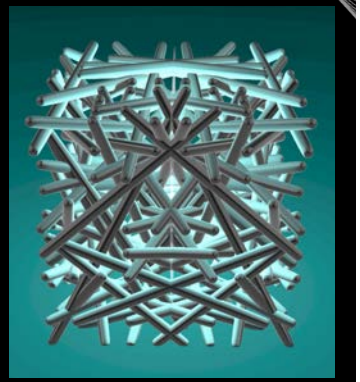
MATERIAL CHOICES IN PHOTONIC QUANTUM TECHNOLOGY

PEPIJN PINKSE



QuMat, Tuesday 12 Nov. 2024

Quant Quantum Nanotechnology Twente

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OUTLINE

Material choices in
Quantum Authentication
Quantum Information Processing

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*Optical **Physical Unclonable Keys**** *

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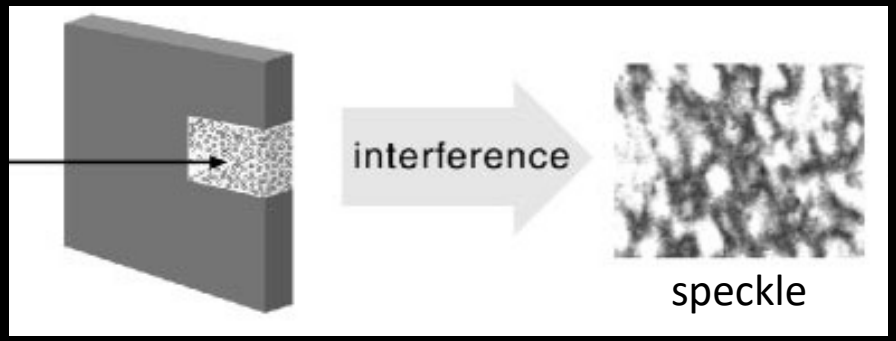

* in cryptography also known as
Physical Unclonable Functions (PUFs)

Pappu *et al.*, *Physical One-Way Functions*, Science **297**, 2026 (2002)

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Quantum Readout of hardware keys (PUFs)

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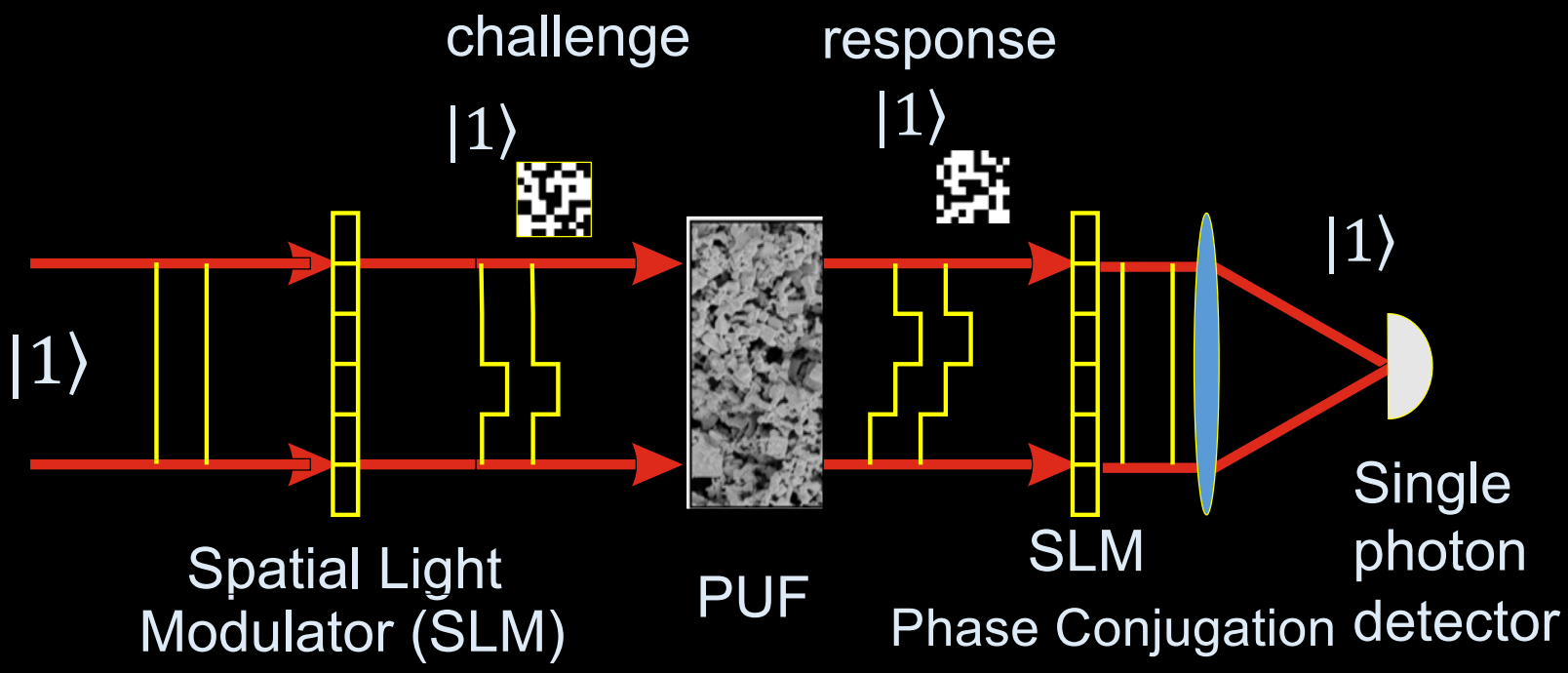

Goorden *et al.*, *Quantum-Secure Authentication*, Optica **1,** 421 (2014)

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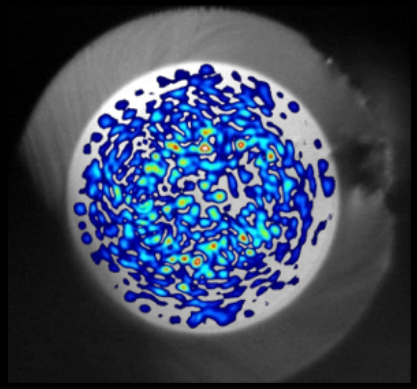
Key material for Quantum-Secure Authentication



A multimode fiber?

ZnO
Pigment /
paint

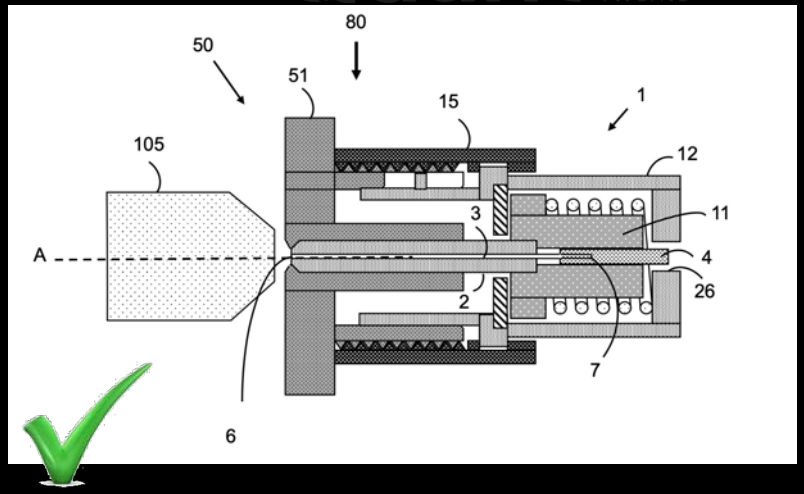
White (glass-)
ceramic
materials

Biometric keys

Goorden *et al.*, Optica **1,** 421 (2014); https://vimeo.com/145129613

Quantum-Secure Authentication

HSM



High-security applications sought!

Car access keys?

Goorden *et al.*, Optica **1,** 421 (2014); https://vimeo.com/145129613

Cloning an Optical PUF?

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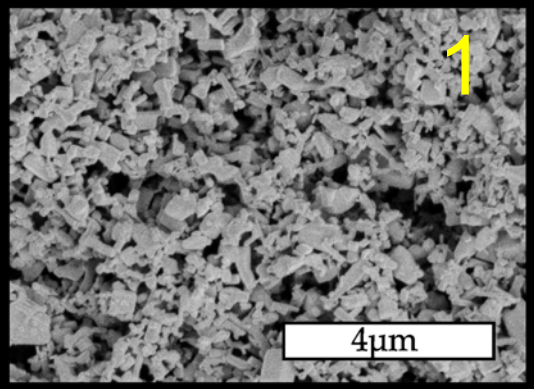
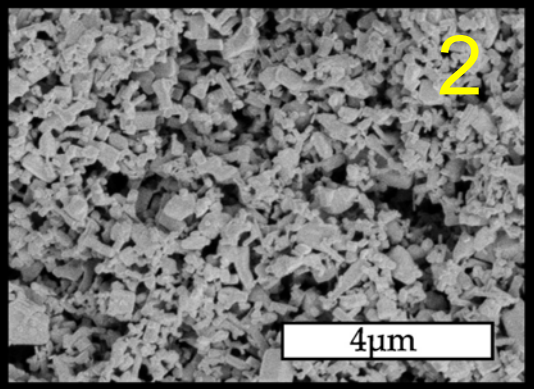
- Need to implement ~10^6 elements in 30 μm^3
- Seems impossible, but let‘s try anyway

Starting simple:
Can we make an artificial PUF twice?
Direct Laser Writing (DLW)





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Direct Laser Writing (DLW)

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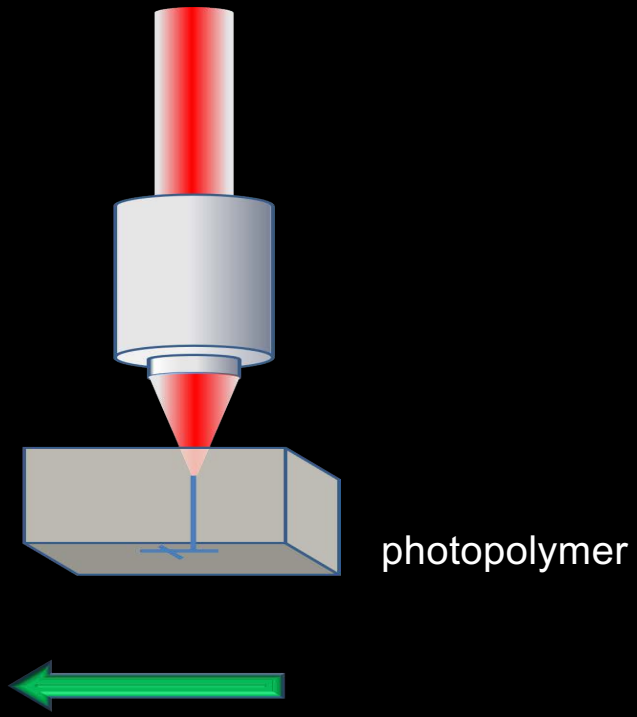
Femtosecond (fs) pulses
to induce polymerization.



