Standardisation for chip, board and system-level quantum interconnect

Dr Richard Pitwon

Chair Chair IEC TC 86/SC 86B & StandICT.eu 2023 Fellow

CEO Resolute Photonics

9th Stand ICT Walk and Talk

EU Standardisation Priorities - Quantum Technologies

13th October 2022

RESOLUTE PHOTONICS

Why do we need standards?

Standardisation can accelerate commercial adoption of emerging technologies by establishing commonly agreed frameworks, terminologies, design guidelines and performance benchmarks by which to apply the technology.
Crucially it also ensures interoperability

Standardisation Readiness Level (SRL)

Gauges how useful standardisation will be in the course of technology development
SRL determined by technological **and** social needs
Example: For QKD SRL is relatively high, because the social need is strong

Credit: Barbara Goldstein, NIST

Standardisation readiness and activity

SRL 1	SRL 2,3	SRL 4,5	SRL 6,7,8,9	Beyond TRLs
Basic Research	Feasibility Research	Prototype Development	Mature Technology	Market Established

Quantum memory
Quantum repeaters
Quantum computers
Quantum networks

Randomness generation
Single photon sources and detectors
Quantum sensors
Post quantum encryption algorithms

Quantum Key Distribution
Quantum annealers

Technologies ⇅ Standards

Terminology
IEEE P7130
ISO / IEC JTC1 WG14

Architectures
IETF/IRTF QIRG
ITU-T

Software languages

Benchmarks
QED-C prototypes

Measurement protocols

Use cases
IETF/IRTF QIRG

Software algorithms
NIST post-quantum crypto

Guidelines, best practices

Physical standards
NIST, NRC, NPL, etc

Interoperability
IEEE 1913 NETCONF/YANG
IEC TC86 – cables, fibres
ITU-T

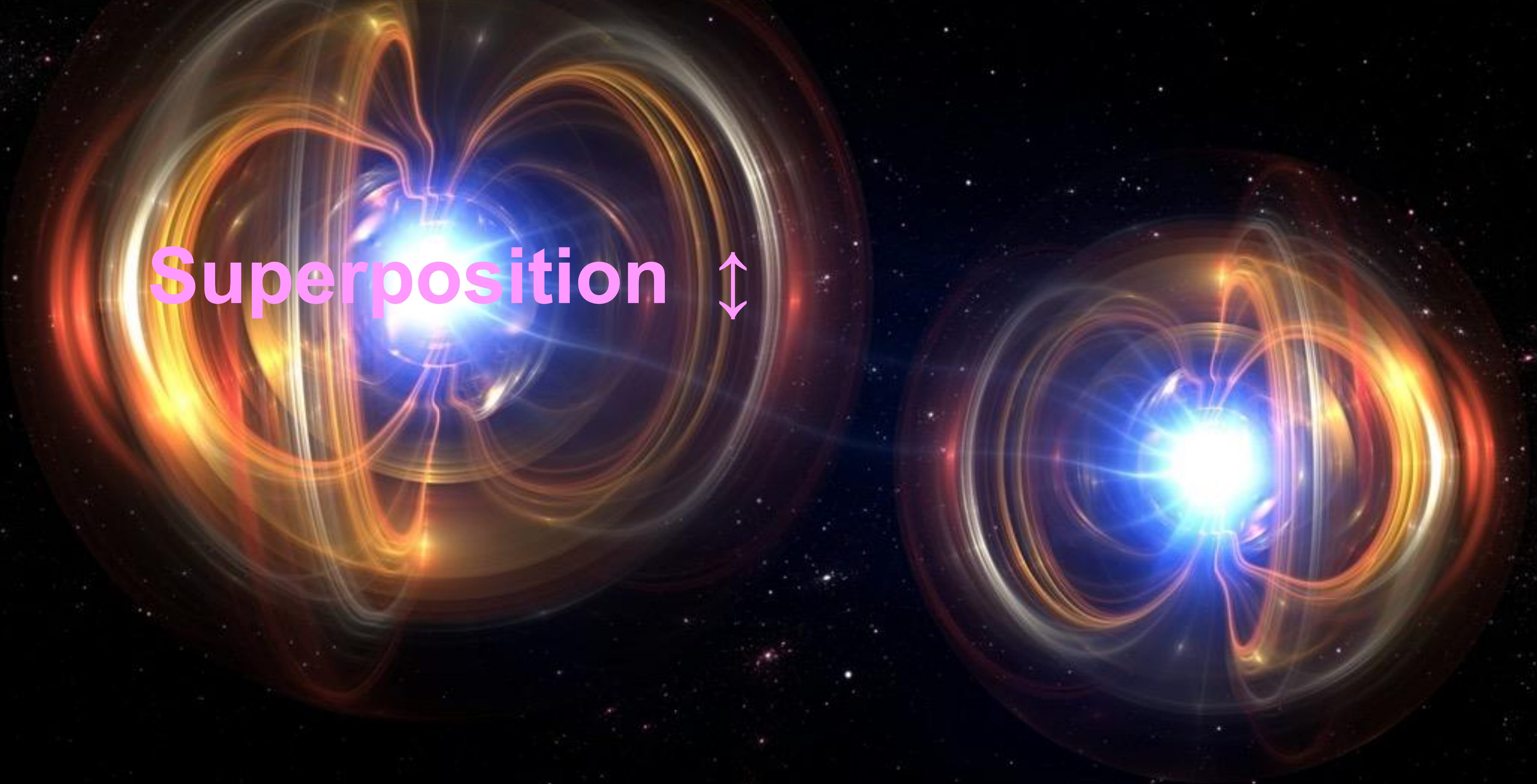
Certification / test protocols
ETSI QKD
ISO / IEC JTC1 SC25 QKD

Procurement

Regulatory standards

Credit: Barbara Goldstein, NIST

Moving hyperscale into the quantum realm



Quantum Computers

High performance computers increasingly complemented with **Quantum Computer** nodes

Advanced computing

Artificial Intelligence
Neural networks (neuromorphic)
World-scale simulation

Future hyperscale data centres and exascale computers may increasingly incorporate quantum computer and communication nodes to complement their capabilities including for example the provision of "**Quantum As A Service**".

These quantum nodes will be interconnected by special quantum networks

Quantum Communication

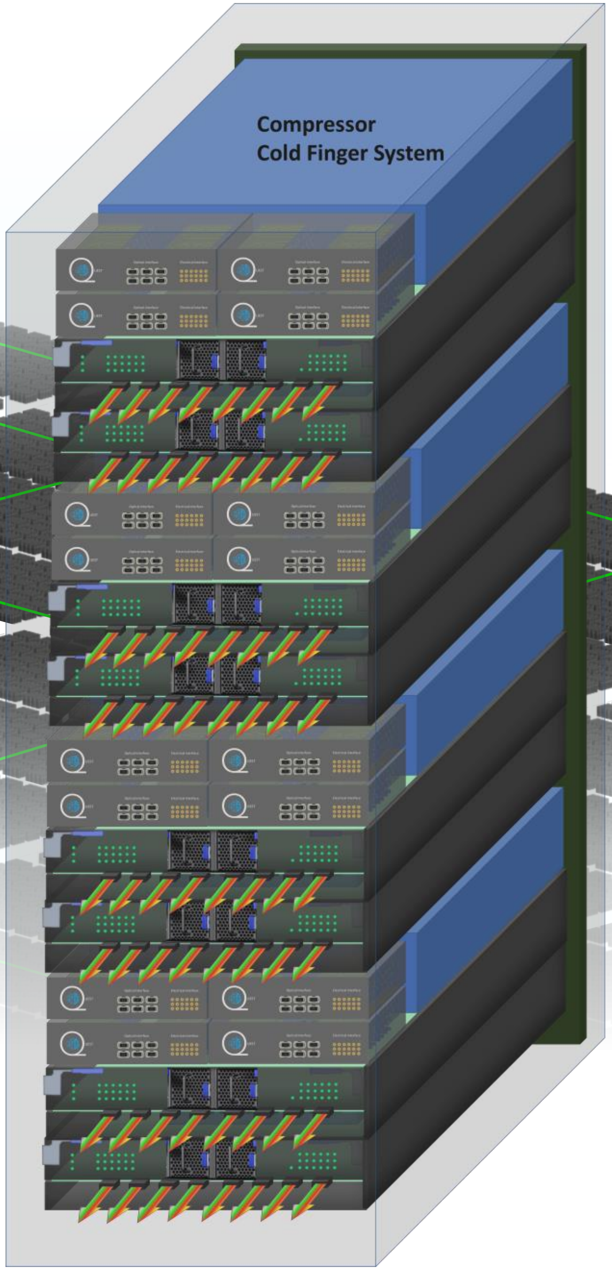
Quantum Key Distribution uses the principles of quantum superposition and entanglement to determine if data has been transferred securely

Security

Unhackable databases and smart contracting using **Blockchain** servers.
Required for Medical, Financial, Cryptocurrencies

Quantum Computers

High performance computers increasingly complemented with **Quantum Computer** nodes



Quantum Communication

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Quantum Computers

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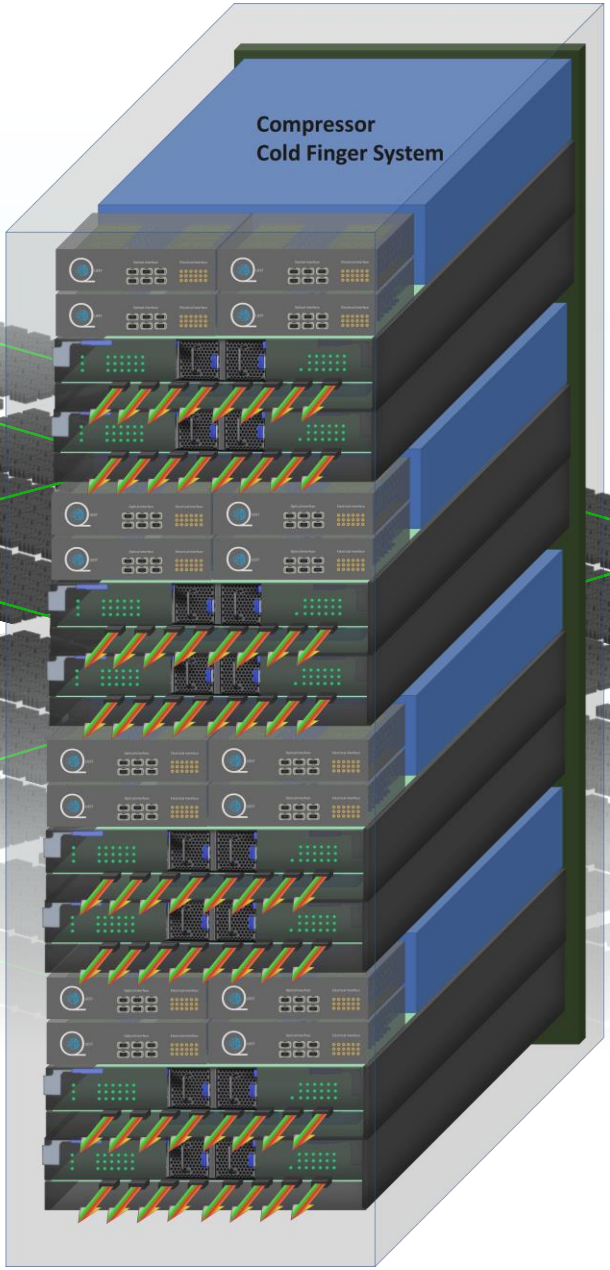


Quantum Communication

Quantum Key Distribution uses the principles of quantum superposition and entanglement to determine if data has been transferred securely

Overview on global quantum standards activities

ISO/IEC JTC1
SC7 formed SG1 to investigate quantum standards
SC27 focusses on security and privacy in ICT systems
WG14 Quantum Computing

ITU -T
SG 17 – Quantum security
SG 13 – QKD
FG-QIT4N – Quantum information technology for networks

IEEE
P7130 Standards for QC Definitions
P1913 for Software Quantum Communications
P7131 for QC performance metrics & Performance Benchmarking

IEC SMB/SWG 10
WP on Quantum Information Technologies

ETSI
ISG QKD – Quantum key distribution
TC Cyber WG QSC – Quantum Safe Cryptography

CEN / CENELEC
FGQT – Focus Group on Quantum Technologies

Organisations developing quantum standards

ISO
ITU
IEEE
IEC
ETSI
cen CENELEC
QED·C
IMEKO International Measurement Confederation
Technical Committee TC25 Quantum Measurement and Quantum Information
QUANTUM INDUSTRY CONSORTIUM
bsi.
UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME
IRTF
GSMA

StandICT Fellowships

Three fellowship series on different aspects of quantum standardisation

- Cross-SDO Harmonisation for Future Quantum Networks
- Standards Development for Quantum Physical Layer
- Standards for Quantum Photonic Integrated Circuits

Introducing quantum interconnect into mainstream fibre optics standards

About BSI - British Standards Institute

BSI has a presence on every continent, with 87 offices in 31 countries across the world. Our clients range from globally recognized brands to small, local businesses.

