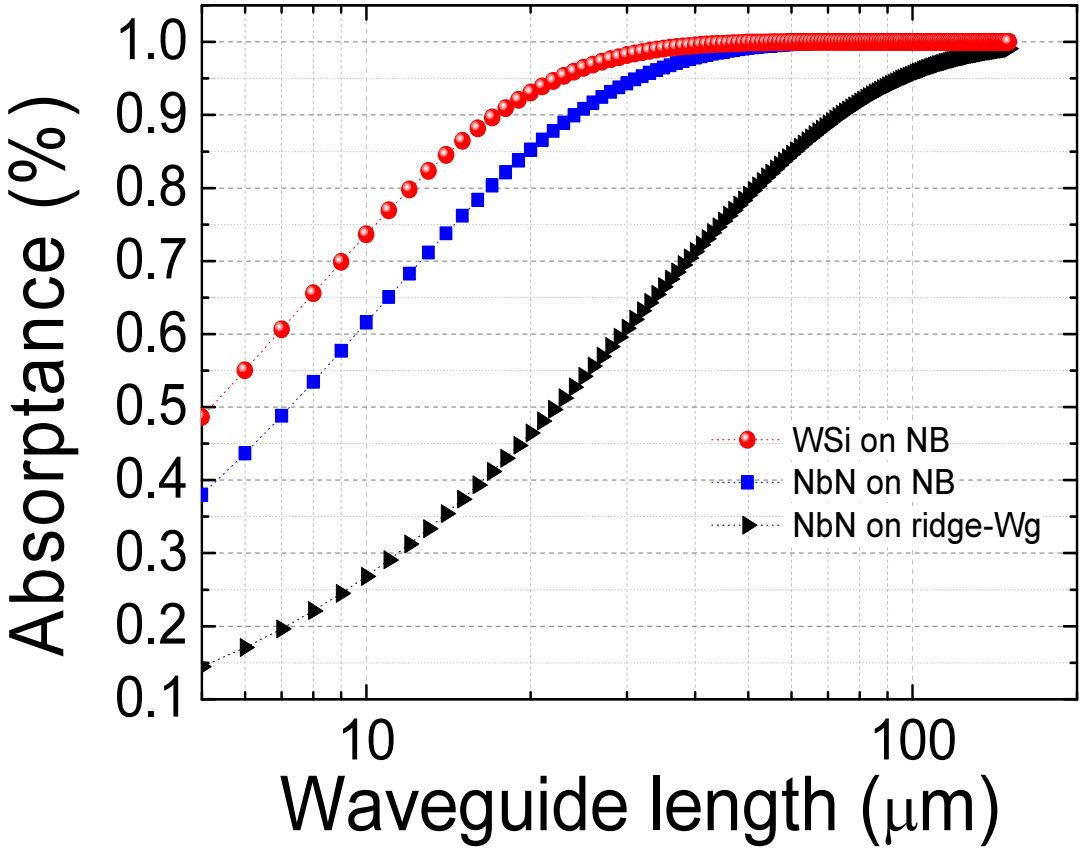
Addresses inhomogeneity of NbN nanowires, especially on GaAs





D Sahin et al., JSTQE **21** (2015)

SNSPD on Nanobeam



Simulated for TE polarized light at 1310 nm.

A= 90%
17 μm-long for TE
6 μm-long for TM

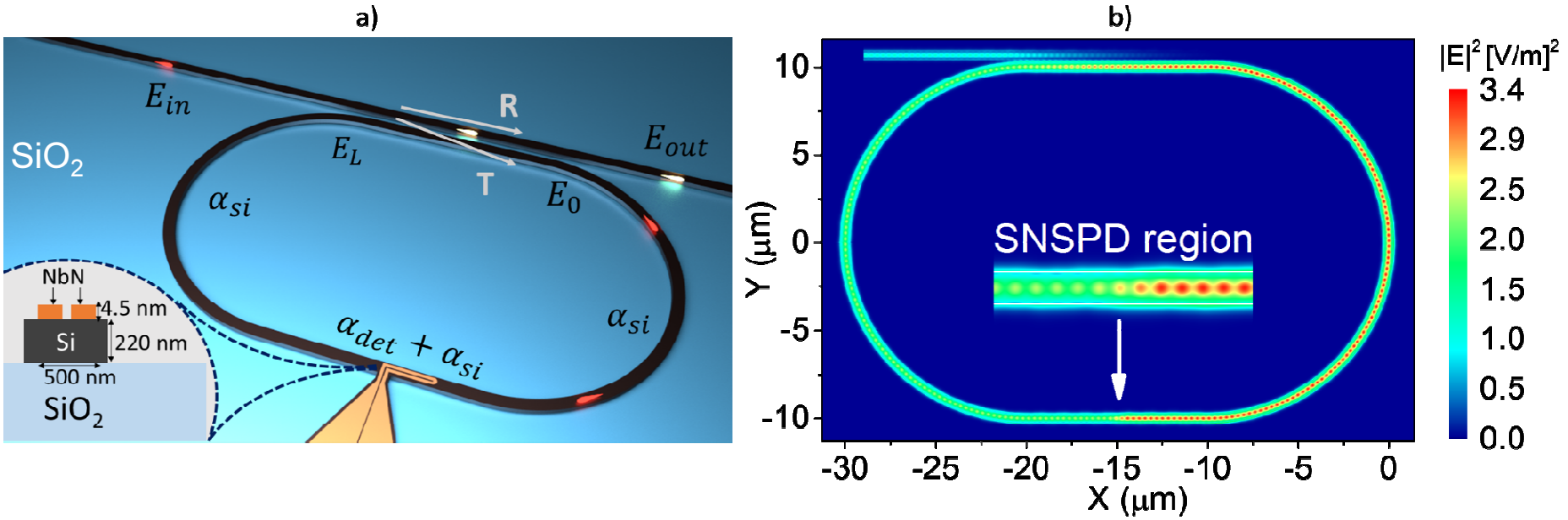
α_{abs}^{TE} = 1333 cm^{-1} & α_{abs}^{TM} = 3810 cm^{-1}