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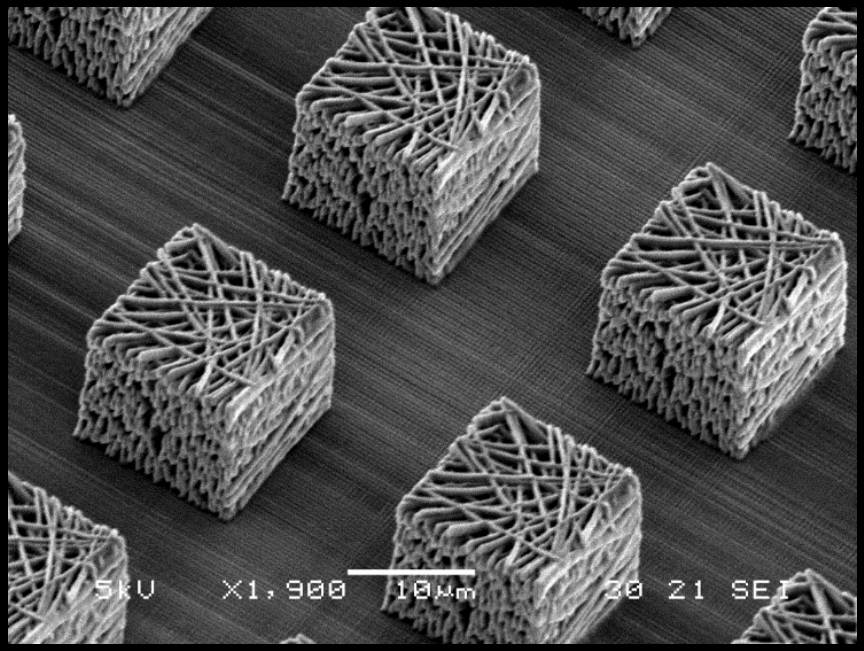
Deterministic Scattering Media



Deterministic scattering media: Marakis *et al.*, Adv. Opt. Mat. 2020, 2001438

Several DLW Samples

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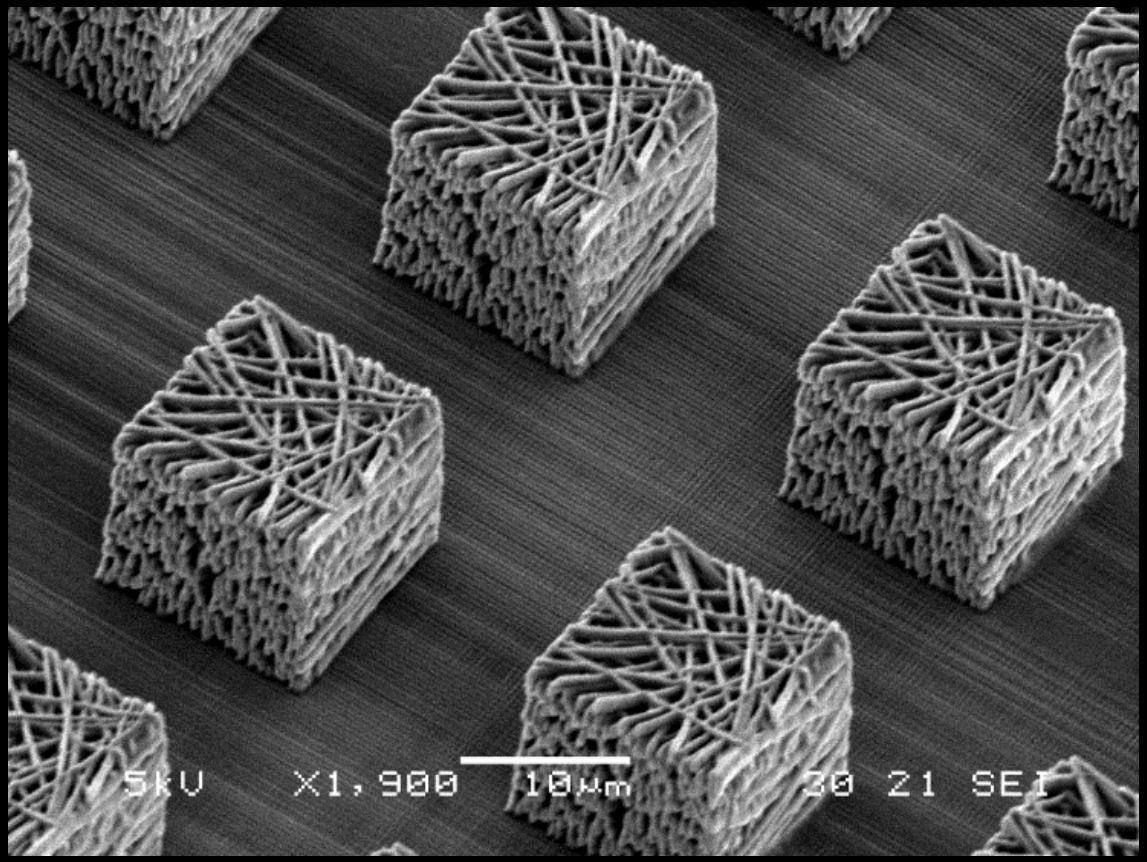
Electron microscopy



New security protocols possible

Deterministic scattering media: Marakis *et al.*, Adv. Opt. Mat. 2020, 2001438

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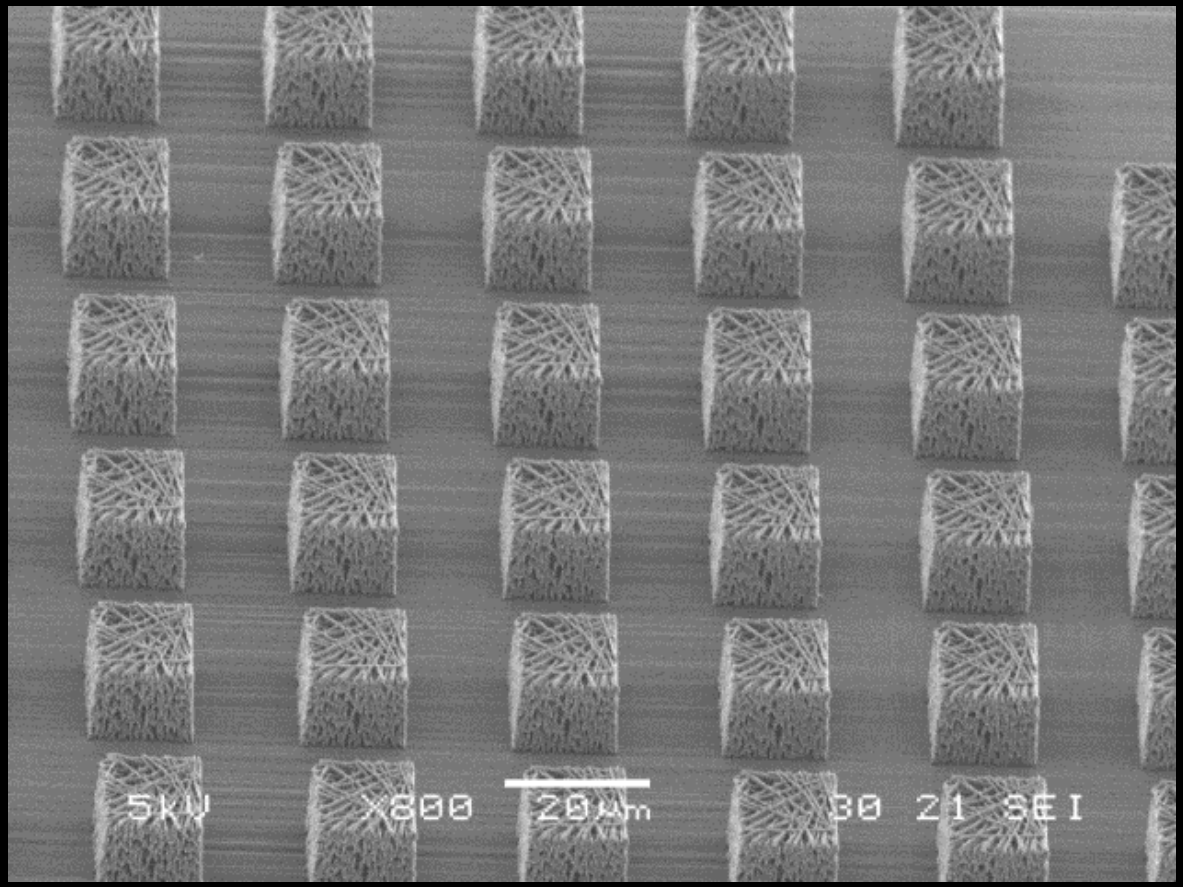
Many DLW Samples