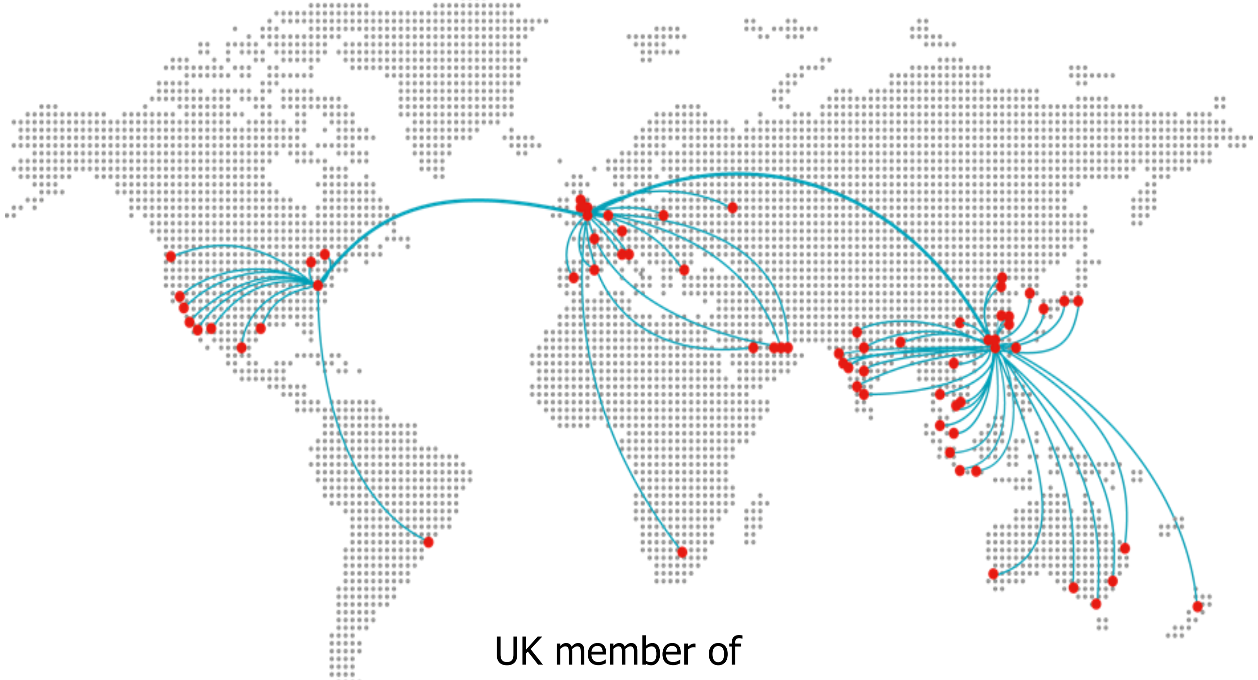
By Royal Charter

- **Knowledge Solutions**
- **Assurance**
- **Regulatory services**
- **Consulting**

Formed in 1901, BSI was the world's first National Standards Body. We were responsible for originating many of the world's most commonly used management standards and publish over 2,700 standards annually.

84,000 Clients in...

93 Countries



UK member of

ISO, CEN, CENELEC, IEC, ETSI

BSI Quantum Technology Panel

The BSI, with support from NPL, has launched a new panel to bring together interested parties from across the UK quantum technology landscape.

BSI designation: ICT/1/1/2 - Quantum Technology Panel

Chair: Tony Holland (tony.holland@uk.ibm.com)
Co-chair: Emelie Bratt (Emelie.Bratt@bsigroup.com)

Start: July 2021

Purpose:

- **Over 60 members** - UK stake-holders and experts on quantum technologies including **industry (SMEs)**, **research** and **UK government** (NPL / DCMS / BEIS / GCHQ)
- **Purpose:** help develop international standards documents spanning detailed specifications on bespoke topics to larger foundational work across technologies.
- **Coordinate** with ISO and IEC
- www.bsigroup.com/en-GB/industries-and-sectors/quantum-technology

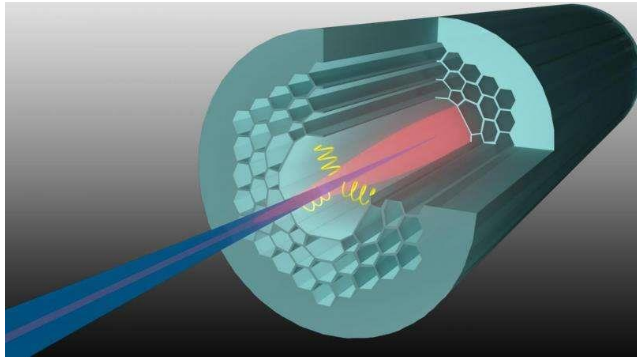
International standards for fibre-optic interconnect

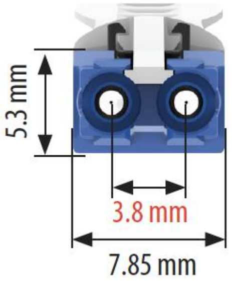
Technical Committee 86 – Fibre Optics

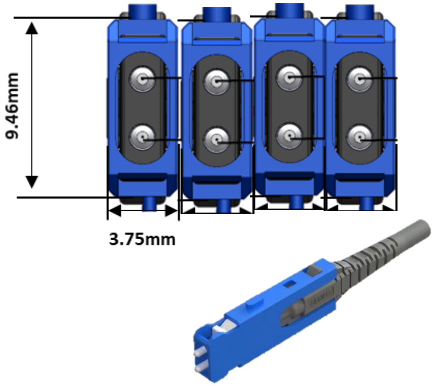
SC86A
<u>Fibres and cables</u>
Optical fibres and optical cables embracing all types of communications applications. Established and next generation

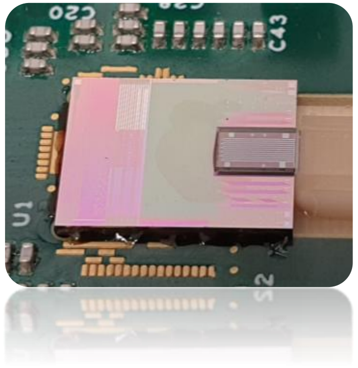
SC86B
<u>Fibre optic interconnecting devices and passive components</u>
Fibre optic interconnecting devices and passive components, embracing all types of communications applications.

SC86C
<u>Fibre optic systems and active devices</u>
Standards for fibre optic systems and active devices embracing all types of communications and sensor applications including Photonic Integrated Circuits









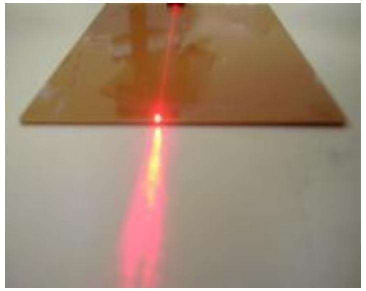
Joint Working Group 9
Optical functionality for electronic assemblies

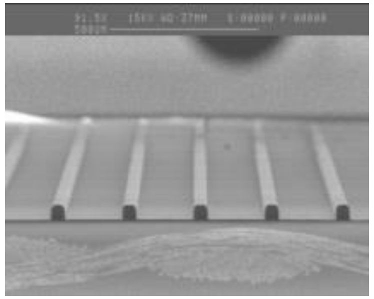
Scope

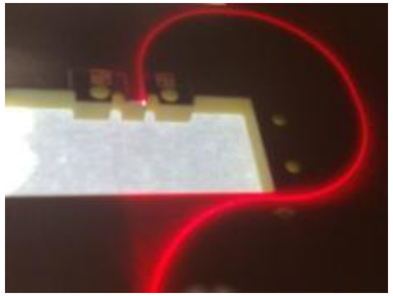
To prepare international standards and specifications for optical circuit boards and optical back planes, intended for use with opto-electronic assemblies. Other devices intended for use with optoelectronic assemblies such as fibre optic connectors, passive optical devices, active devices, dynamic devices, etc., are directly standardized at the existing WGs in TC86.