D Sahin et al., JSTQE **21**, 1-10 (2015)

Cavity enhanced structures

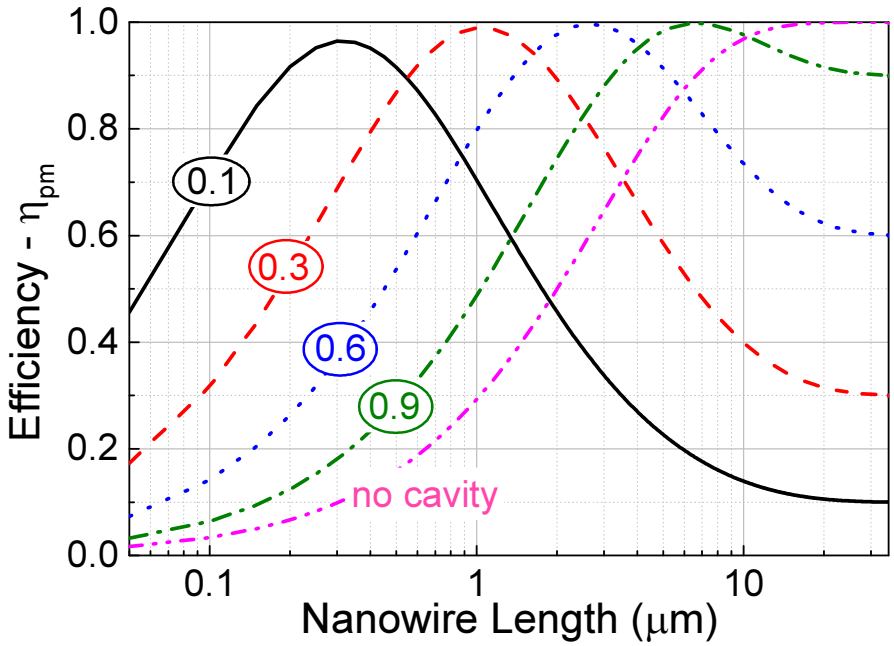
Cavity enhanced efficiency as well as yield enhancement

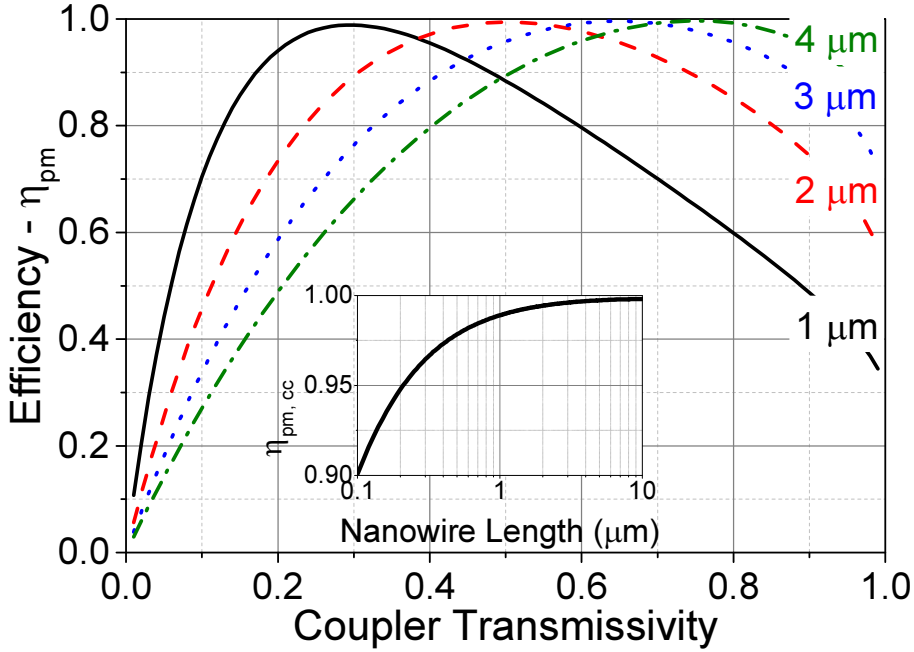
WG: 220 nm thick, 500 nm wide on 1μm SiO_2
NW: NbN, 4.5nm thick, 100 nm wide