Deterministic scattering media: Marakis *et al.*, Adv. Opt. Mat. 2020, 2001438

Twin PUFs

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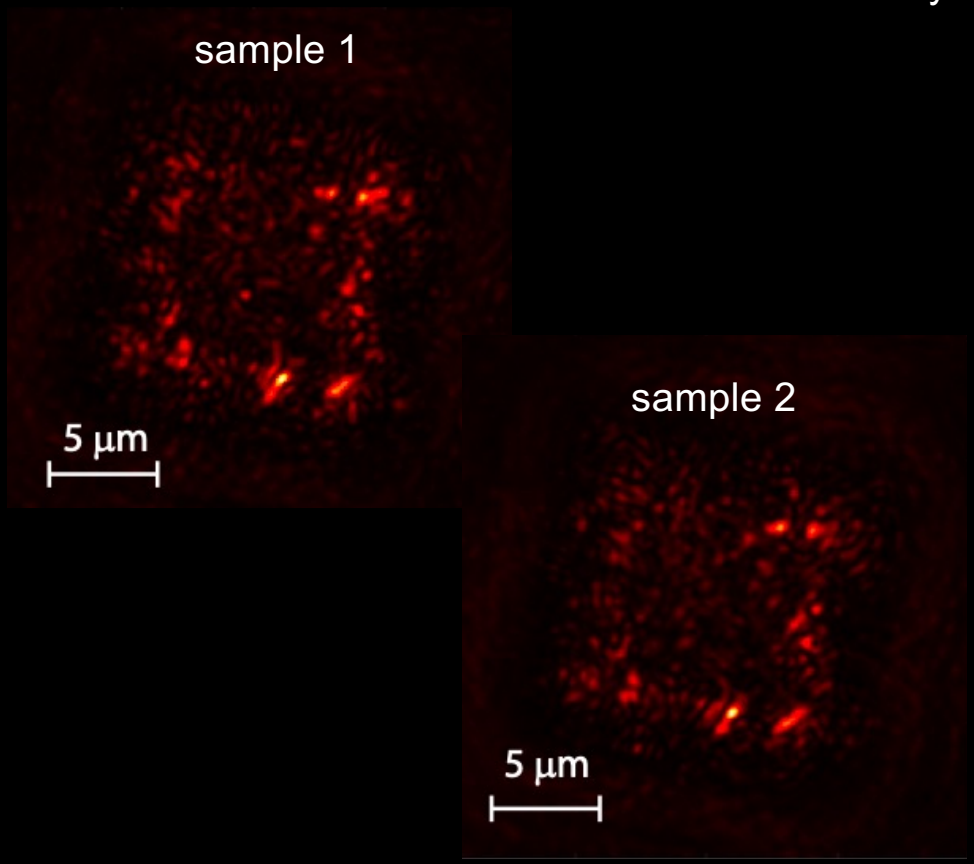
New security applications!



ArXiv 2212.12495 Marakis et al.

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Outlook Deterministic Scattering

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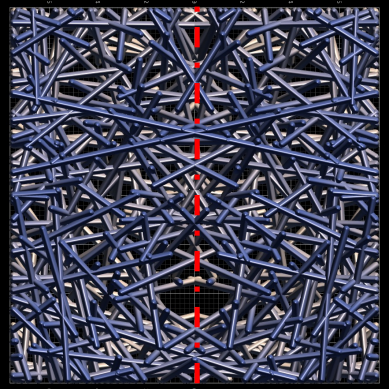
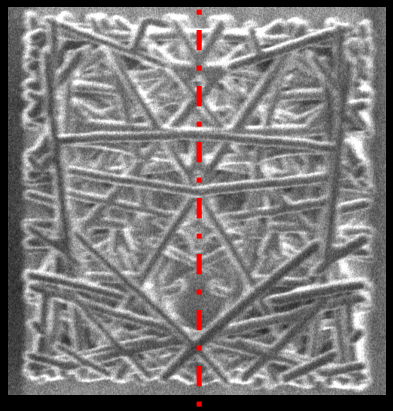


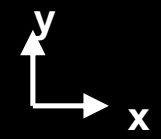
Design (top view) ←

Fabri-cated→



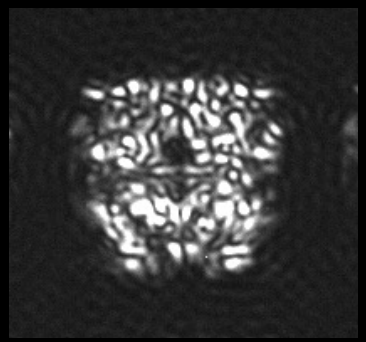
future:
- fs laser engraving?
- anticounterfeiting
- Physical Keys

Experi-mental data:



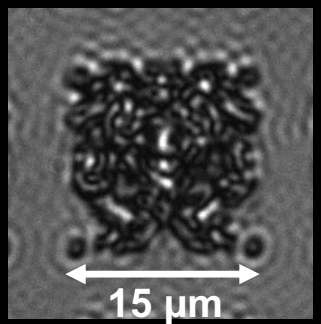
lin. x pol. input

y pol. output



lin. y pol. input

y pol. output



Saini … Pinkse, ArXiv 2310.04862, PRL in press

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Remote Key Readout

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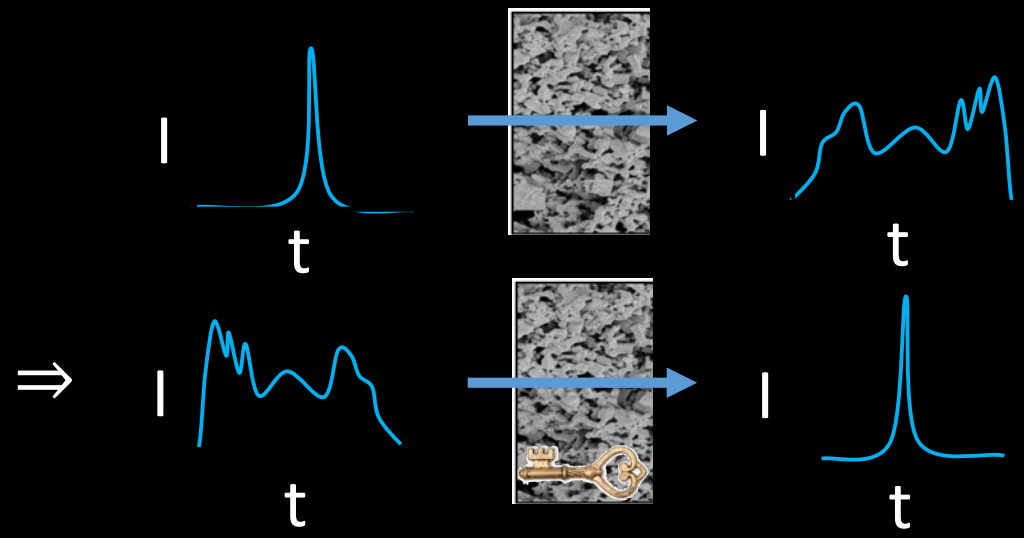
Sofar: wavefront exchange requires proximity
Remote readout in spectral-temporal domain?



Remote Key Readout of Fingerprint Chips

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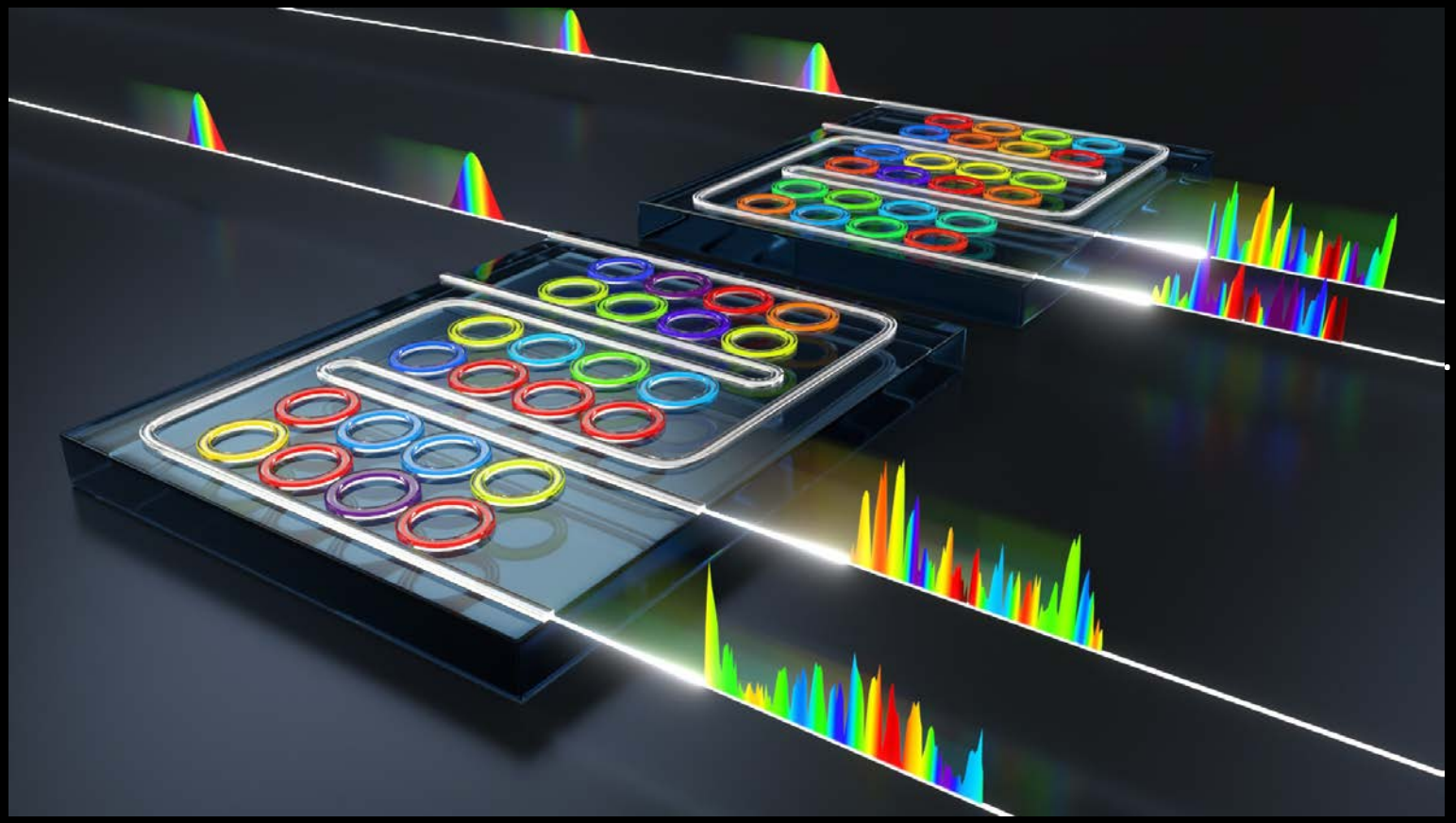

