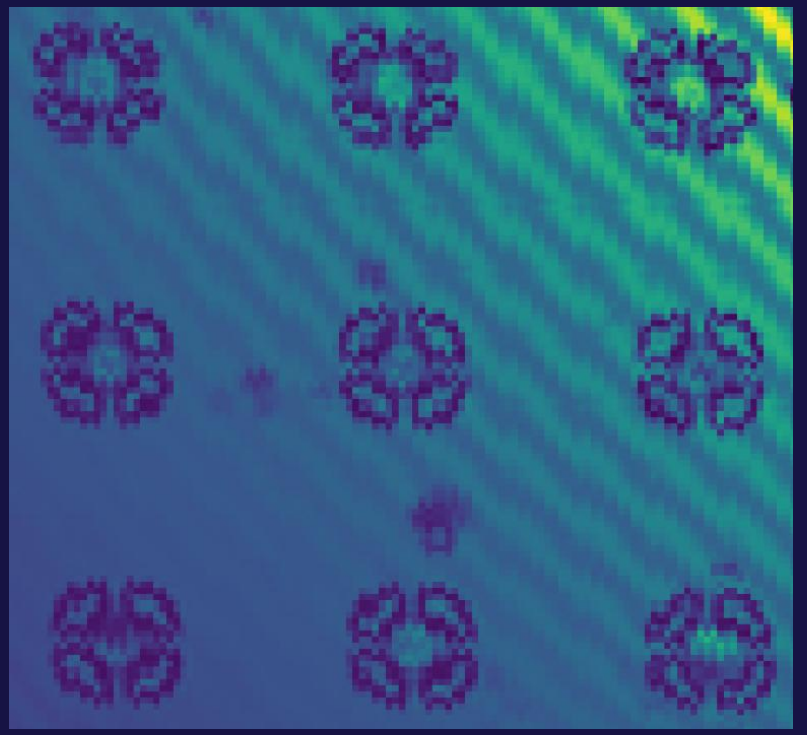
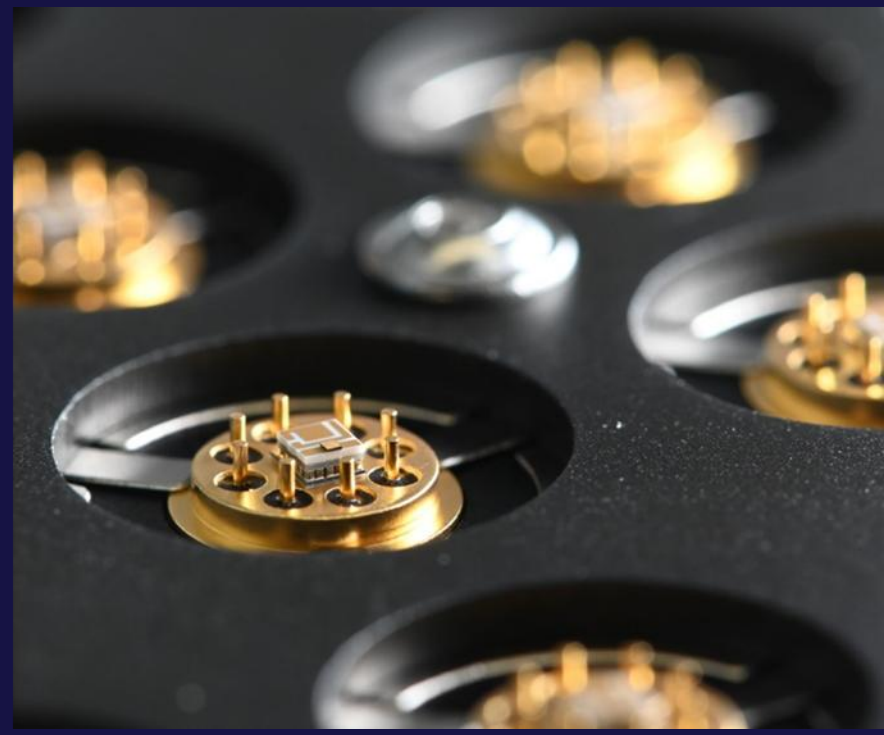
Photonic Packaging for Quantum