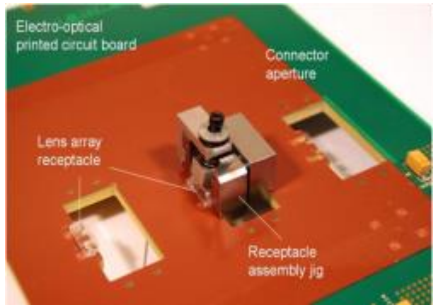
Chair: Hideo Itoh

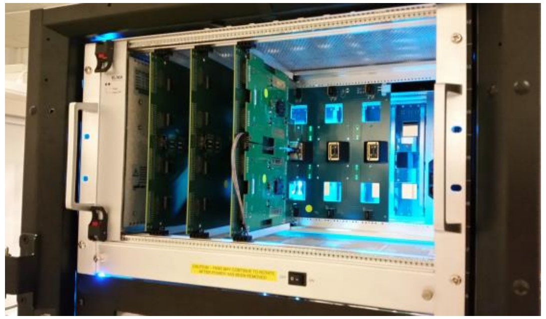
Secretary: Richard Pitwon







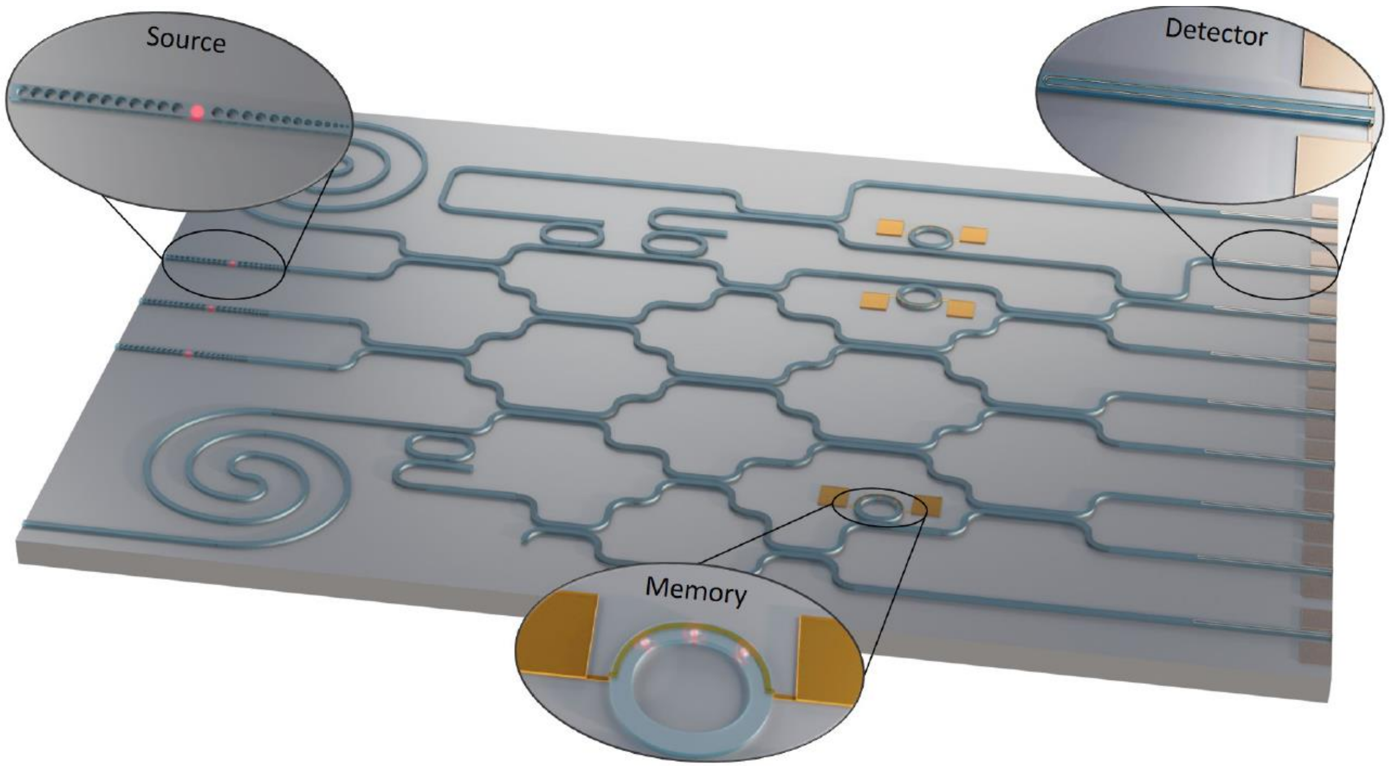




IEC Technical Report Introduction to Quantum Technologies

IEC TR 6xxxx – Introduction to Quantum Technologies

Over the fellowships there has been substantial effort in promoting quantum interconnect in IEC TC86. This Technical Report under preparation in JWG9 will lay the foundation for quantum interconnect standards in TC86



Formation of IEEE UK and Ireland Quantum Group

UK and Ireland Quantum Group formed in 2021 to leverage UK's current world-leading position in quantum technologies

This group engages with UK quantum hubs and universities to promote and support **quantum engineering** as a new engineering discipline.

Please contact chair **Richard Pitwon** for further information

Cross-SDO symposia on quantum standards

During 2021 and 2022, a series of symposia were organised, which were jointly hosted by the major international standards bodies.

- **ITU/IEC/ISO/IEEE Joint Symposium on Standards for Quantum Technologies** on 23rd March 2021
- **ITU/IEC/ISO/IEEE Joint Symposium on Quantum Transport** on 28th April 2021
- **ITU/IEC/ISO/IEEE/ETSI Joint Symposium on Harmonisation of Terminology in Standards for Quantum Technology** on 23rd June 2021
- **ITU/IEC/IEEE Joint Symposium on Quantum Photonic Integrated Circuits** on 5th November 2021
- **IEC/ISO/CEN/CENELEC/BSI/IEEE Joint Symposium on Quantum Interconnect and Metrology** on 24th March 2022
- **IEC/BSI/ISO/IEEE/CEN/CENELEC Joint Symposium on Quantum Technologies** at NPL on 13th and 14th September 2022

SDO experts were brought together to discuss where standardisation would be most useful for quantum technologies.

NPL

NPL Joint Symposium on Quantum Technologies

13th – 14th September 2022

NPL, Teddington, UK

IEC ISO cen CENELEC bsi. IEEE QUANTUM United Kingdom & Ireland IEEE Photonics Society UK & Ireland chapter

Joint Symposium on Quantum Technologies

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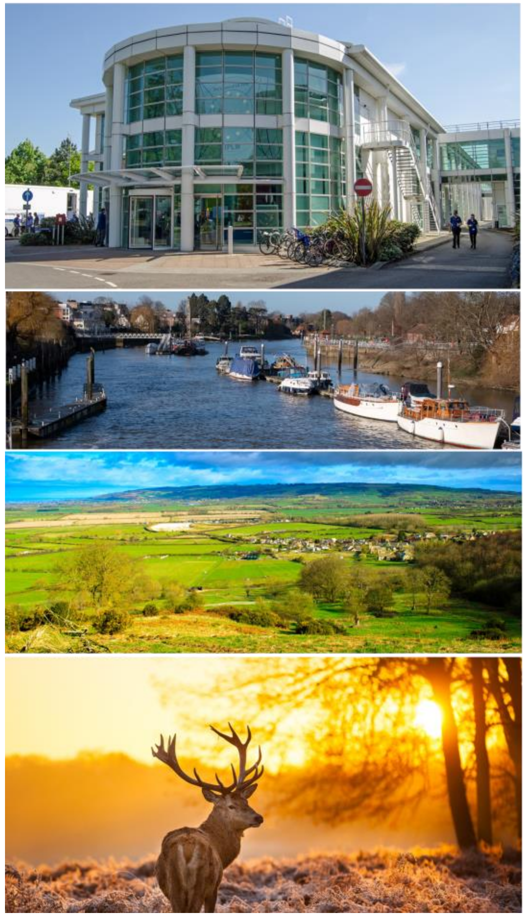


NPL National Physical Laboratory

RESOLUTE PHOTONICS

SENKO® Advanced Components

Joint Symposium on Quantum Technologies

13th and 14th September 2022

Key findings of cross-SDO symposia

Quantum grade optical interconnect

In the short term the most useful standards would be standards for low loss optical interconnect to better allow delicate quantum states, qubits, in the form of single or entangled photons, to be conveyed over longer distances with a lower chance of decoherence and disruption.

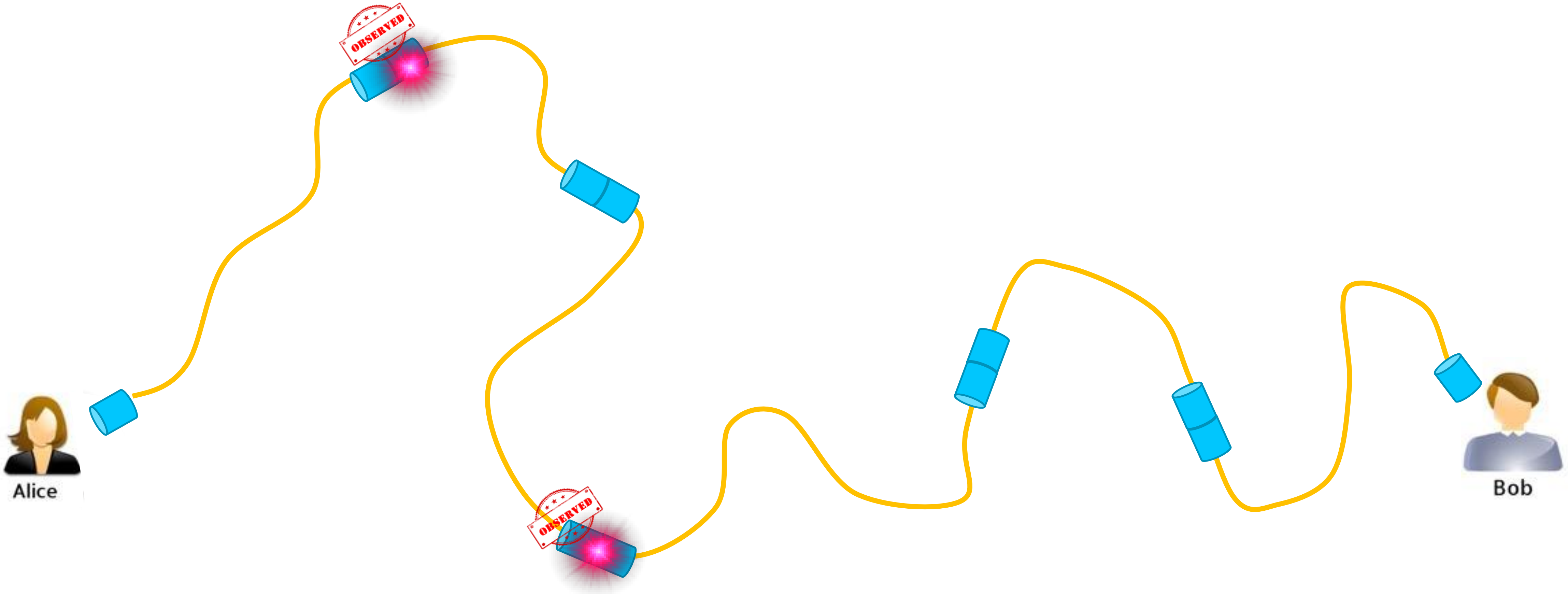
This means ultra low loss:

- Optical connectors
- Fibres and
- WDM components

Collaboration with

Key findings of cross-SDO symposia

Quantum grade optical interconnect

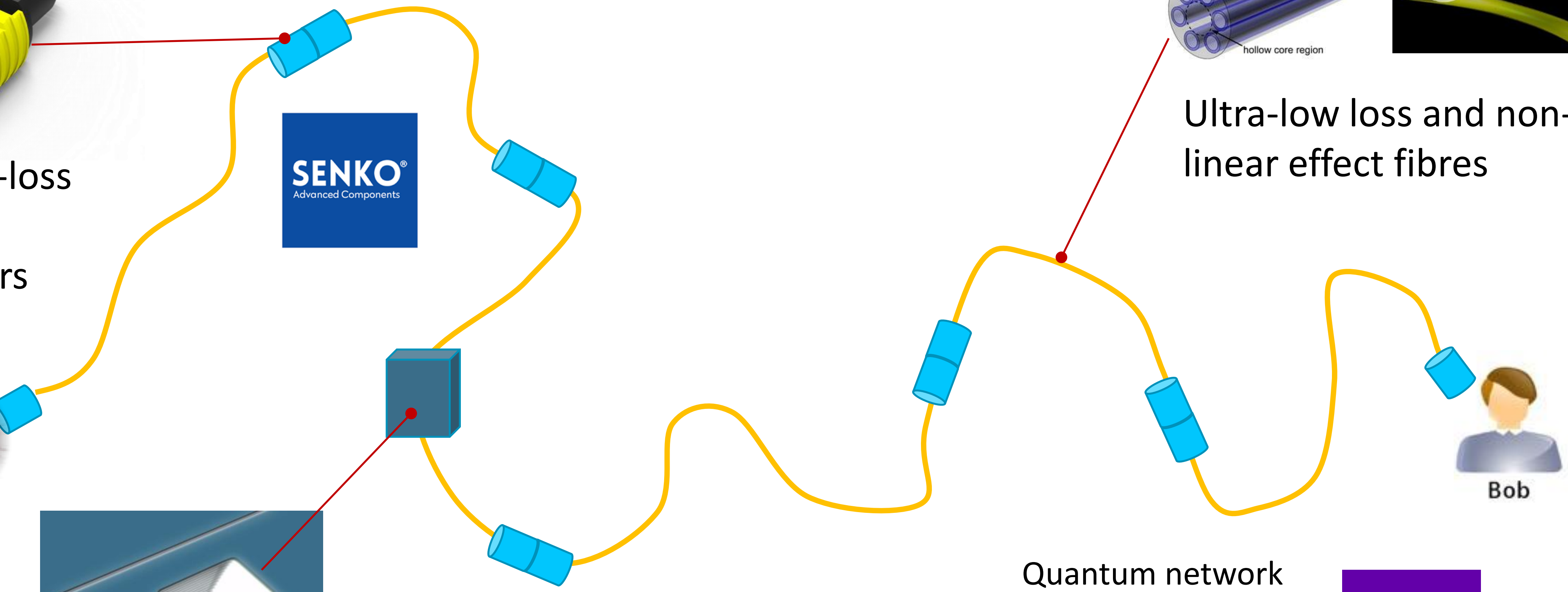


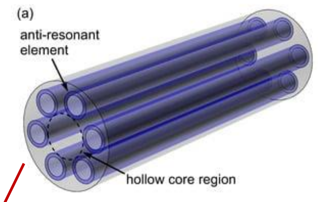
Extremely **low loss** and extremely **low reflectance**