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Integrated photonic platforms

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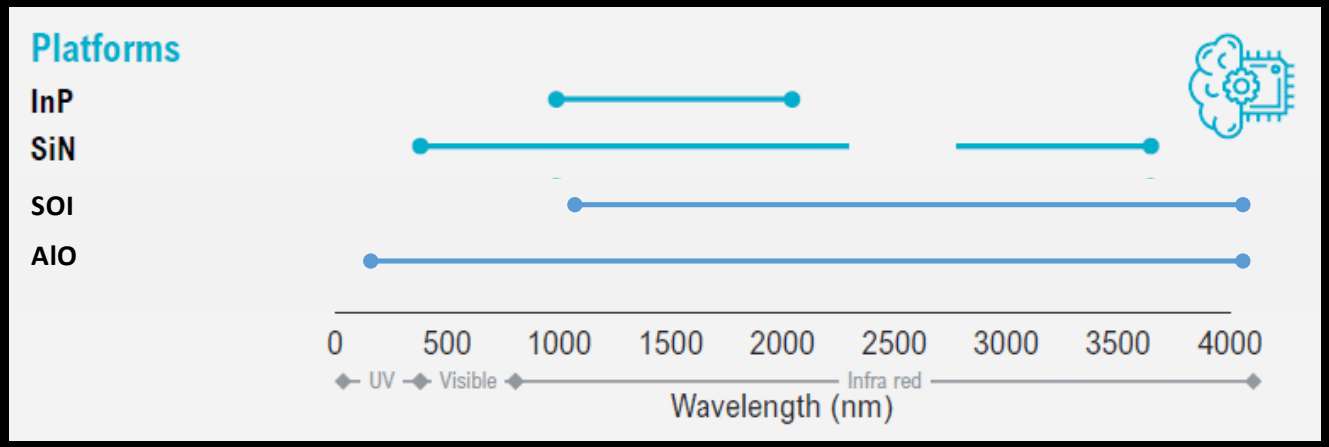

photondelta.com

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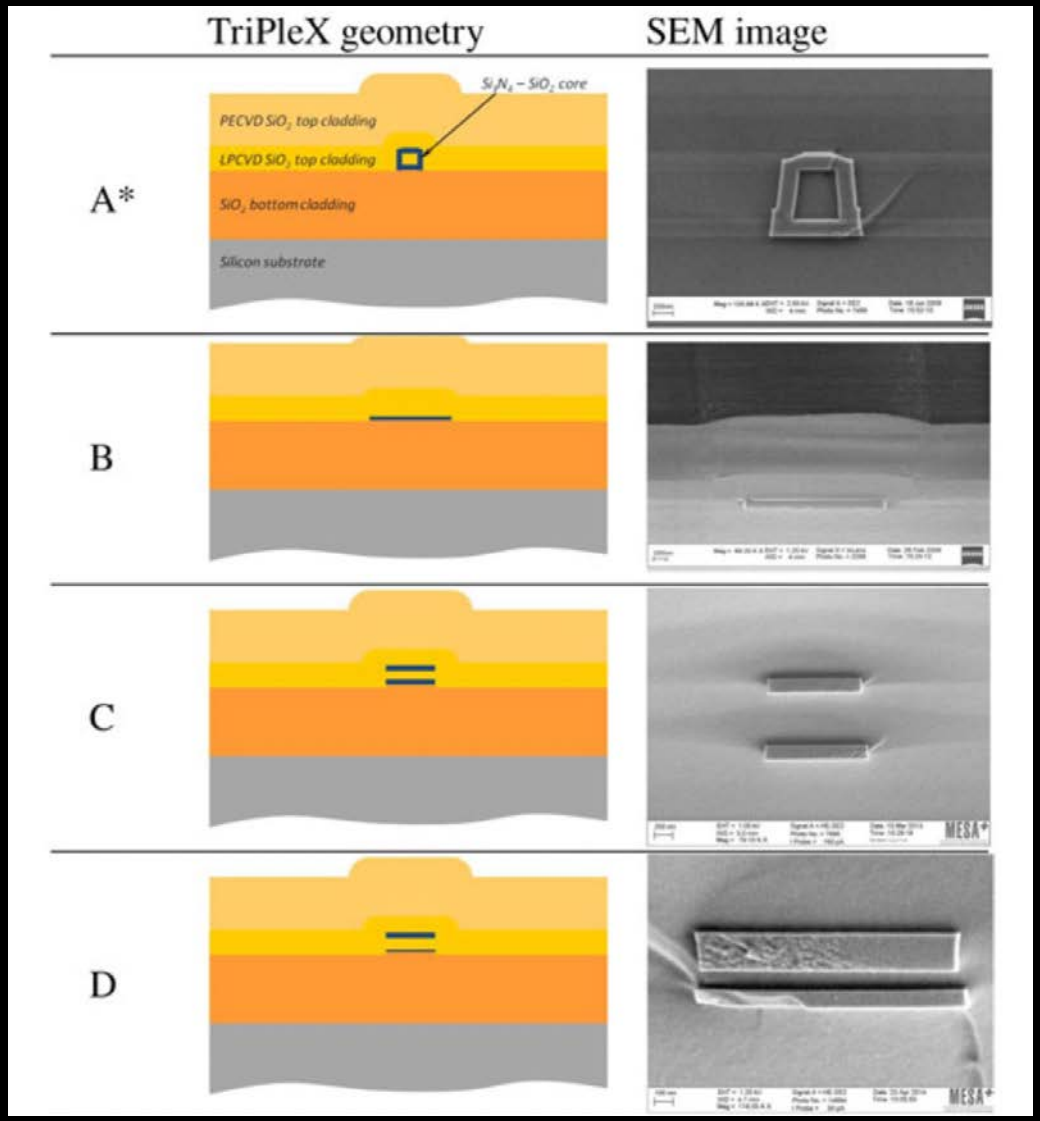
SiN Platform



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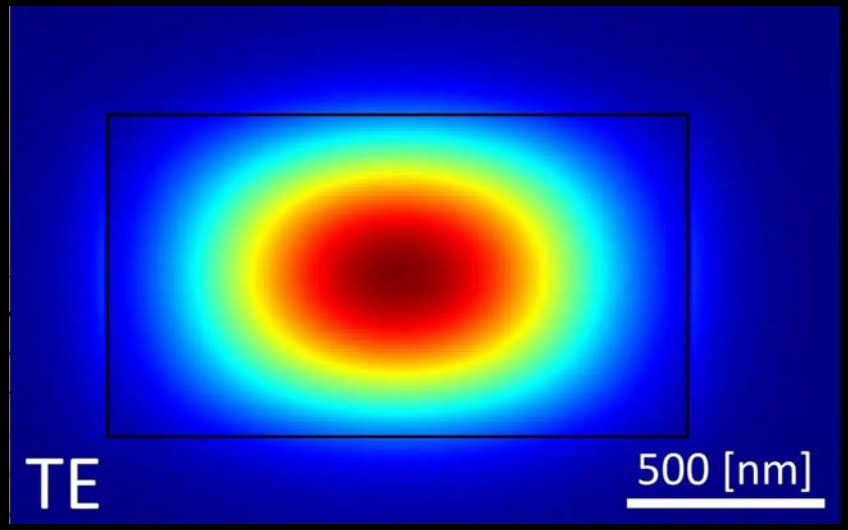
LIONIX INTERNATIONAL

Loss <1dB/m
in C-band

$n_{SiN} = 1.98$ and $n\_SiO_2 = 1.45$

Roeloffzen *et al.*, IEEE J. of Selected Topics in Quantum Electronics, **24**, 4400321 (2018)

Quant Quantum Nanotechnology Twente



Loss <1dB/m
in C-band

LIGENTEC

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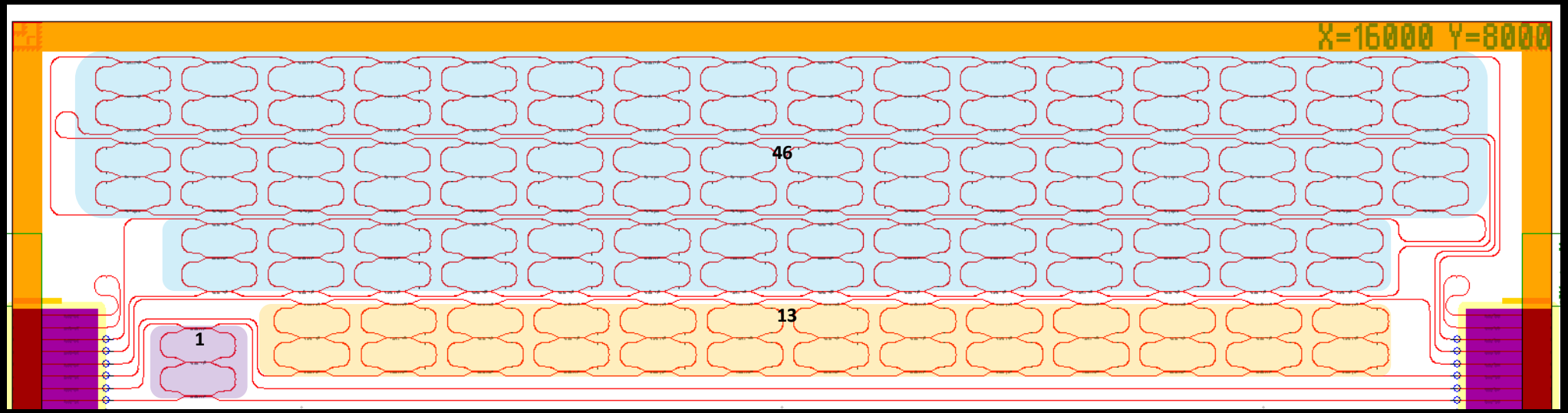
Physical-Key-based Quantum Authentication