bay photonics
Advanced Photonics Assembly and Packaging

Challenges of Semiconductor Photonic Packaging for Quantum Applications

Andrew Robertson - CTO





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Company Intro

- Founded in 2007
- Downstream photonic semiconductor (chip) processing
- 33 employees – Operators, Process Engineers, R&D Engineers
- ISO9001:2015 Certification UKAS
- Design & contract manufacture

Located in new "Electronics & Photonics Innovation Centre" EPIC, Paignton

Since 2007 Bay have provided open access advanced photonic semiconductor packaging, from prototype to pilot line

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IP R&D

TRL1 TRL2 TRL3 TRL4 TRL5 TRL6 TRL7 TRL8 TRL9

VOLUME

Prototype **Process Development** **Pilot**

Providing innovators with affordable, rapid prototyping services for NPI/NPD
Accelerating product development cycle with pilot build
Scale-up ready build processes to prepare for growth

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Complete packaging Service

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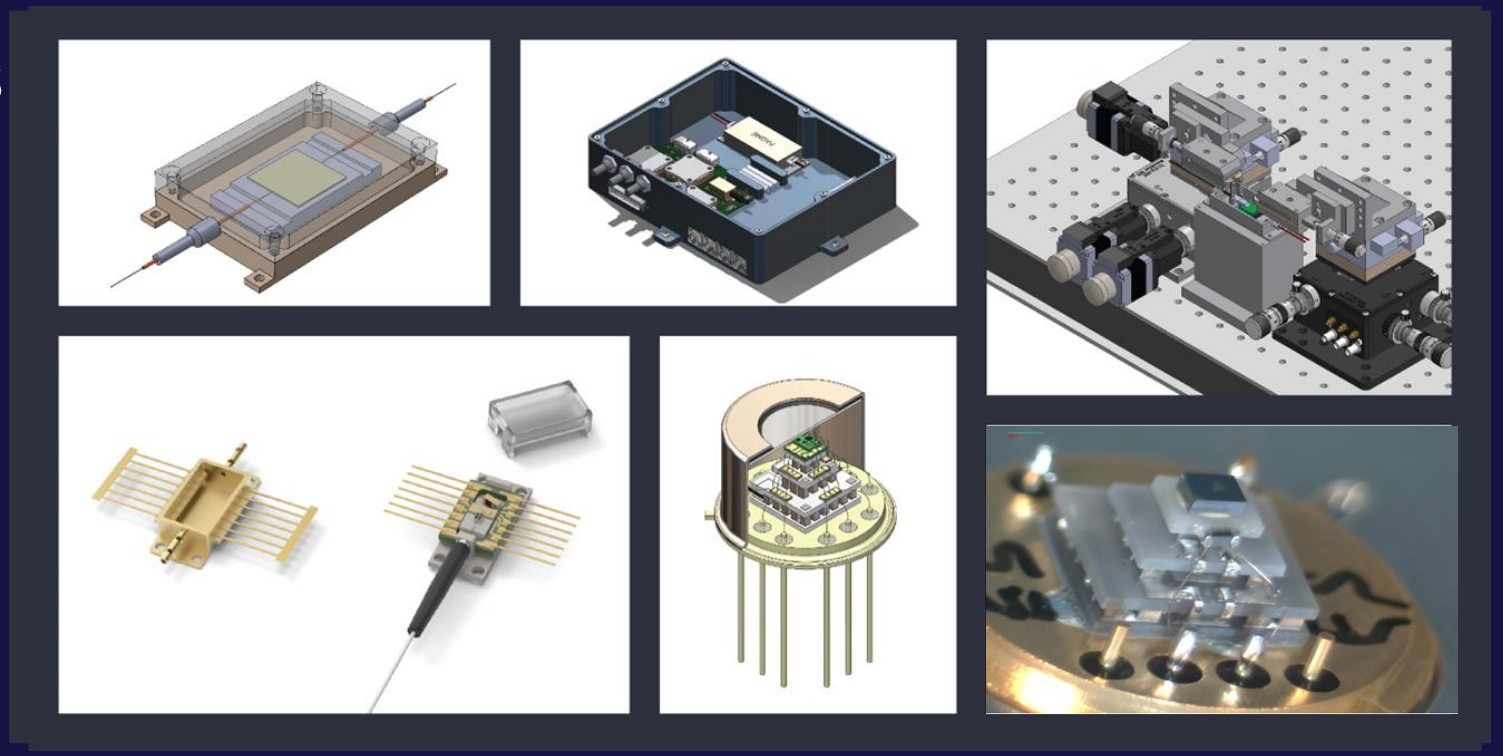
- Design the packaging
- Source the components
- Assemble the components
- Test the device
- Prototypes to Production
- Die & wire bond
- Optical alignment & attach
- Thermal control
- Hermetic seal