N. A. Tyler et al. OPEX, 24 , p: 8797 (2016)

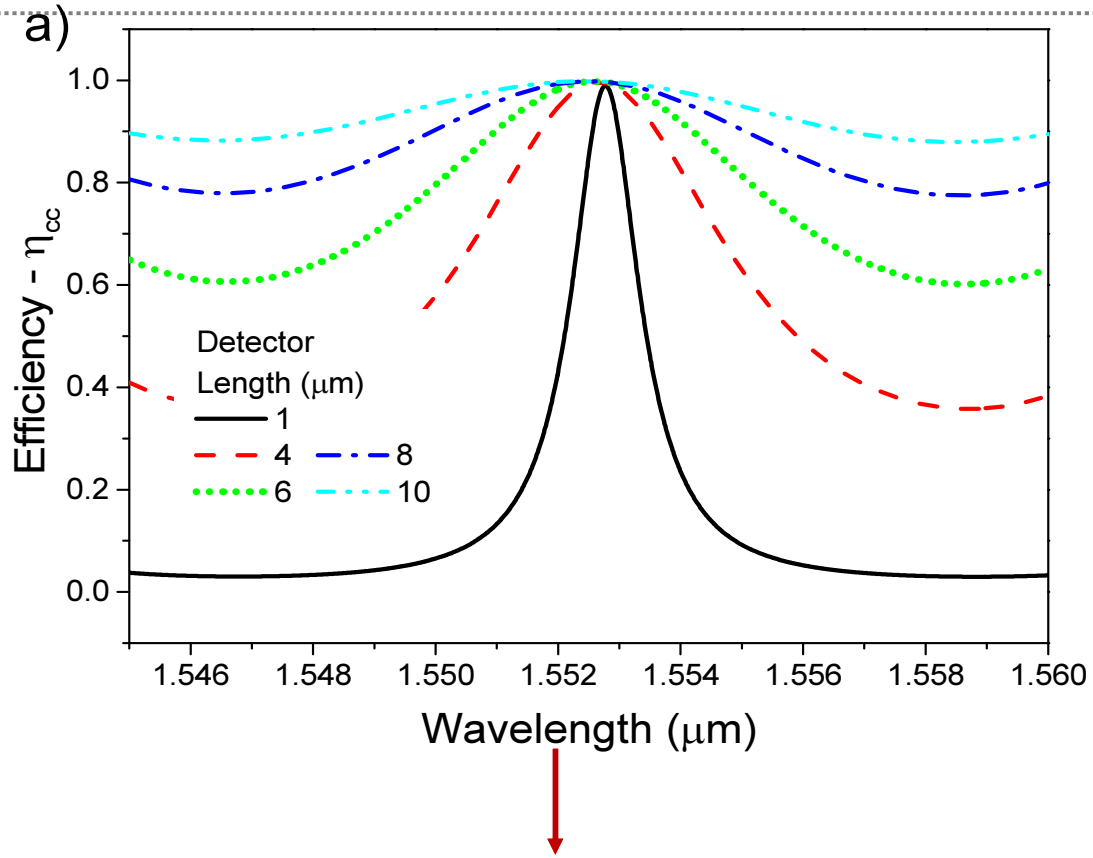
SNSPDs in cavity - efficiency





N. A. Tyler et al. OPEX, 24 , p: 8797 (2016)

SNSPDs in cavity - performance

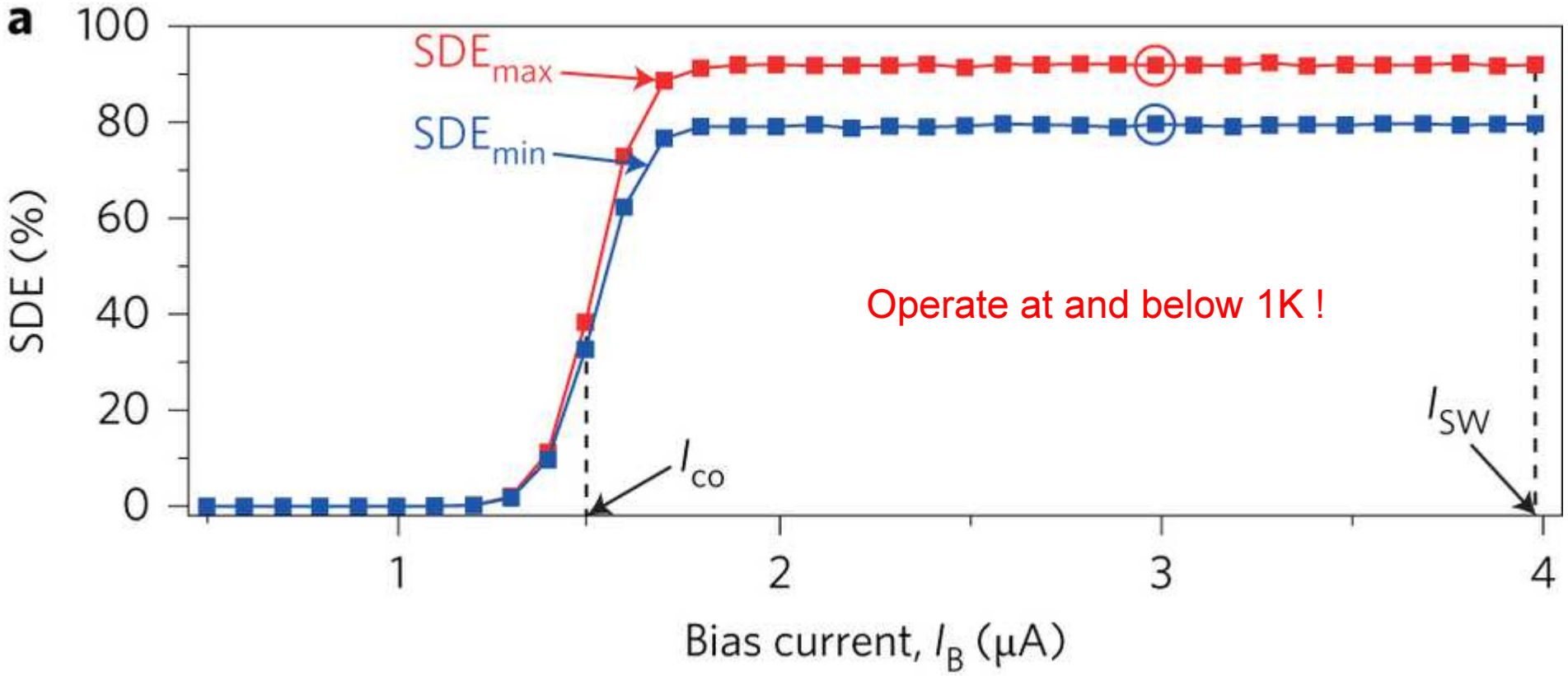