The ring resonators are designed with different sizes

➔ Rings all have different sets of resonant frequencies



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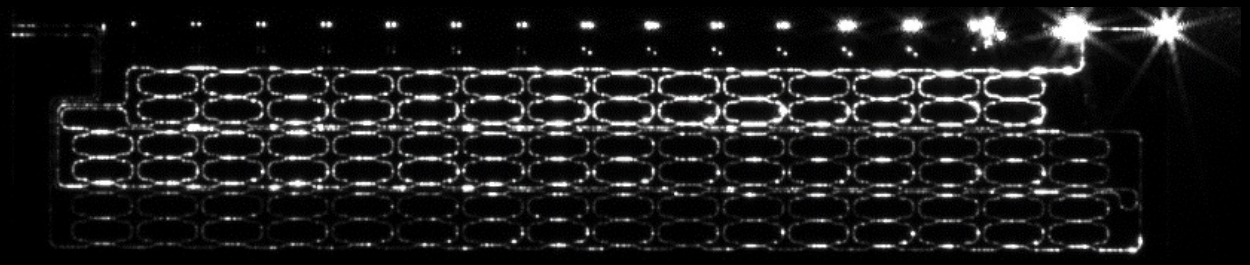
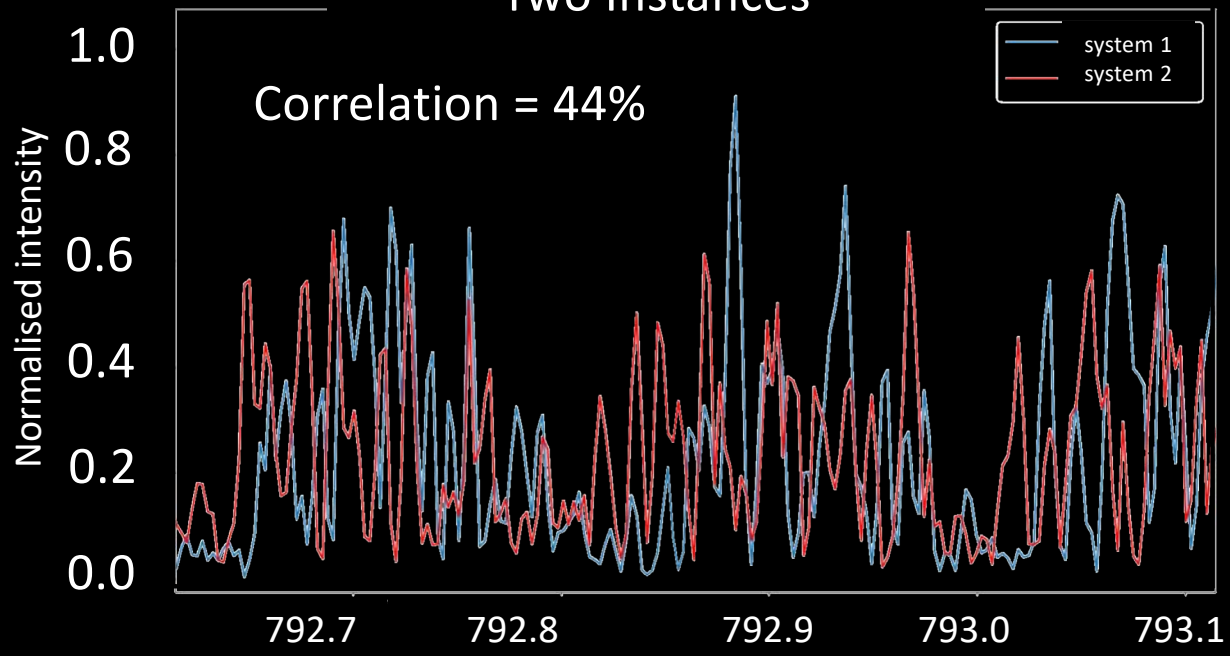


Two Instances



Open Questions:

-origin of variability?

-temperature dependence?

-stability in time?

(unpublished)

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An overview of narrow spectral-feature systems and materials.

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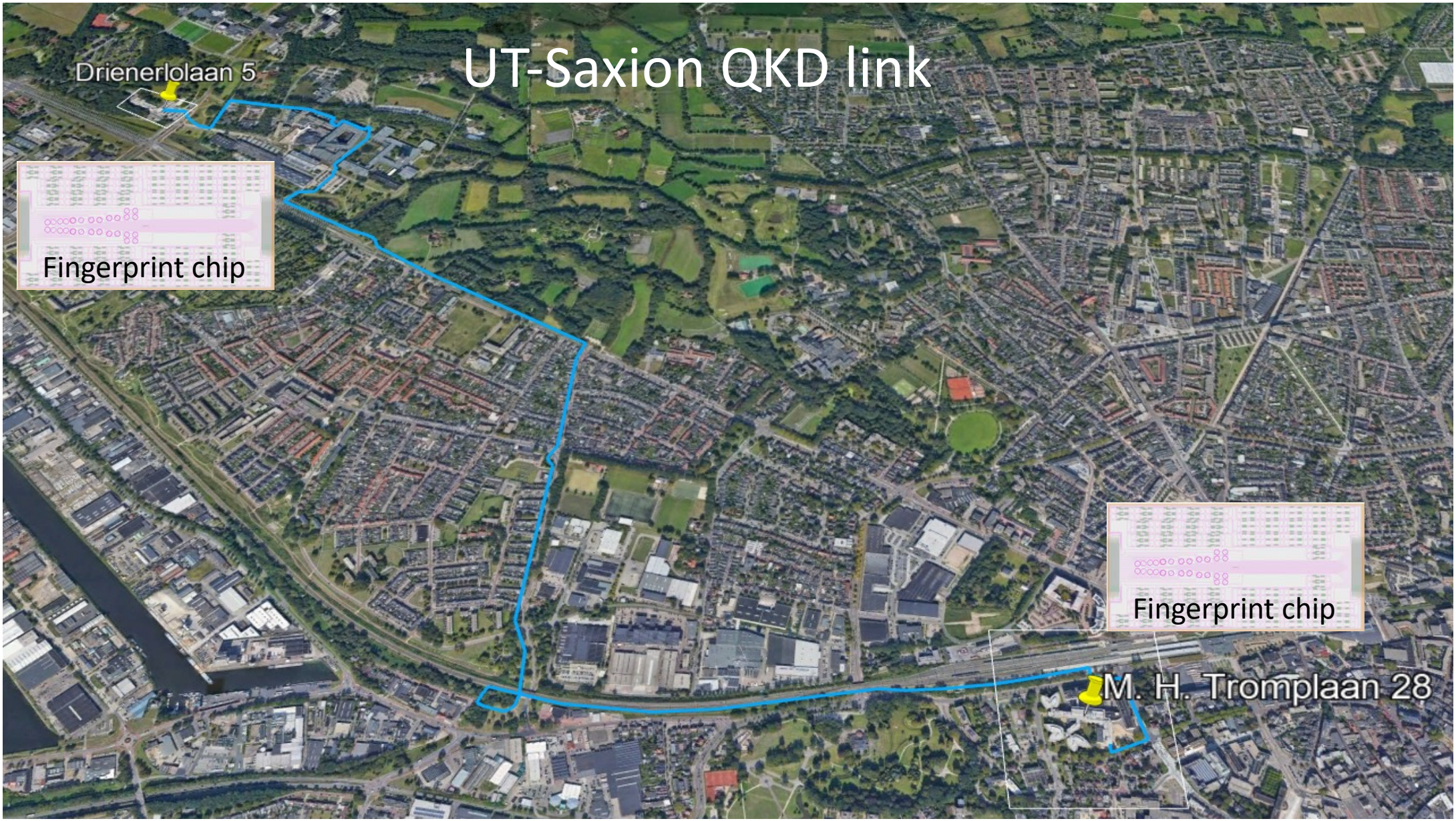
Material	Remark	Linewidth
Rhodamine 6G dye	Widely used in dye lasers	50 nm ≈ 35 THz
Rare-earth doped glass [Mac1987]	Inhomogeneous broadening	3 THz
Polymethine dyes (Organic Dye)	Relatively small homogeneous broadening	10 - 100 GHz
Narrow-band Interference filters [Fab2000]		100 GHz
Lyot filter	Using a thick birefringent material	0.05nm ≈35 GHz
Volume holographic filters [Ral1993]	Thickness limited. In this example, 8 mm	0.01nm ≈ 6 GHz
Metamaterials [Hua2023]	Relatively new development	0.01nm ≈ 6 GHz
Atomic gases	Doppler broadening	0.2 - 1 GHz
Color Centers in Diamond or Carbide	Spin transition lines used for qubit systems.	10 - 100 MHz
Ring Resonators in Photonic Integrated Circuits (PICs)	Artifical	1-100 MHz


UT-Saxion QKD link
Drienerlolaan 5
Fingerprint chip
Fingerprint chip
M. H. Tromplaan 28

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OUTLINE

Quantum Authentication

Quantum Information Processing

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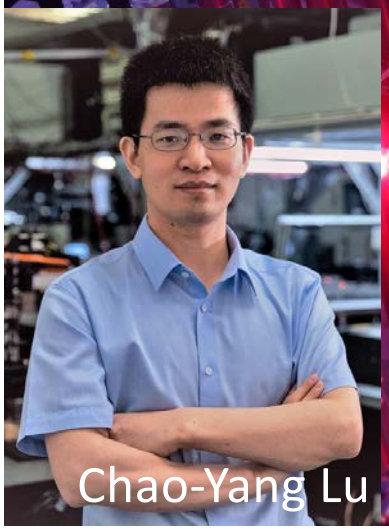
REPORT

Quantum computational advantage using photons

Han-Sen Zhong[1,2,*], Hui Wang[1,2,*], Yu-Hao Deng[1,2,*], Ming-Cheng Chen[1,2,*], Li-Chao Peng[1,2], Yi-Han Luo[1,...]