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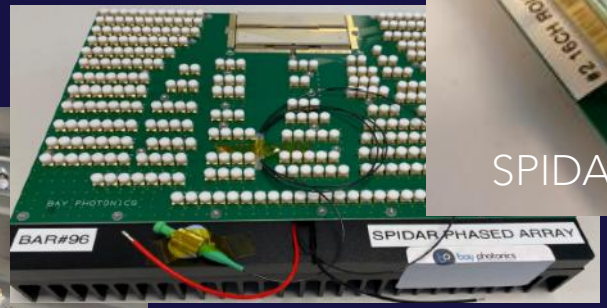
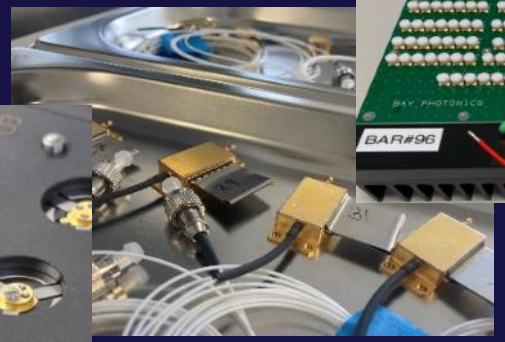
IUK – Quantum Packaging Projects

- AQUASEC (IUK 104615)
- SPIDAR (IUK44835)
- AIRQKD (IUK 45364)
- QFOUNDRY (IUK 48484)
- PADME (IUK 10031438)
- QPODS (IUK10032041)
- Q3MD (IUK 10032009)
- GALACTIC (IUK10077950)
- TRILOBITE (IUK10102696)
- MARCONI (IUK10103658)
- SANTANA (IUK10102355)
- SPARQLE (IUK10140518)
- QTATA (IUK10150866)

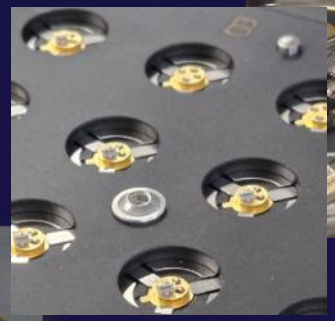
SPIDAR SPAD Array



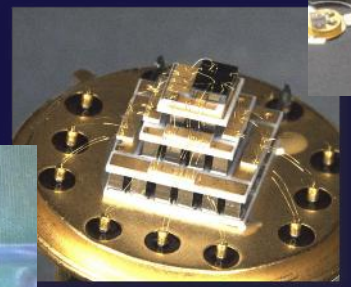
SPIDAR 64 channel laser array



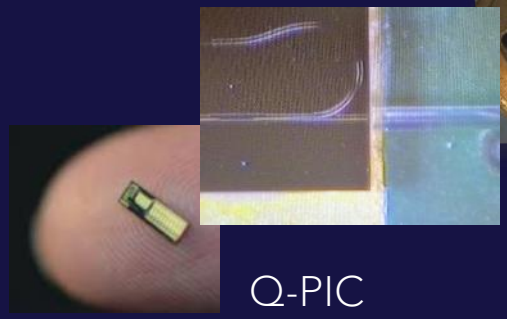
AIRQKD FIBRE COUPLED SPAD detector



QFOUNDRY VCSEL



MARCONI FREE SPACE SPAD detector



Q-PIC

TRILOBITE Module

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SPADs (Single Photon Avalanche Detector)