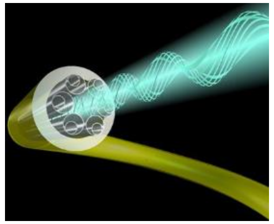
Key findings of cross-SDO symposia

Quantum grade optical interconnect

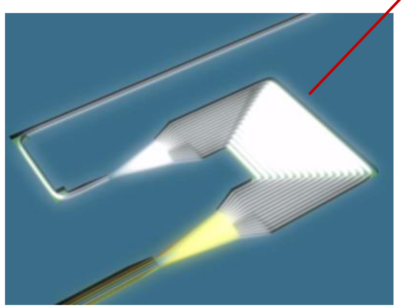
Ultra low-loss optical connectors







Ultra-low loss and non-linear effect fibres



High isolation WDM routers

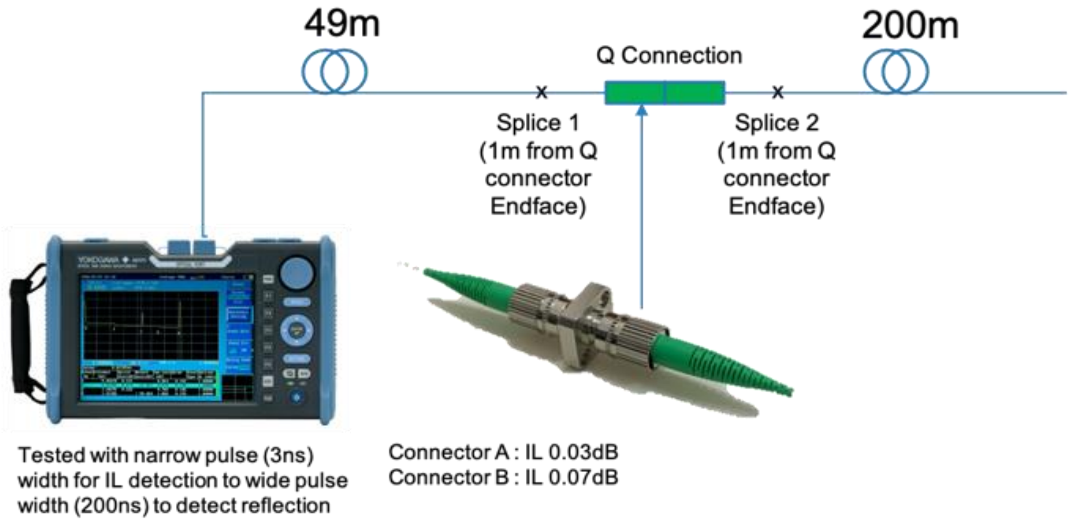
Quantum network infrastructure

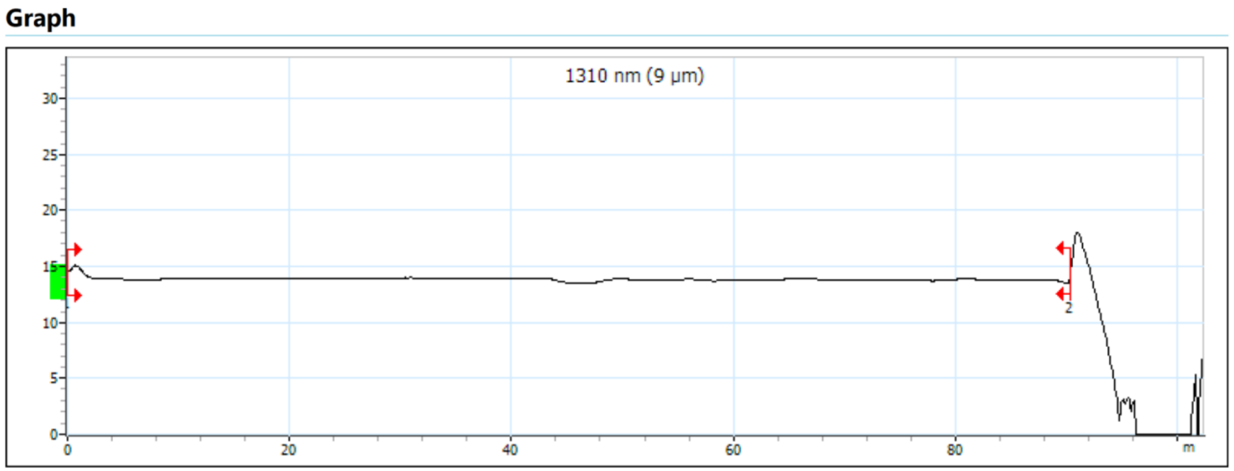
Key findings of cross-SDO symposia

Quantum grade optical interconnect

In the short term the most useful standards would be standards for low loss optical interconnect to better allow delicate quantum states, qubits, in the form of single or entangled photons, to be conveyed over longer distances with a lower chance of decoherence and disruption.

SPIE 11881-9: The evolution of optical interconnect technology: from long-haul telecommunication to quantum networks





Key findings of cross-SDO symposia

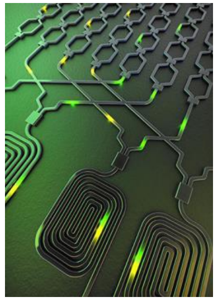
Quantum computing

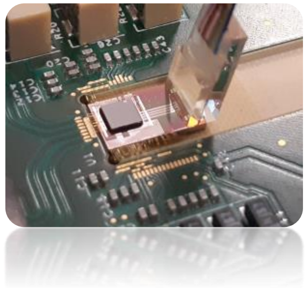
- Quantum computing is still very much in its infancy, with new methods of quantum computation emerging now on a frequent basis.
- QC needs total freedom to innovate, to breathe and to proliferate. This cannot be impeded, hindered or constrained in any way.
- So it is probably too early to look at standards for quantum computing directly
- There are, however, some areas in which standards would be helpful, including raising the performance benchmarks for the equipment and infrastructure required to support quantum computing and more generally quantum measurement and quantum communication.

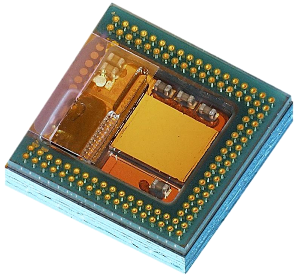
Key findings of cross-SDO symposia

Quantum Photonic Integrated Circuits (QPICs)

- Photonic Integrated Circuits (PICs) set to become a **key enabling technology** for quantum devices.
- Useful standards for QPICs would include:
  - Performance benchmarks specifying very low loss coupling between fibre and QPICs e.g. <0.5 dB
  - QPIC interfaces allowing higher volumes of QPIC connecting devices to be made available at lower cost



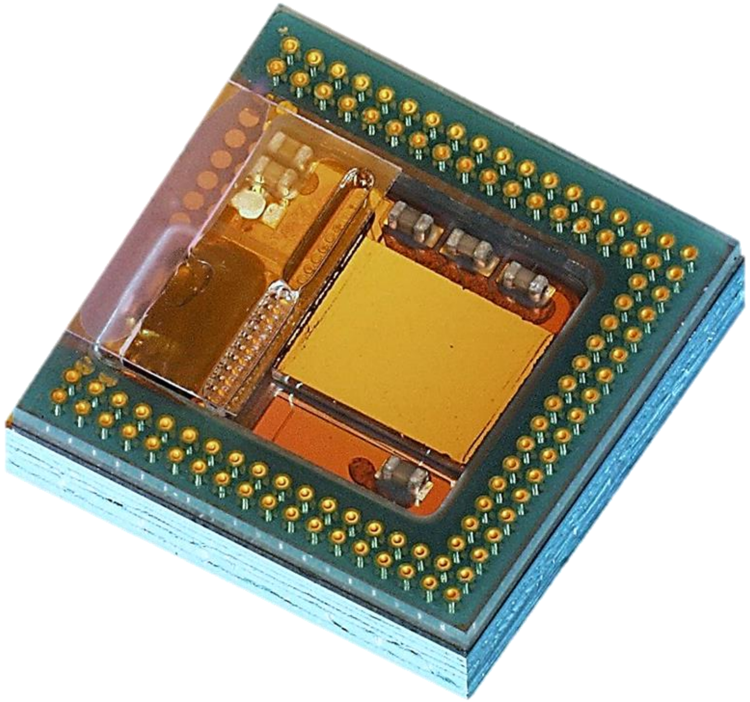




IEC / SC86C / WG4
Fibre optic active components and devices

Scope
Standardization in the field of optical active components, devices and hybrid modules, including **<u>photonic integrated circuits</u>**, for communication applications (e.g., data communications, telecommunications) for the purpose of trade and commerce.

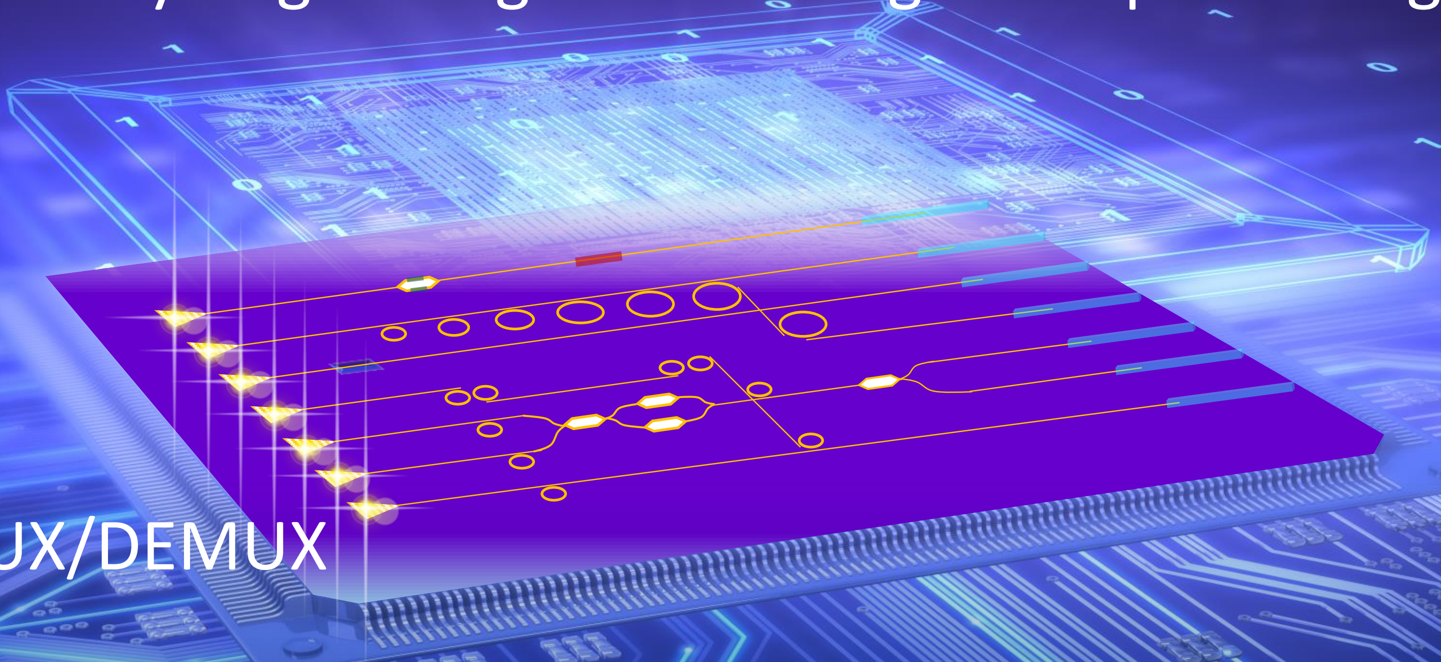
Chair
Hideki Isono



Source: AIO Core

Photonic Integrated Circuits

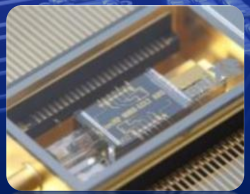
Combining the ability to guide light and change the speed of light opens the door to:



- Modulation
- Splitting
- Switching
- Wavelength MUX/DEMUX

Silicon

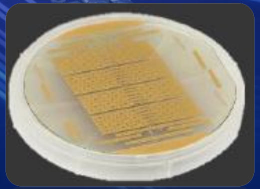
Indium Phosphide



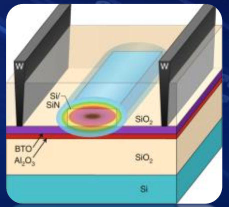
Silicon Nitride

Silica (glass)

Polymer



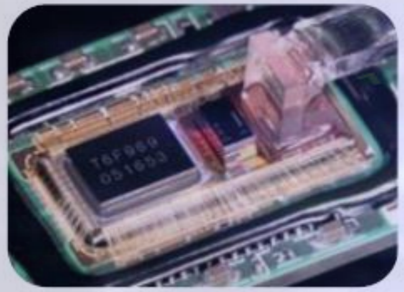
Lithium Niobate
$LiNbO_3$



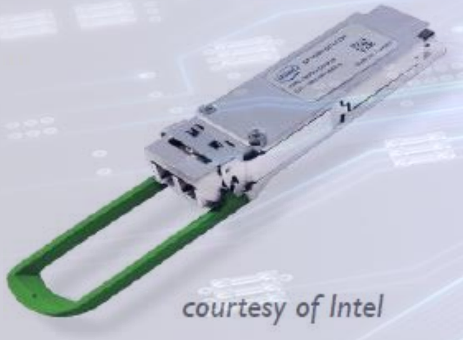
Barium Titanate
BTO

Integrated photonics will form the basis of many applications

Optical transceivers



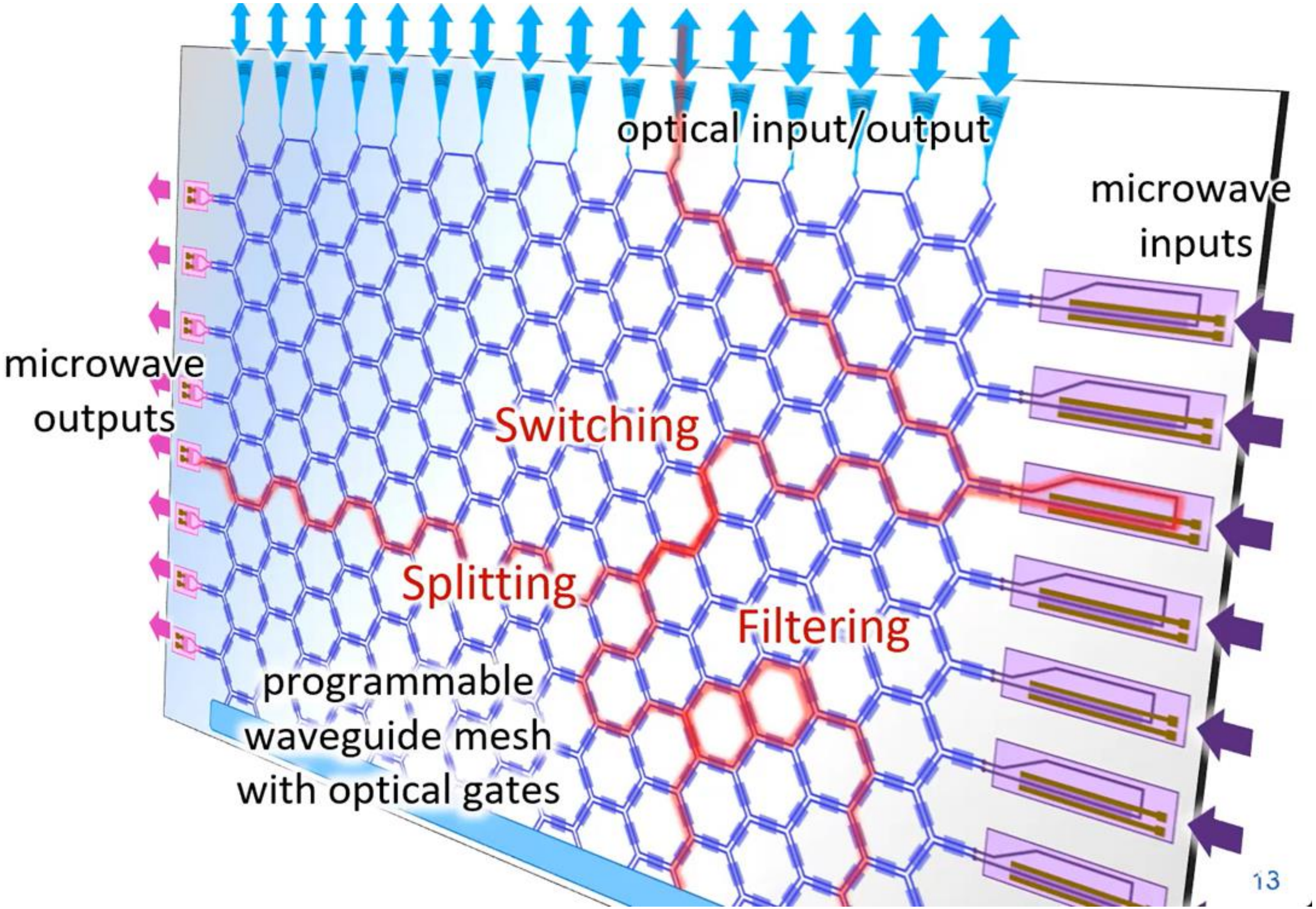
courtesy of Luxtera



courtesy of Intel

Programmable photonics

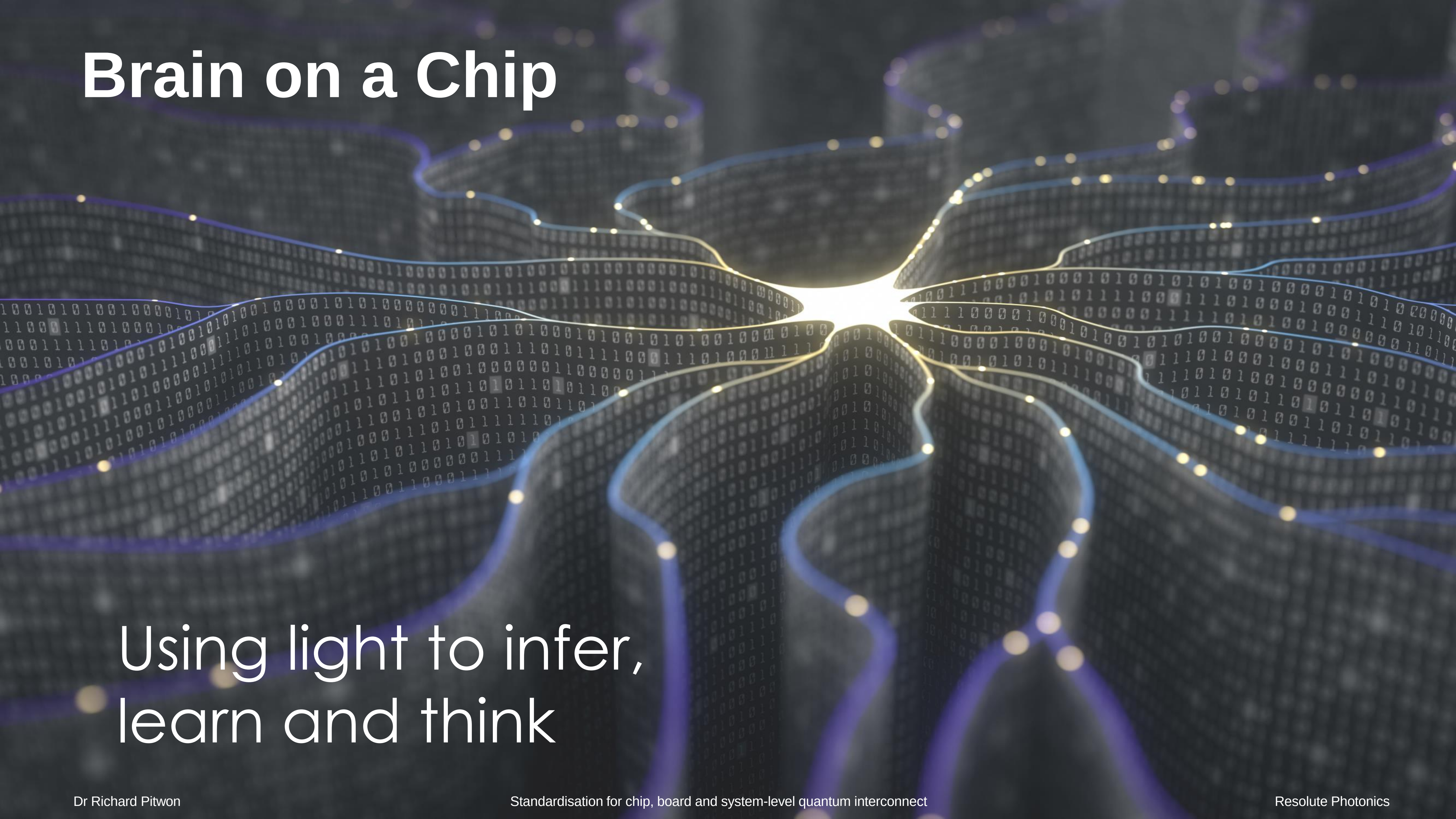
Source: Wim Bogarts – University of Ghent



Photonic meshes with programmable units allow general purpose devices.