+ See all authors and affiliations

Science 18 Dec 2020:
Vol. 370, Issue 6523, pp. 1460-1463
DOI: 10.1126/science.abe8770



Chao-Yang Lu

Integrated Quantum Photonics

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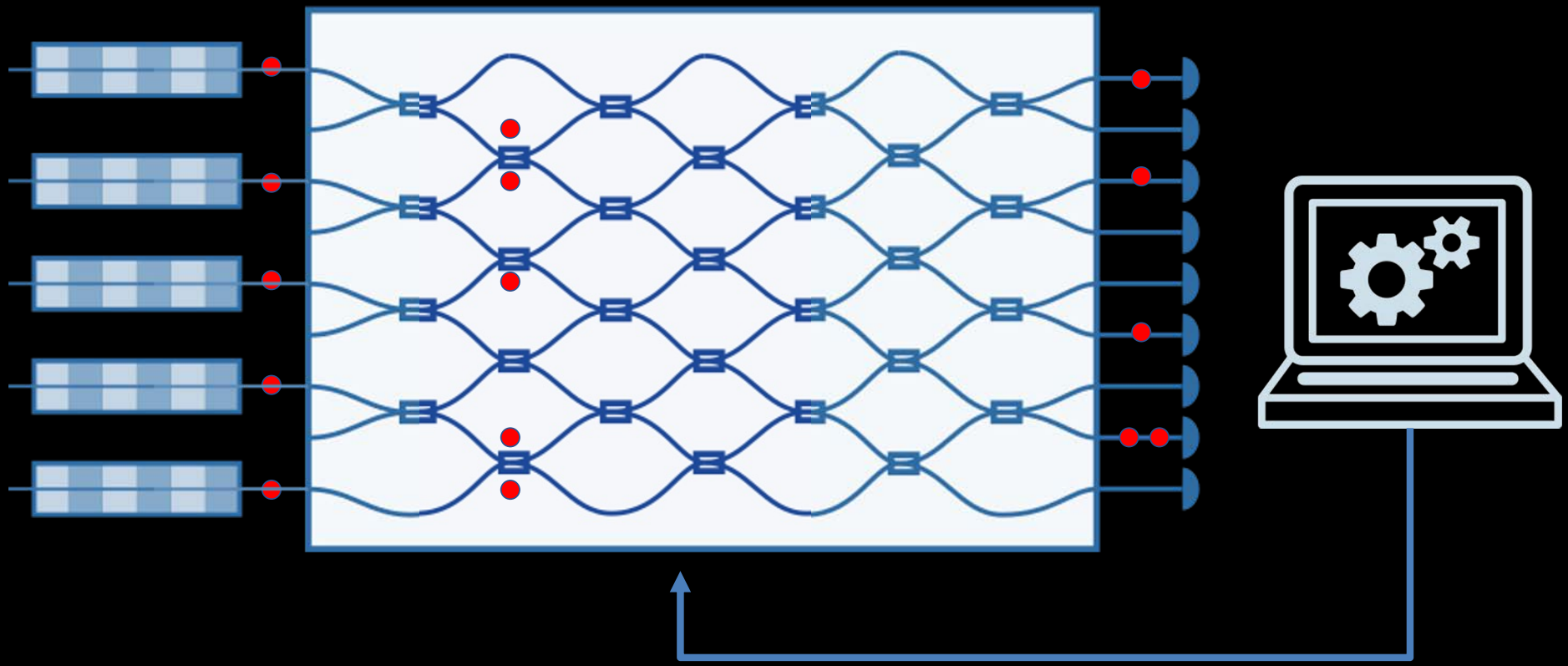
Single-photon Sources

Single-photon Detectors



Material Platform Choice

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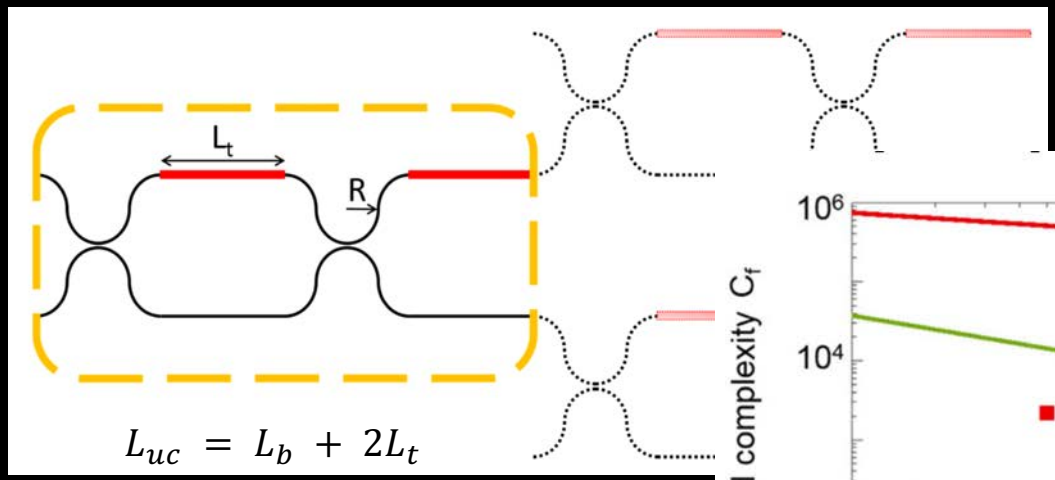
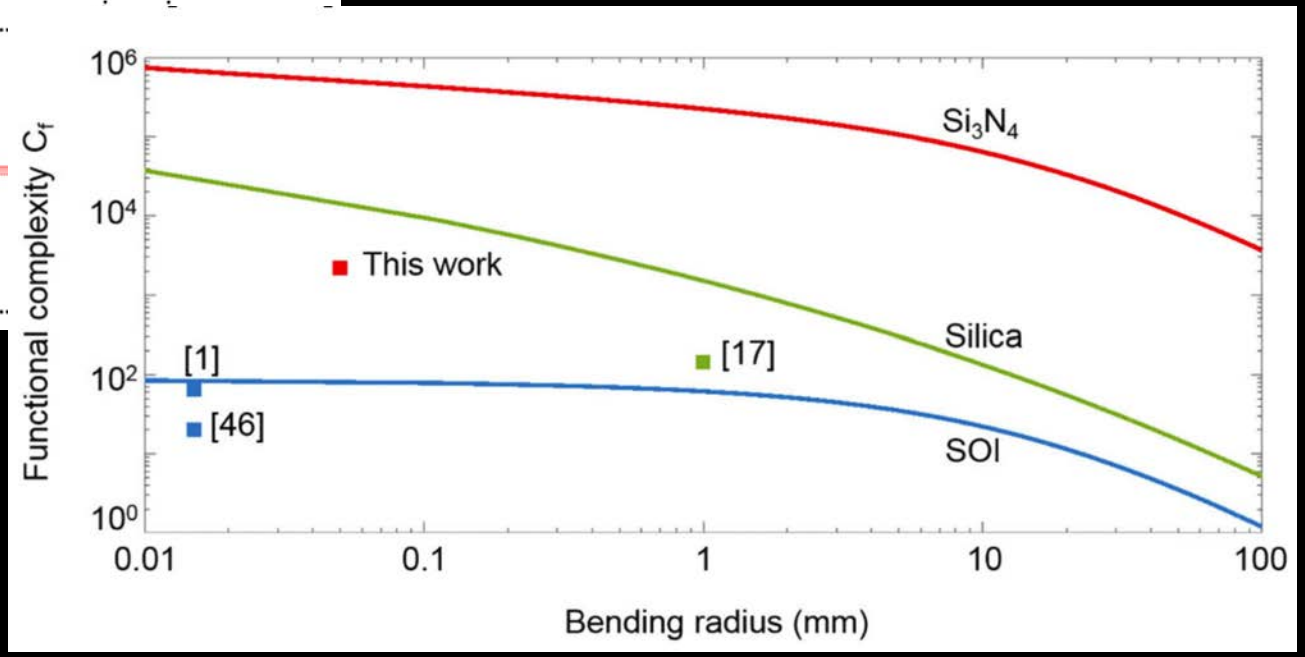


$$T_n = e^{-\frac{n \cdot \alpha \cdot L_{uc} \cdot \ln(10)}{10}} = e^{-1}$$

$$C_f = n^2 = \left(\frac{10}{\alpha \cdot L_{uc} \cdot \ln(10)}\right)^2$$



Functional complexity C_f: numer of unit cells before light is reduced by e

Taballione *et al.*, Opt. Expr. **27**, 6842 (2019)