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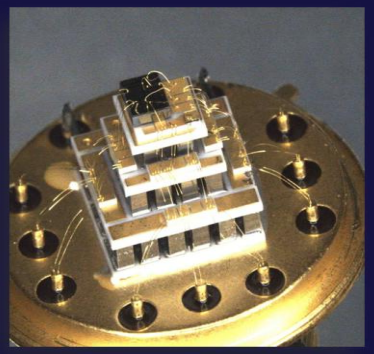
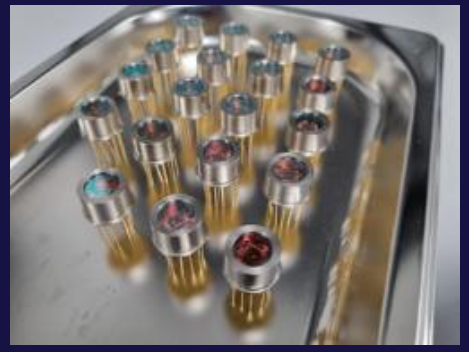
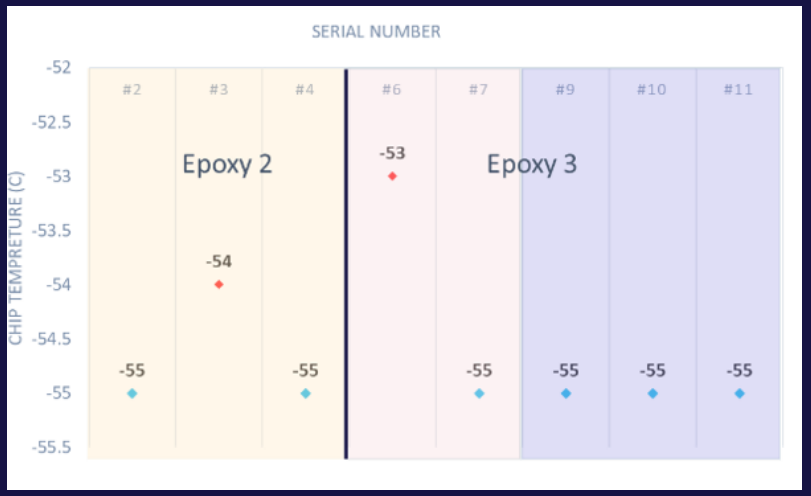
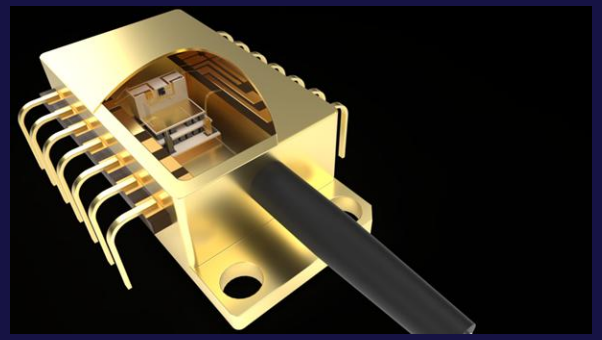
- Free space TO package & fibre coupled butterfly cools to -50C for low noise operation
- Quantum cryptography
- LIDAR (e.g. gas sensing)