Low power phase shifting materials (BTO) + low loss optical waveguides (silicon nitride, glass, polymer)

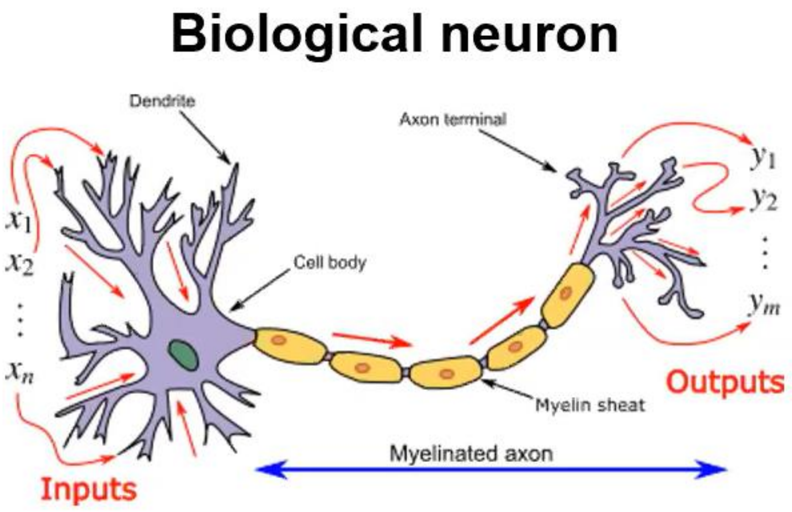
Brain on a Chip

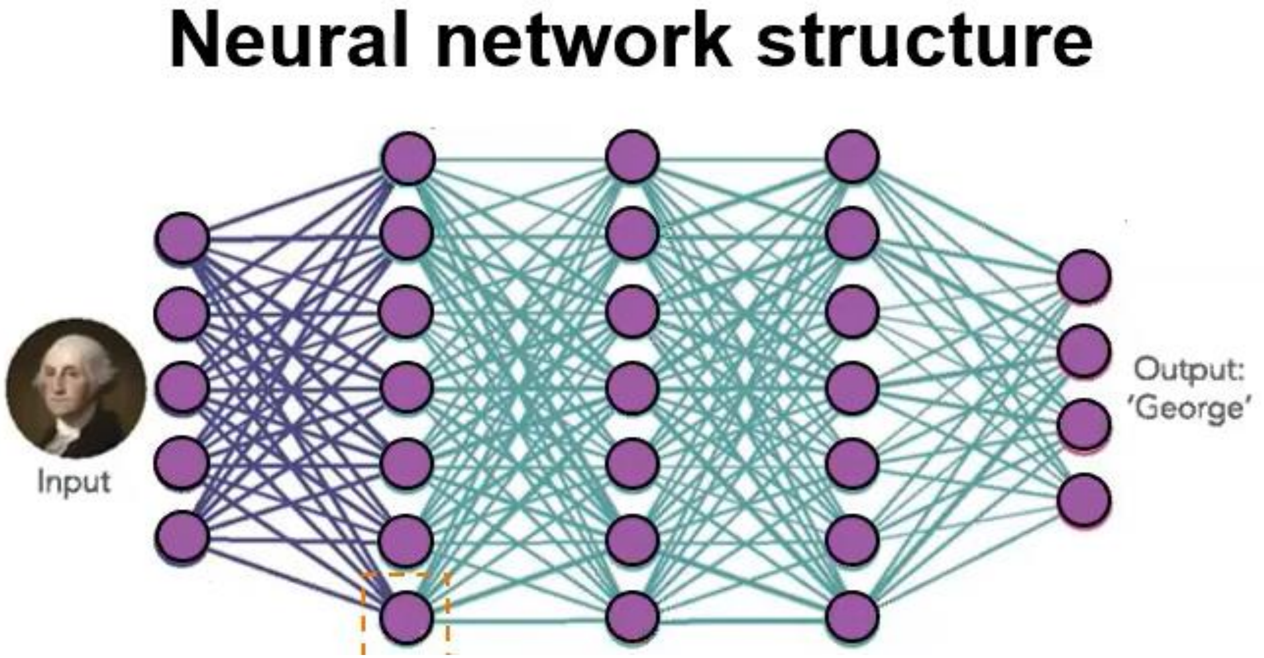


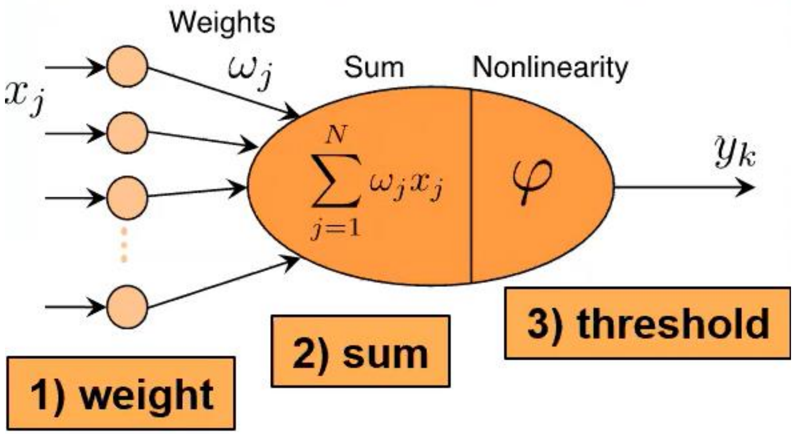
Using light to infer, learn and think

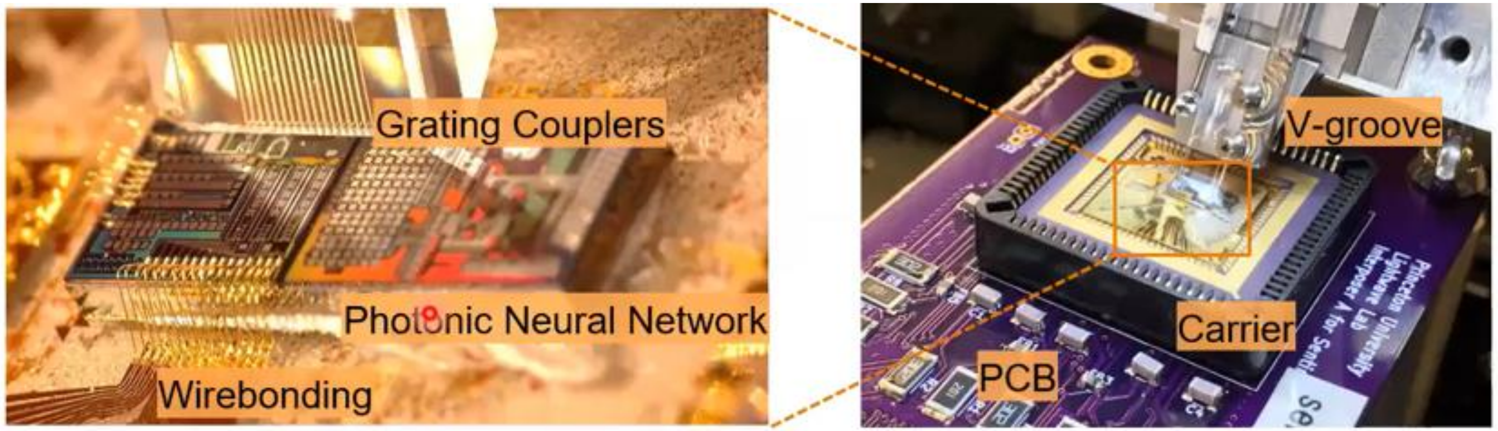
Neuromorphic networks

Emulating the brain on a photonic chip

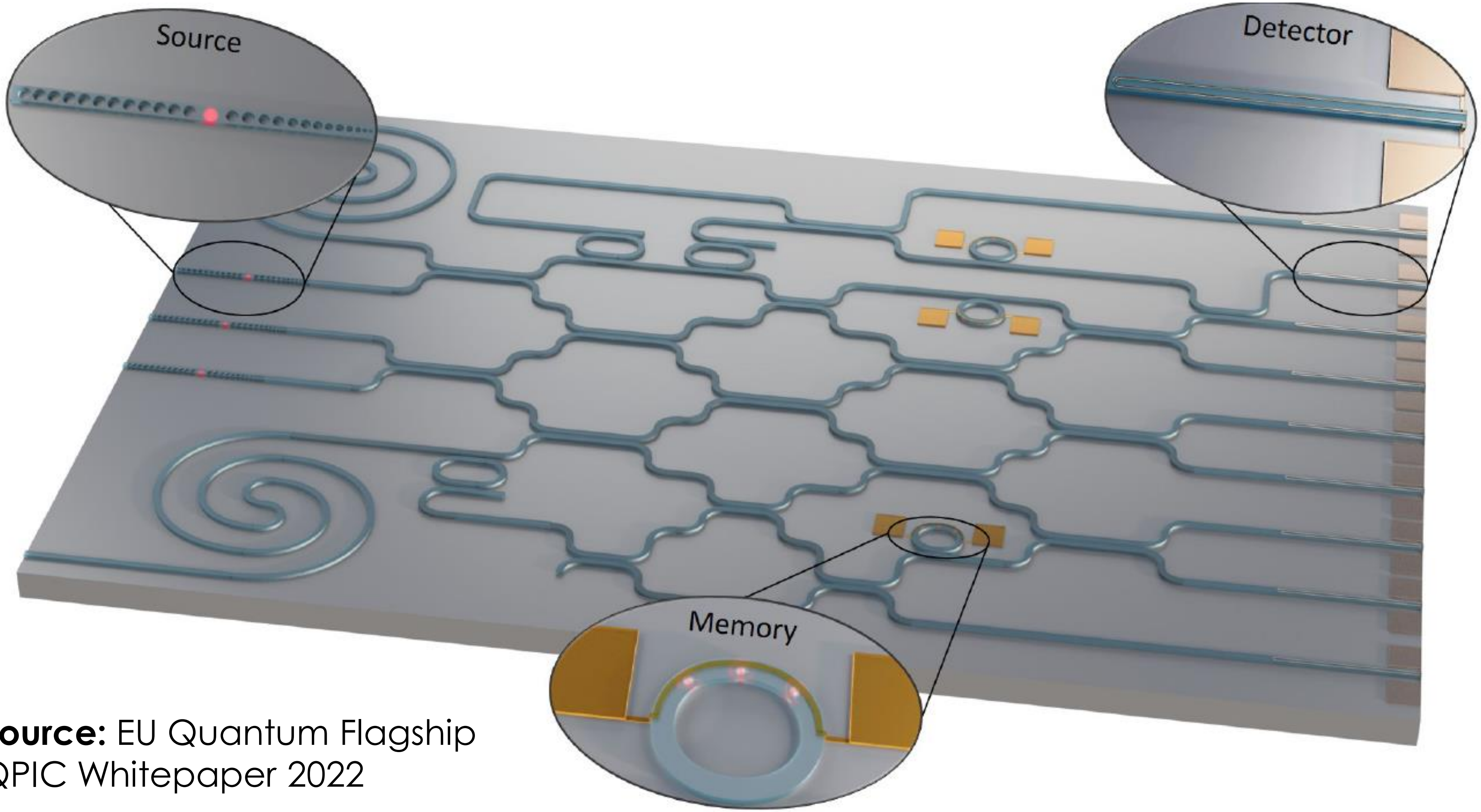






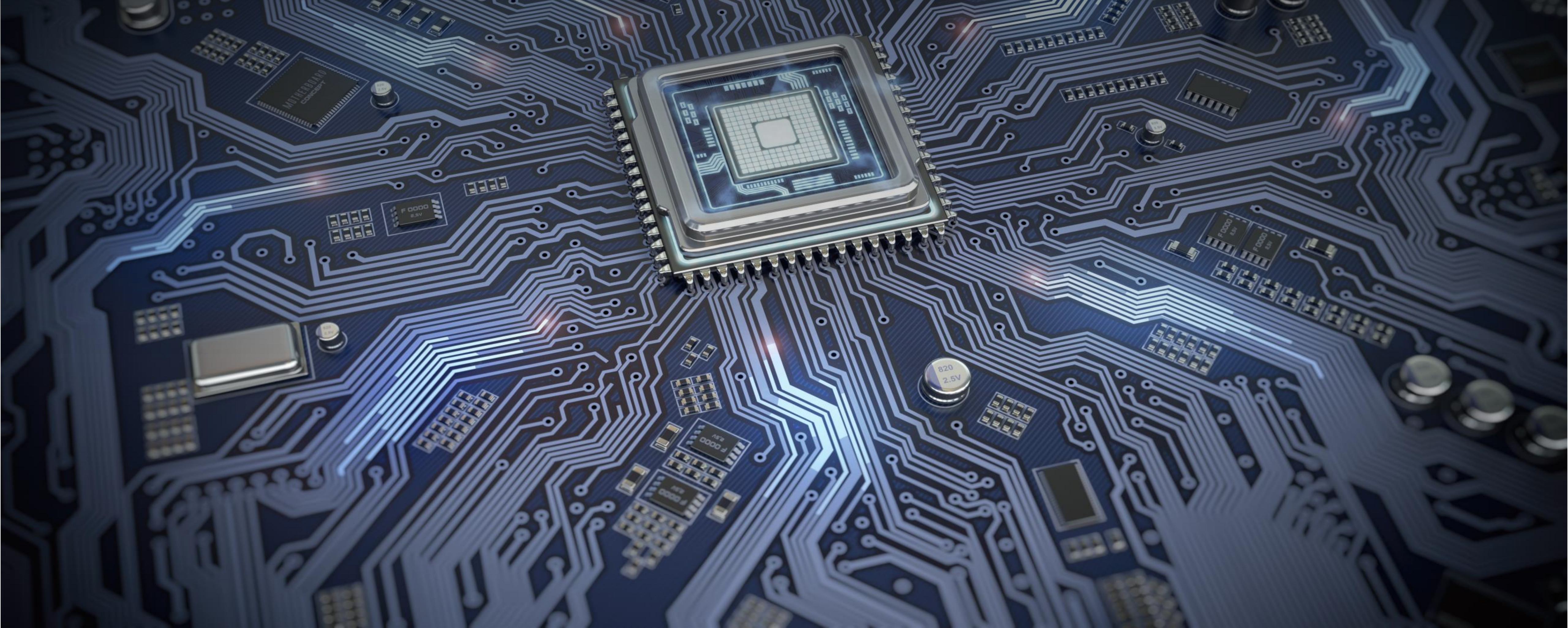


Quantum building blocks



