

THE SMALL GAP BETWEEN NANO & QUANTUM

PEPIJN PINKSE HOLLAND HIGH-TECH 01 NOV 2022



http://utwente.nl/quantum







will end if the transistor is of atomic size.



Quantum Nanotechnology Twente

Nano is Quantum



True, but there's also an Inverse Moore's Law



J.N. Randall *et al.*, Micro and Nano Engineering **1**, 1 (2018)





Outline

 Quantum Authentication using Nanoscale Physical systems

 (sensitivity to nanoscale roughness makes good keys)

 Integrated (Nano) Quantum Photonics (nanoscale control of hardware needed to make good Photonic Integrated Circuits for quantum computing)







<u>Physical Unclonable Keys*</u>



- 1) Unclonable: manufacturing has *uncontrollable* aspects
- 2) Easy to evaluate (a lock!)
- \Rightarrow Properties can be made public;



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It can still not be copied!



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* in cryptography also known as PUFs

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

Quantum Readout of Hardware Keys (PUFs)



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

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Quantum

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Quant

Cloning an Optical PUF?



- Need to implement $\sim 10^6$ elements in 30 μ m³
- 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)

DLW describes a \sim 100 nm precision fabrication method, exploiting two-photon polymerization











Deterministic Scattering Media





Electron microscope image



model

Scaling up is still difficult (cracks, distortion...)

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







Pulse shaping to temporally focus through a medium that distorts temporal wavefronts.



Physical-Key-based Quantum Authentication





Measured Spectra 46 Cells





Variation on nano scale leads to unique fingerprint of chip keys

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(unpublished)



Photonic Quantum Computing



Integrated Quantum Photonics



Dec 2020: Photonic Quantum Advantage demonstrated



Photonics only second after superconducting transmons (Google)

Quantum computational advantage using photons Han-Sen Zhong *et al.*, Science **370**, 1460 (2020)



Integrated Quantum Photonics

Single-photon Sources



Single-photon Detectors



(Superconducting nanowires)



Quantum Dots, Nanodiamonds, Single ions, Single atoms

Our Photonic Quantum Computer Lab & Uant Ruantum Nanotechnology Twente







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Value chain: LioniX Int \rightarrow QuiX (Fab-less) \rightarrow UT/other users

Optical Quantum Computing



Science with a programmable multichannel low-loss interferometer

Quantum photo-thermodynamics (ArXiv 2201.00049)



A 20-mode Universal Quantum Photonic Processor: Taballione et al., ArXiv: 2203.01801 (2022)

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Quantum Photo-Thermodynamics



A system in contact with a bath tends to evolve to a thermal state



After sufficiently long time



Quantum Photo-Thermodynamics - Intro

Pure Quantum State



How is this possible?

Quantum mechanics is a purity-andinformation-preserving theory

> Short answer: Entanglement

(Nobel prize 2022!)













Prepare 3 indistinguishable photons





Program out an effective interaction







Measure **single-mode** statistics after taking samples







Measure single-mode statistics after time 'snapshot' τ









Prepare 3 distinguishable photons





Quantum Thermodynamics on a **WUant** Programmable Photonic Quantum Processor

Measure single-mode photon statistics after time evolution *t*





Bose-Hubbard (nearest-neighbour) interaction Hamiltonian

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



Nanotechnology

Summary

Nanotech is essential for quantumtech!

Twente the place to be in NL for Optical Quantum Nanotechnology

References

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

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



Thanks to















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Neighbouring countries are also investing!

September 23, 2022

QuiX Quantum wins €14 million contract with the German Aerospace Center to delivera Universal Quantum Computer

Homepage - QuiX Quantum wins €14 million contract with the German Aerospace Center to deliver a Universal Quantum Computer

https://www.quixquantum.com/news/quix-quantum-winseu14-million-contract-with-the-german-aerospace-center-todeliver-a-universal-quantum-computer