Bandwidth can be modified, narrow bands are ideal for spectrometers at single-photon sensitivity.

N. A. Tyler et al. OPEX, 24 , p: 8797 (2016)

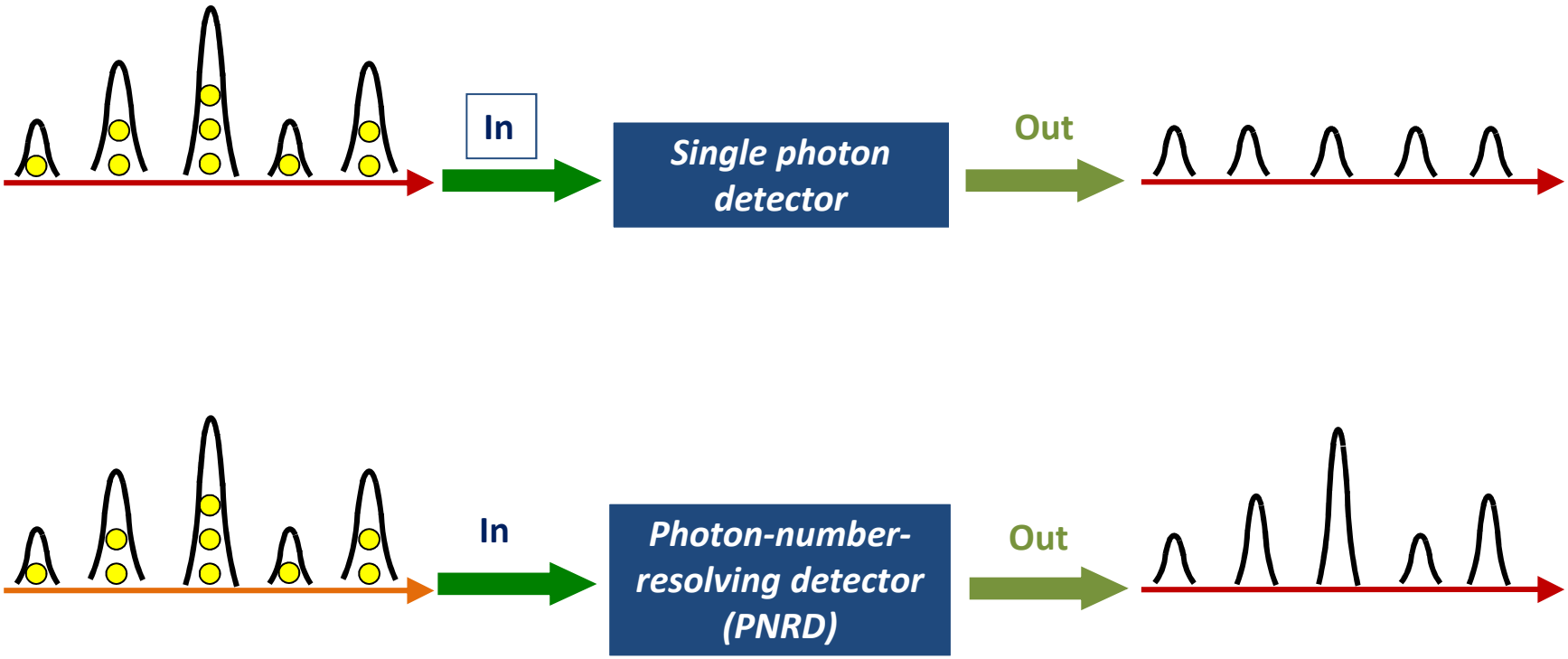
Recent advancements: SNSPD with WSi nanowires on Si