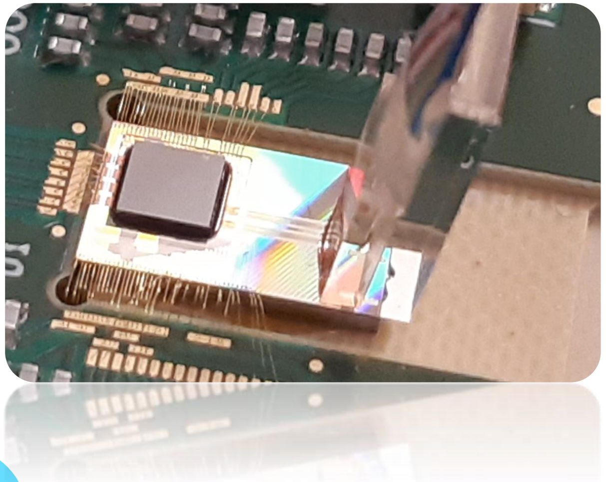
Source: EU Quantum Flagship QPIC Whitepaper 2022

Fibre to Quantum PIC coupling and packaging standards

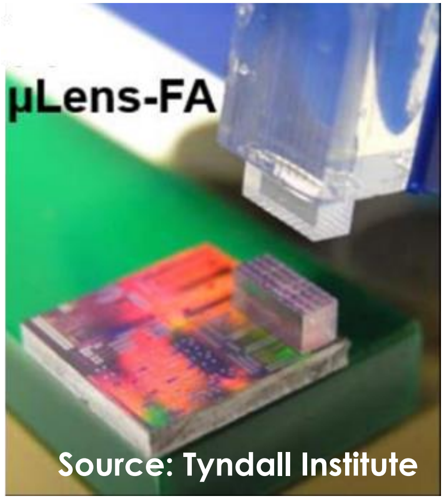


Fibre-to-QPIC coupling requires packaging standards

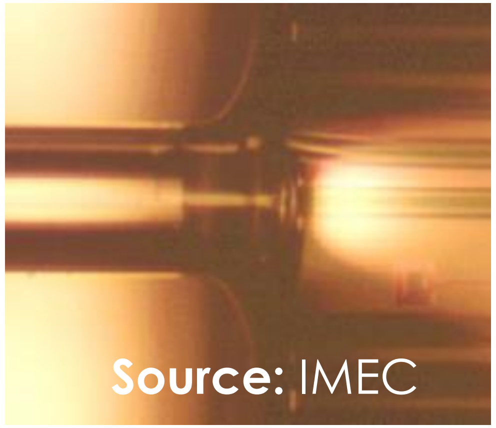
1 Vertical fixed coupler



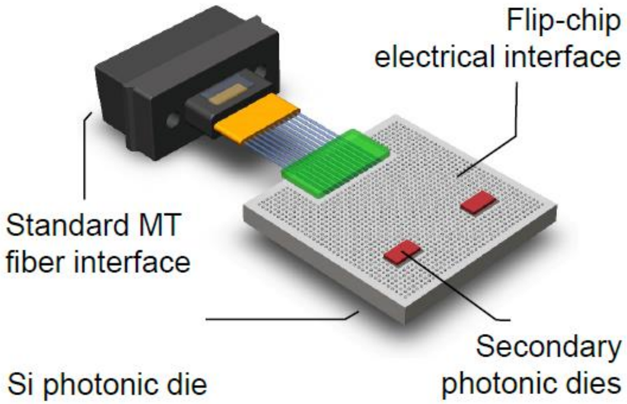
2 Vertical free space coupler



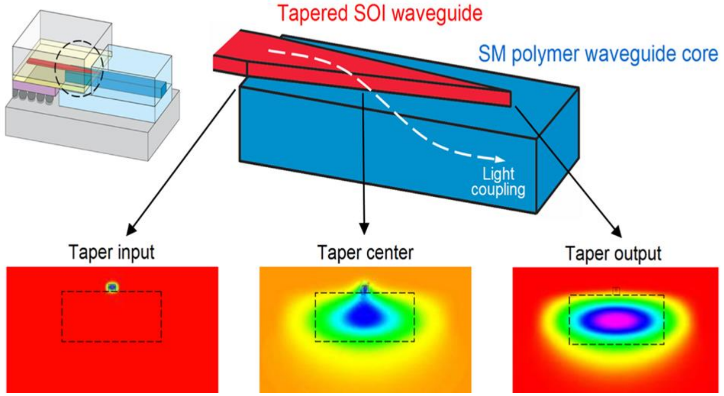
3 Edge coupler (actively assembled)



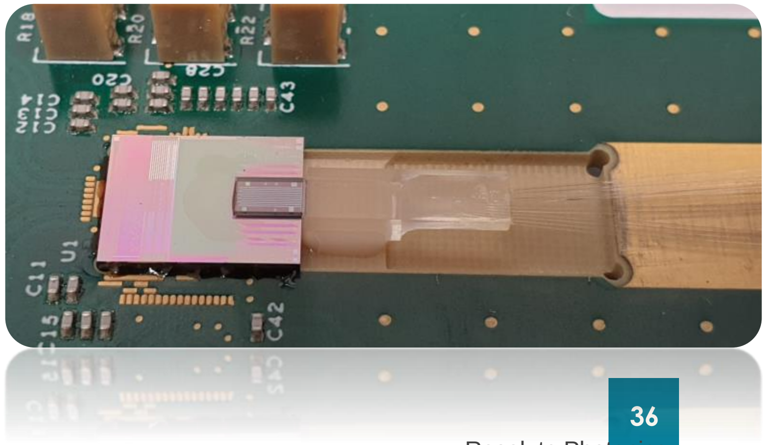
4 Edge coupler (passively assembled)