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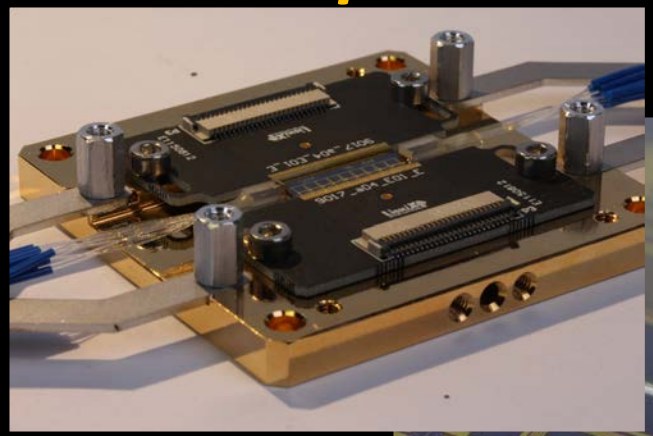
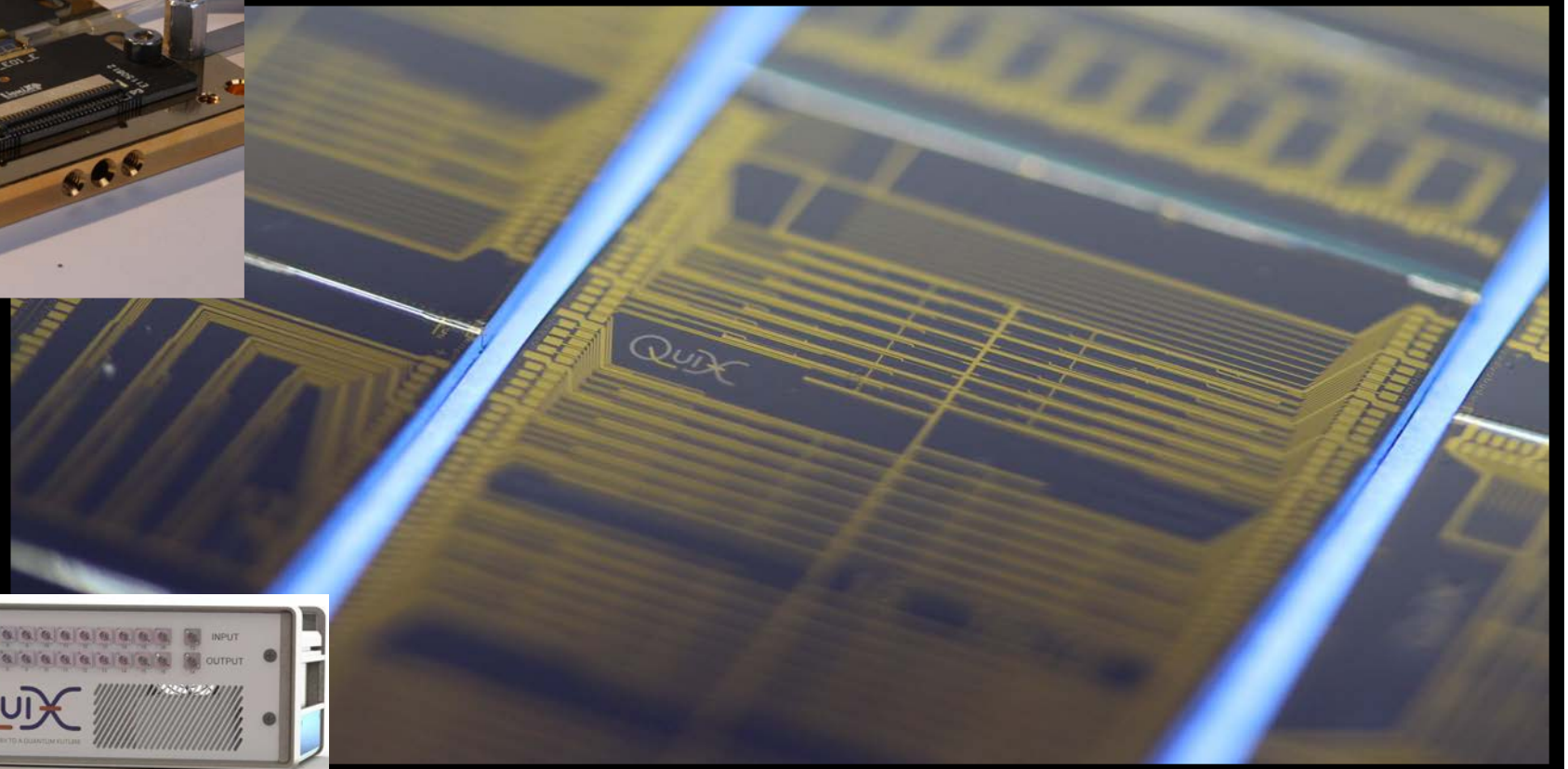
Our photonic quantum computer lab

Quant Quantum Nanotechnology Twente





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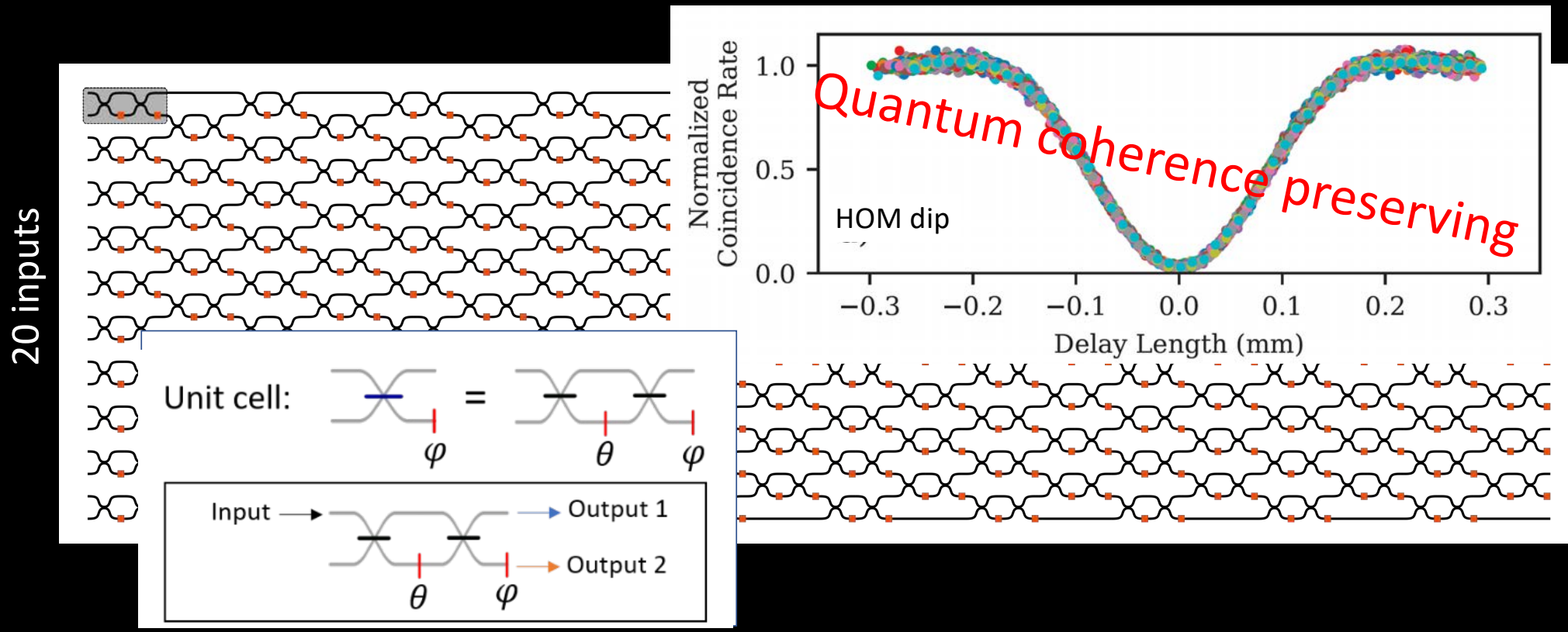
A 20-mode Universal Photonic Processor

Quant Quantum Nanotechnology Twente



20-Mode Universal Quantum Photonic Processor: Taballione *et al.*, Quantum **7**, 1071 (2023); ArXiv: 2203.01801v2

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The Twente Quantum Photonics Platform

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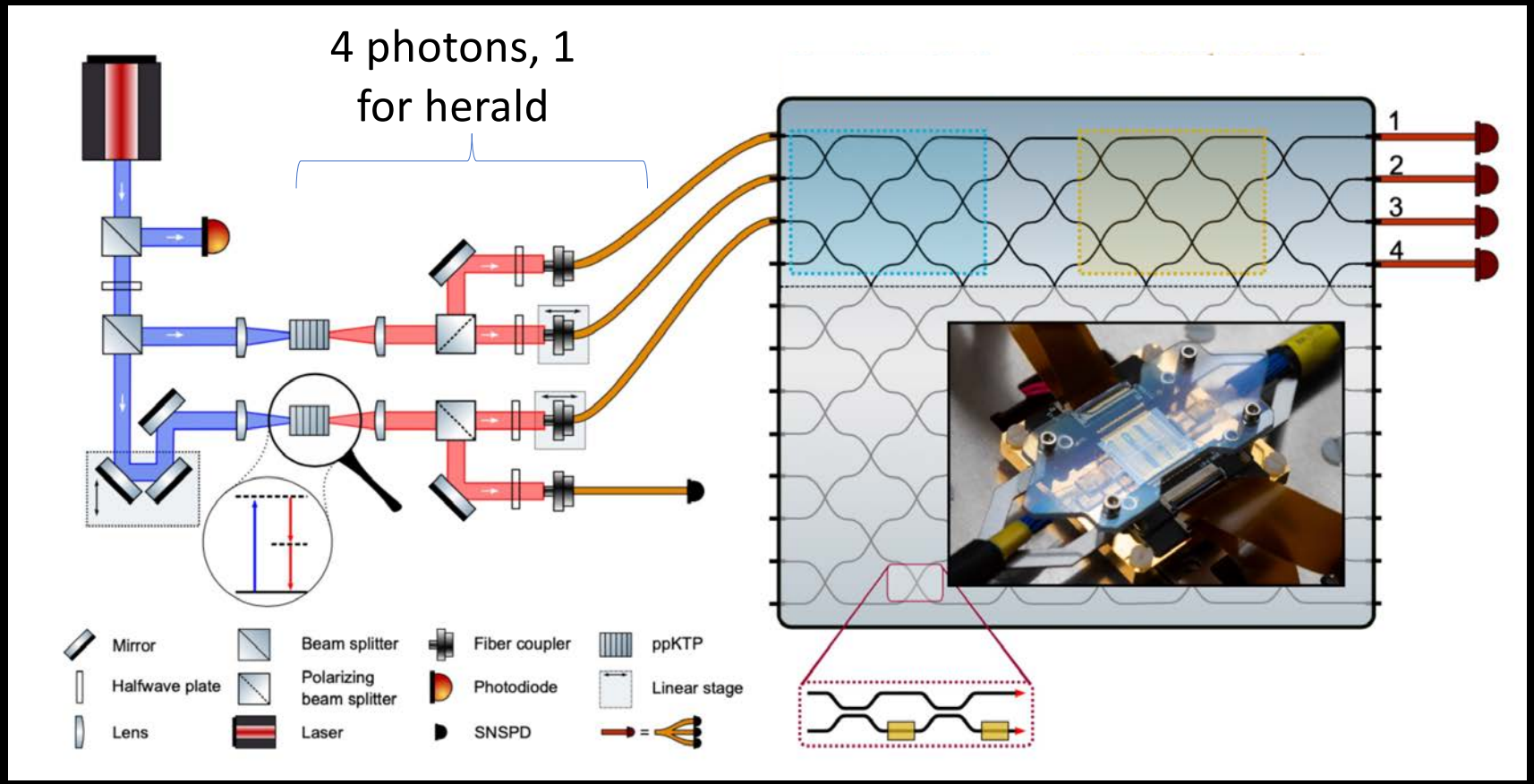
12…20 modes, universal linear optical transformations