No WG but a mirror cavity structure is implemented



F. Marsili et al. Nature Photon 7.3 (2013): 210-214

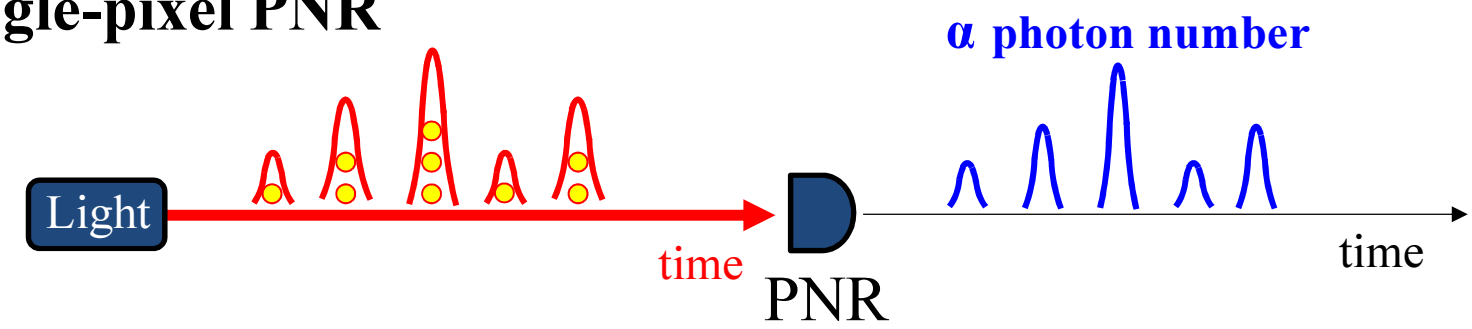
Single-photon detector vs PNRD



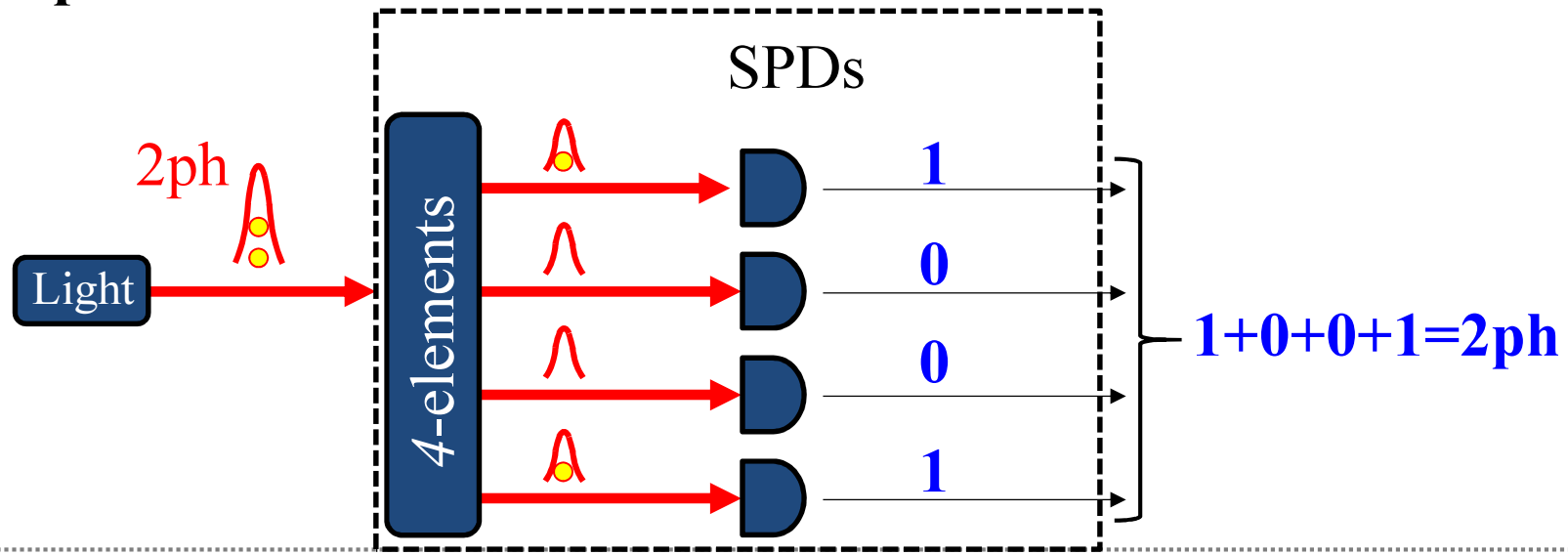