5 Adiabatic coupler

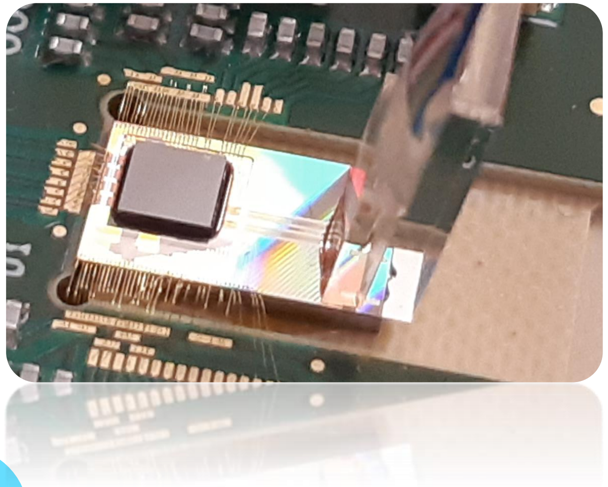


Source: IBM

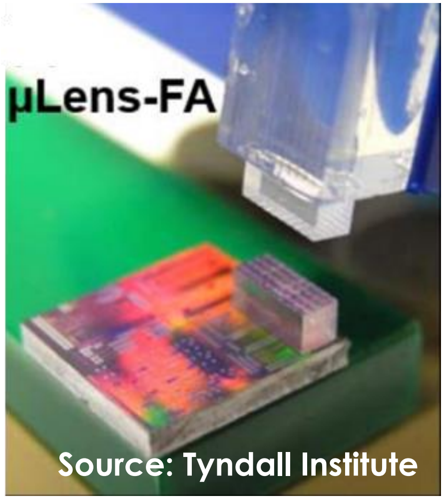


Fibre-to-QPIC coupling requires packaging standards

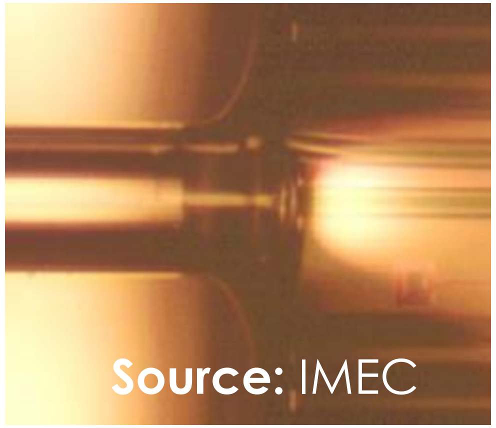
1 **Vertical fixed coupler**



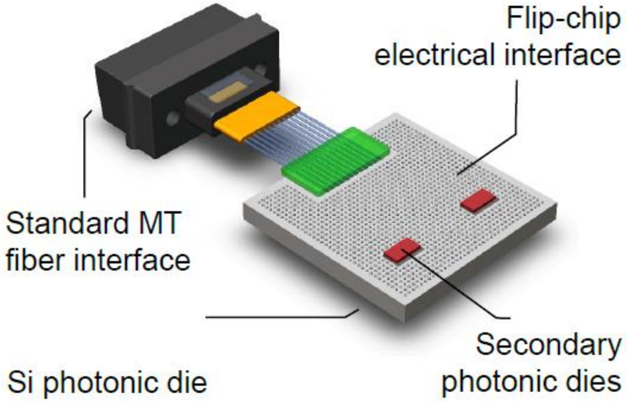
2 **Vertical free space coupler**



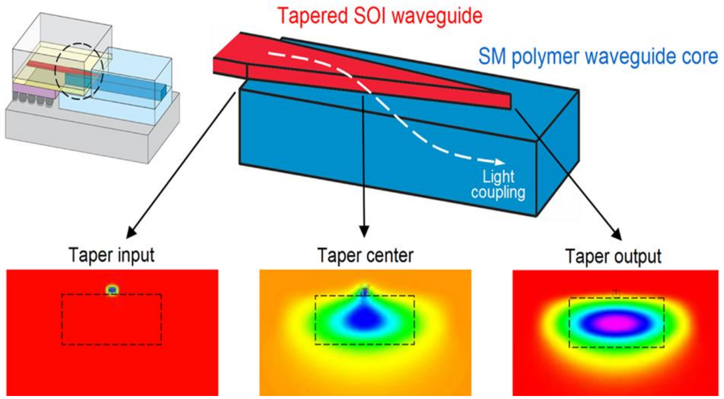
3 **Edge coupler (actively assembled)**



4 **Edge coupler (passively assembled)**

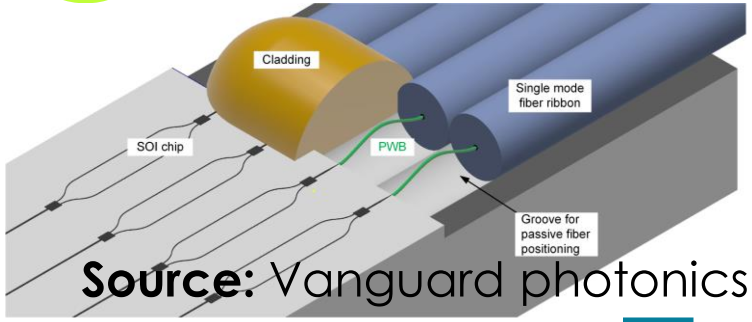


5 **Adiabatic coupler**



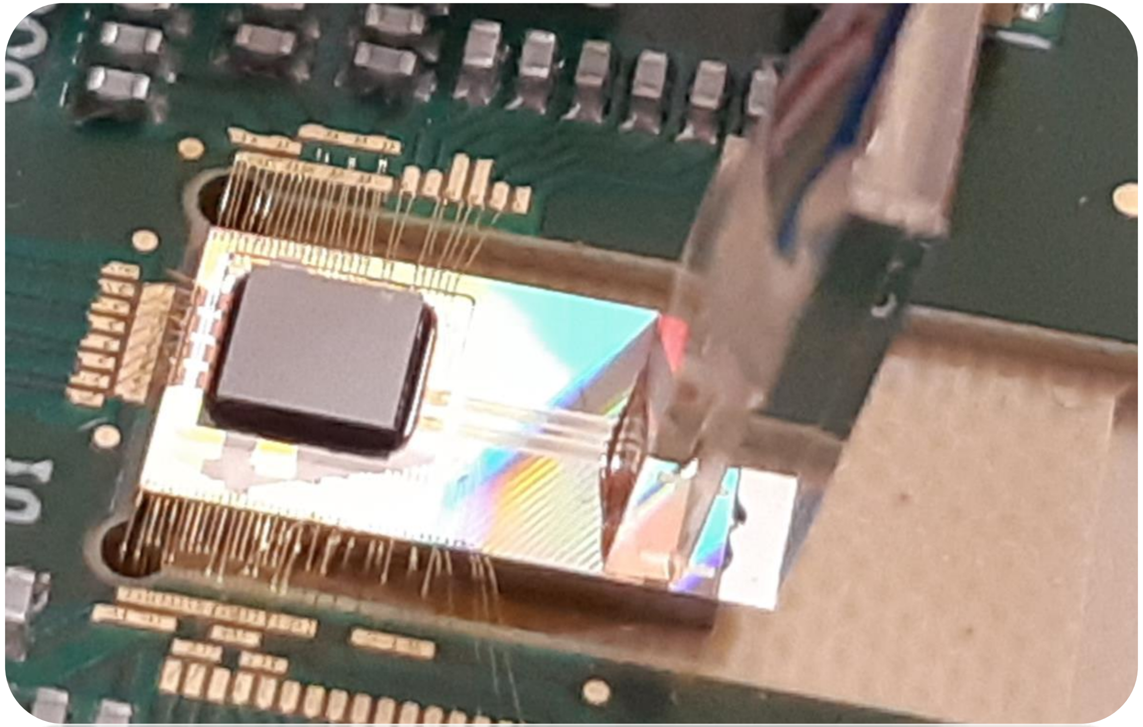
Source: IBM

6 **Polymer wire-bonding**

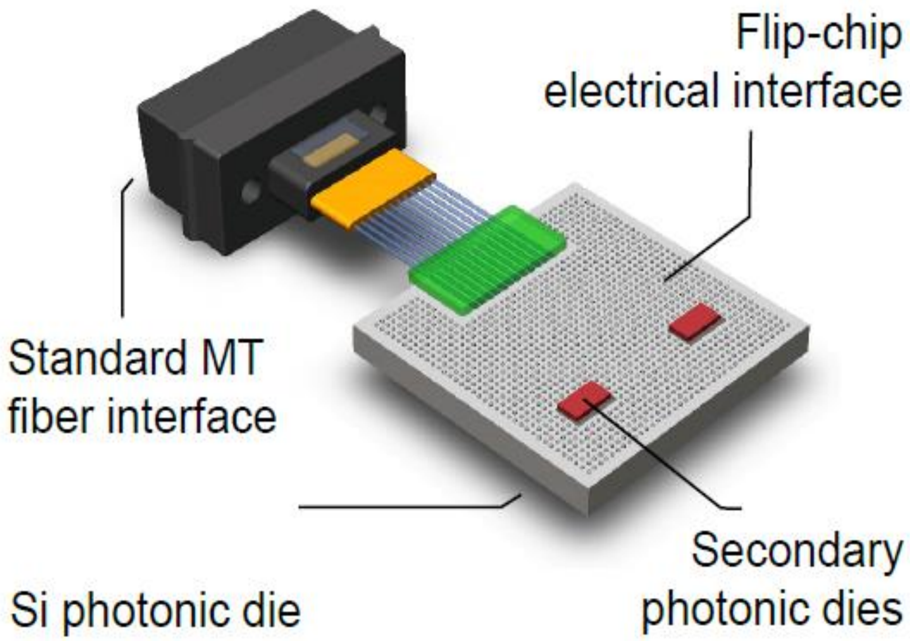


Fibre-to-QPIC coupling requires packaging standards

1 **Vertical fixed coupler**



4 **Edge coupler (passively assembled)**



Source: IBM

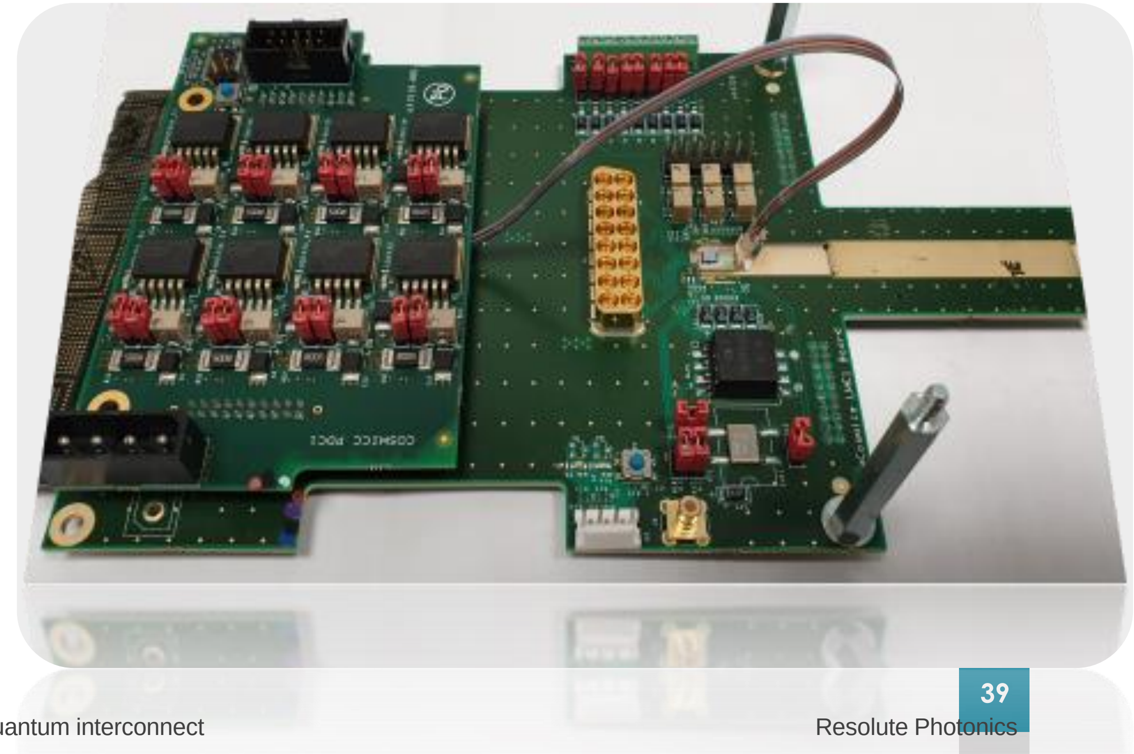
GlobalFoundries™

S86C/WG4 highlight – publication of new IS

IEC 62150-6:2022 - Fibre optic active components and devices - Test and measurement procedures - Part 6: Universal mezzanine boards for test and measurement of photonic devices

Publication on 28th January 2022

Abstract
IEC 62150-6:2022 specifies a generic mezzanine board system to support test and measurement of devices based on micro-optical and micro-photonic technologies, including but not limited to photonic integrated circuit (PIC) devices.



Key findings of cross-SDO symposia

Quantum Random Number Generators (QRNGs)

- QRNGs are an important building block in many different quantum technologies, including quantum computers and QKD.
- The purpose of these devices is to generate purely random numbers, and there are levels of "**purity" of randomness**.
- Generating truly random number is challenging but many organisations are coming up with more and more sophisticated ways of harnessing nature to produce increasingly random numbers.
- Standardized benchmarks on new properties such as **“purity of randomness”** would therefore be a useful way of assessing the suitability of a technology to an application.
- **Quantum randomness tiers:** While total randomness could be overkill for non-critical, cost-sensitive applications, other applications such as highly secure military, defence intelligence data would require the highest levels of randomness to encrypt their data at a cost premium.

Publications

1. Tiger Ninomiya, Bernard H. L. Lee, Richard Pitwon, "Advancement in optical interconnect technology for high speed data transmission," Proc. SPIE 12007, Optical Interconnects XXII, 120070R (5 March 2022); https://doi.org/10.1117/12.2609301
2. T. Ninomiya, B. H. Lee, S. Lee, G. Hsu and R. Pitwon, "Optical Interconnect Ecosystems and Challenges in Co-Packaged Optics," *2021 IEEE CPMT Symposium Japan (ICSJ)*, 2021, pp. 138-141, doi: 10.1109/ICSJ52620.2021.9648898.
3. Pitwon, R., Lee, B., "Harmonising international standards to promote commercial adoption of quantum technologies," Proc. SPIE 11881, Quantum Technology: Driving Commercialisation of an Enabling Science II, 118810H (6 October 2021); https://doi.org/10.1117/12.2602888
4. Lee, B., Pitwon, R., "The evolution of optical interconnect technology: from long-haul telecommunication to quantum networks," Proc. SPIE 11881, Quantum Technology: Driving Commercialisation of an Enabling Science II, 118810A (6 October 2021); https://doi.org/10.1117/12.2603291
5. H. L. Lee and R. Pitwon, "Quantum Fiber Optic Interconnect for Quantum Networks," 2021 IEEE 71st Electronic Components and Technology Conference (ECTC), 2021, pp. 1583-1589, doi: 10.1109/ECTC32696.2021.00251.

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THANK YOU