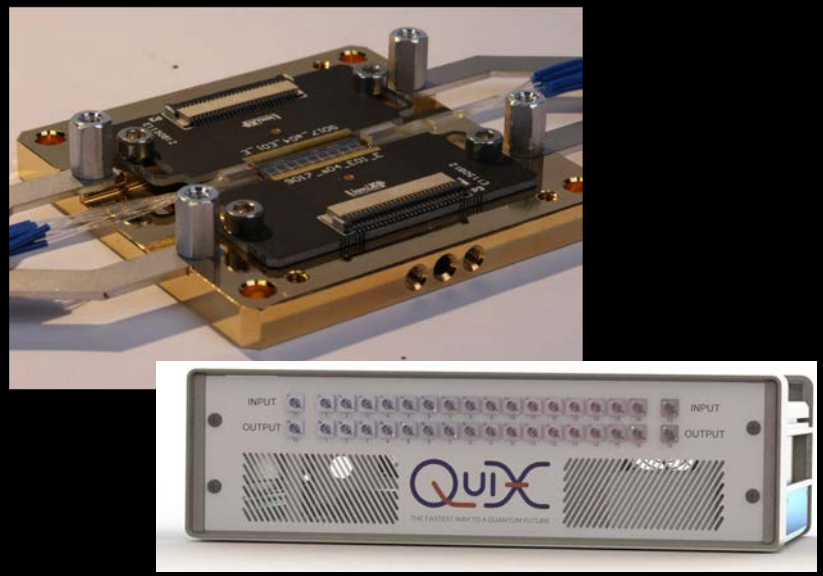


12 detectors + 1 herald

Optical Quantum Computing

Quant Quantum Nanotechnology Twente

A programmable multi-channel low-loss interferometer!



A 20-mode Universal Quantum Photonic Processor: Taballione *et al.,* Quantum (2023)

1. Quantum photo-thermodynamics (Nature Commun. 2023)
2. Entanglement witness (2112.00067)
3. Analog simulation of classical scattering (2110.04380)
4. Loop quantum gravity on a photonic chip. NPJ Q. Inf. (2023)
5. Photon Destillation (2404.14262)
6. More to come…

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Quantum Thermodynamics on a Programmable Photonic Quantum Processor

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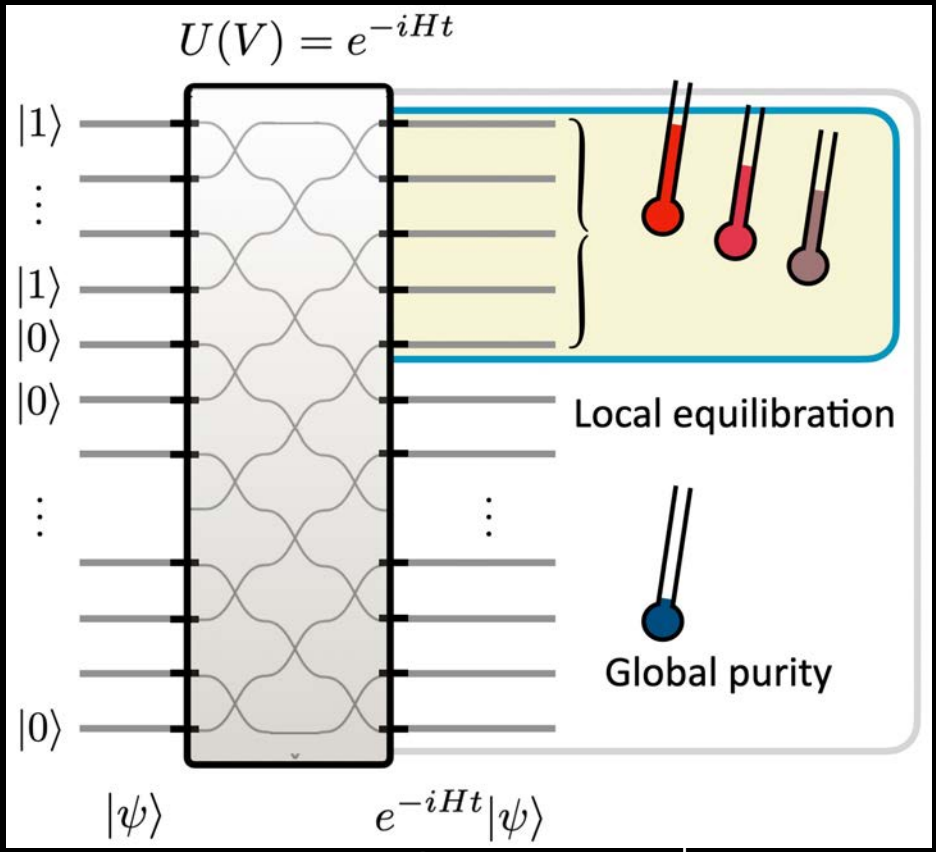
Theory: “almost all *global* quantum evolution produces *local* thermal states by entanglement [1]”

Our exp [2]



[1] S. Popescu, A. J. Short, and A. Winter, Nat. Phys. (2006)

[2] Somhorst, van der Meer, Correa Anguita *et al.*, Nature Commun. (2023), arXiv: 2201.00049

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Quantum Thermodynamics on a Programmable Photonic Quantum Processor

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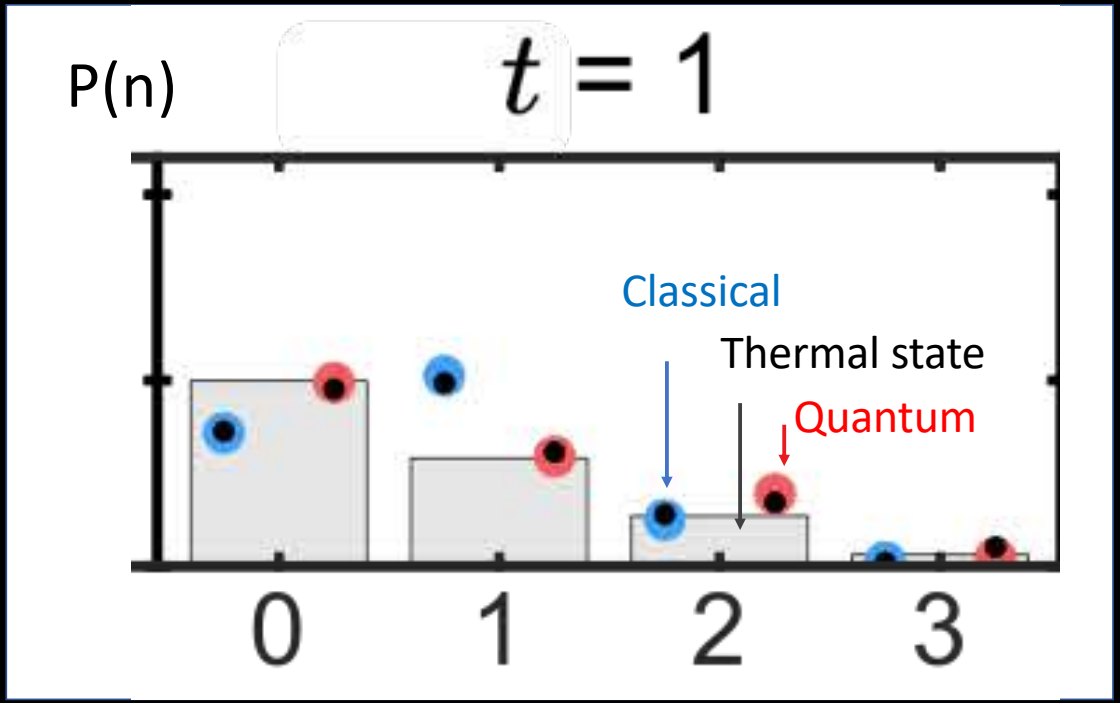
- Program out an effective Interaction (H) on the processor
- Measure single-mode photon statistics after time evolution *t*

Works! 👍



Bose-Hubbard (nearest-neighbour) interaction Hamiltonian

Somhorst, van der Meer, Correa Anguita et al., Nature Commun. 2023, arXiv: 2201.00049

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Bia

Thank you!

Main Collaborator:
Boris Skoric (TUe)

Alumni

References

Quantum-Secure Authentication & Communication: Goorden *et al.*, Optica 1 (2014); Uppu *et al.*, QST (2019); Amitonova *et al.*, Opt. Expr. (2020); Škorić *et al.*, Quant. Inf. Proces. **16**, 200 (2017)

Integrated Quantum Photonics: Taballione *et al.*, Mater. Quant. Tech. **1**, 035002 ('21); ArXiv 2110.04380, 2110.05099, 2112.00067, 2201.00049