University of BRISTOL

PNRDs

Single-pixel PNR

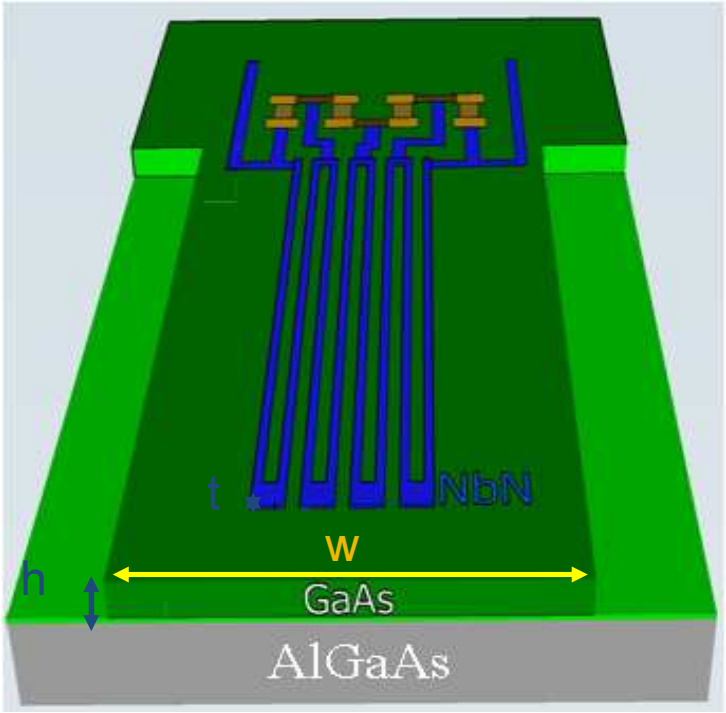


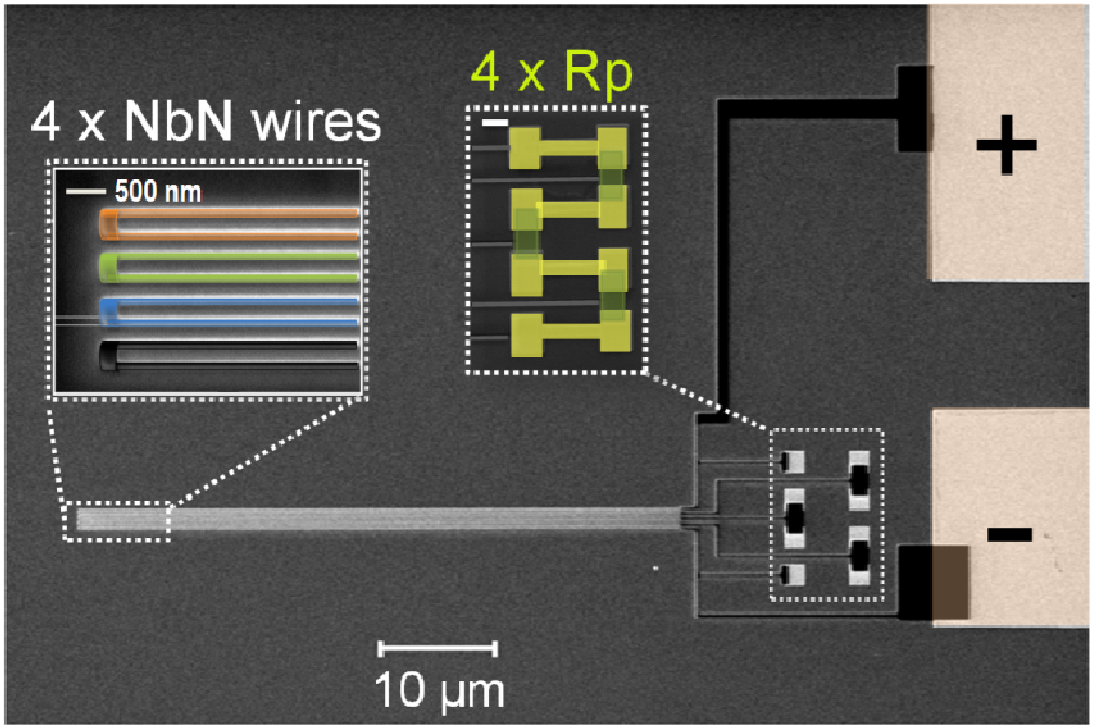
Multiplexed PNR



Multiplexed PNR

Waveguide photon-number-resolving detectors (WPNR)





h_{ridge} = 260 nm
w_{ridge} = 3.85 µm
t_{NbN} = 4.7 nm

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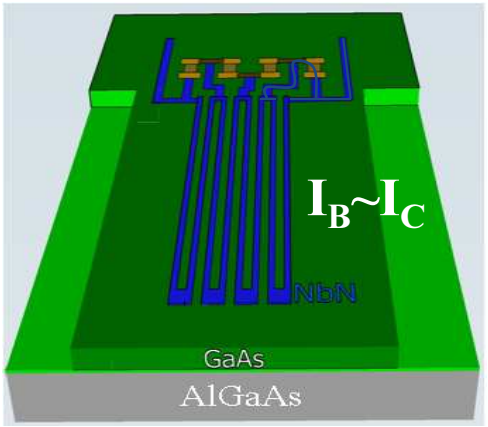
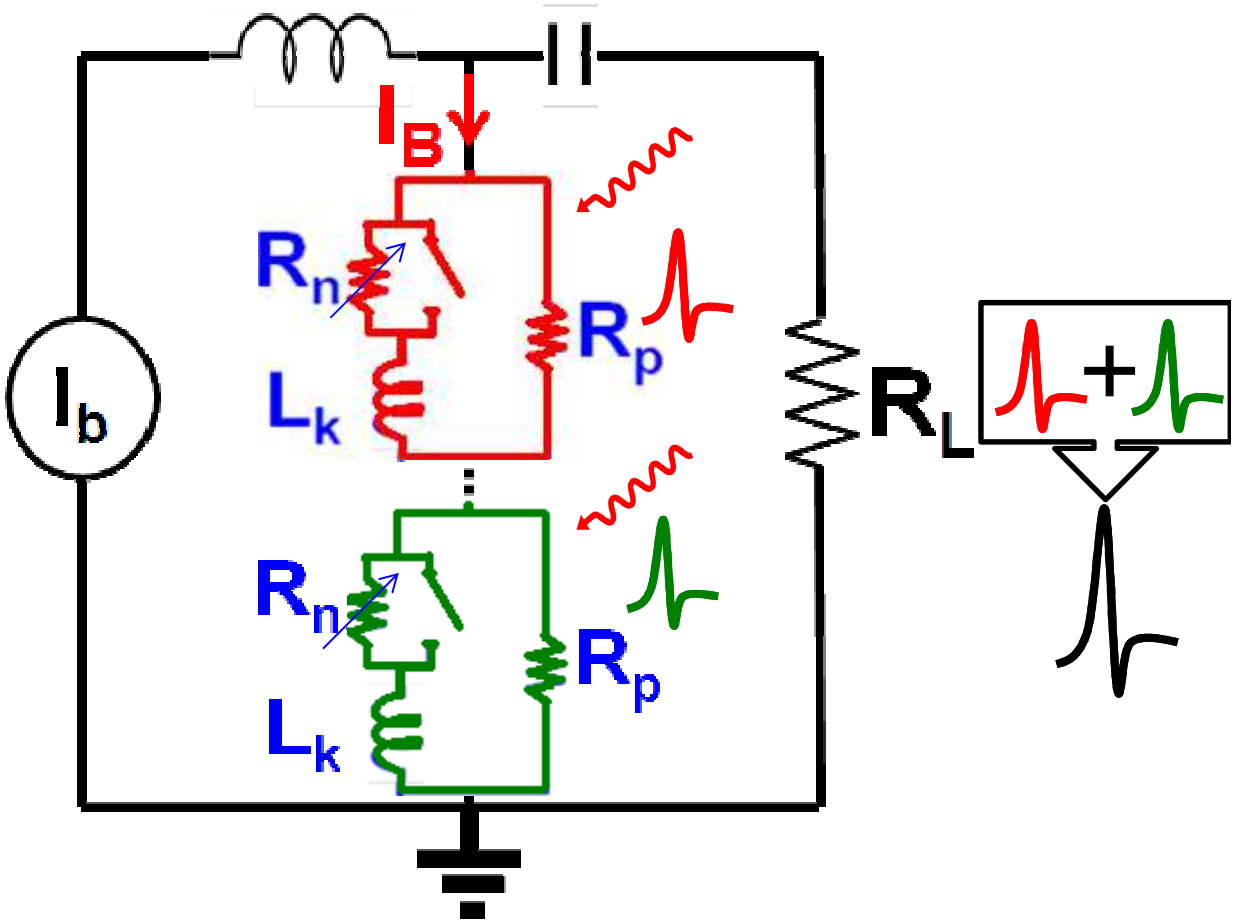
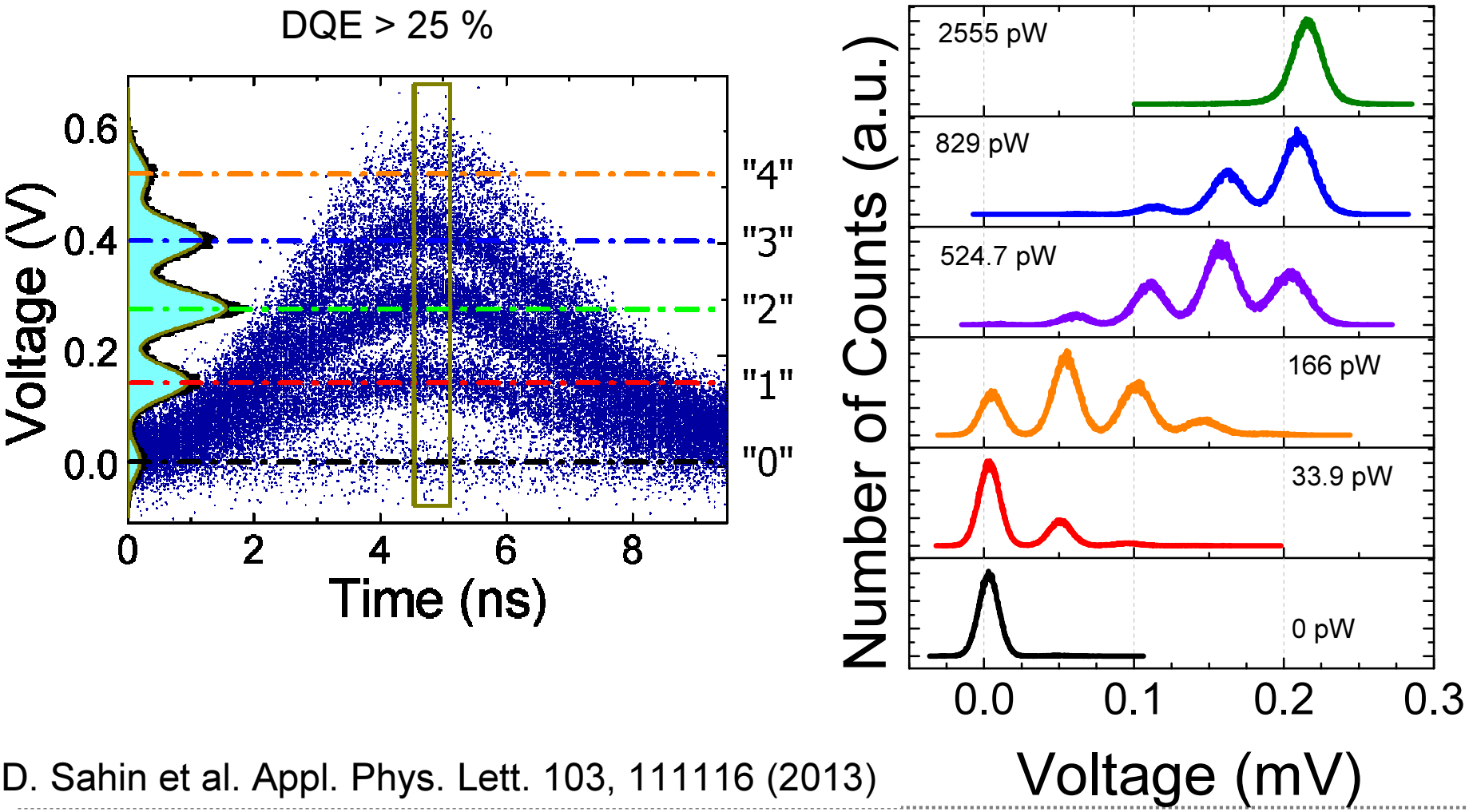
Circuit equivalent





D. Sahin et al. Appl. Phys. Lett. 103, 111116 (2013)

WPNR: Proof of PNR



D. Sahin et al. Appl. Phys. Lett. 103, 111116 (2013)

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TU/e Technische Universiteit Eindhoven University of Technology
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http://www.bristol.ac.uk/physics/research/quantum/engagement/qcloud/

THANKS VERY MUCH

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stw
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