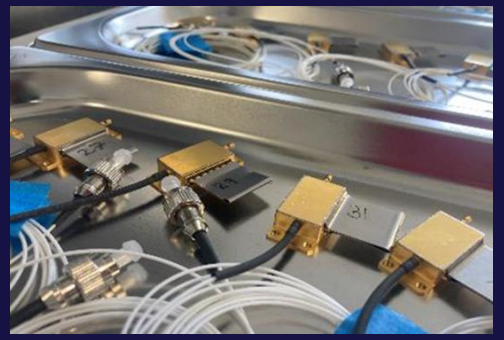




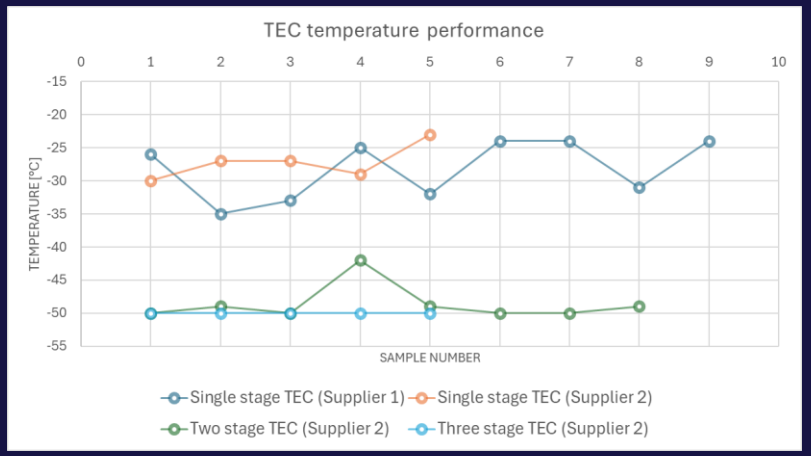
TO Can performance







Butterfly performance



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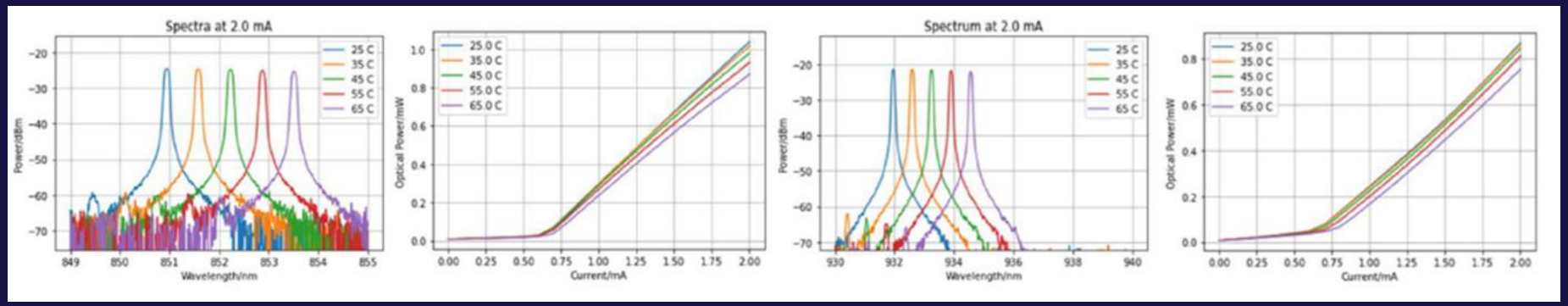
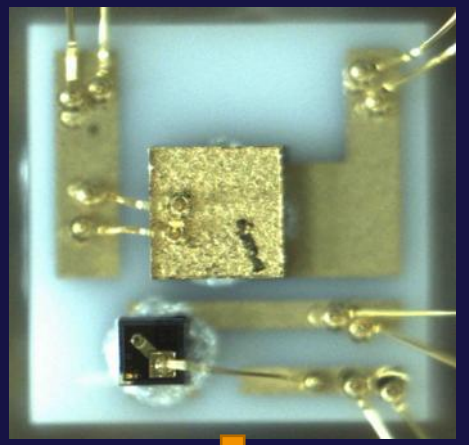
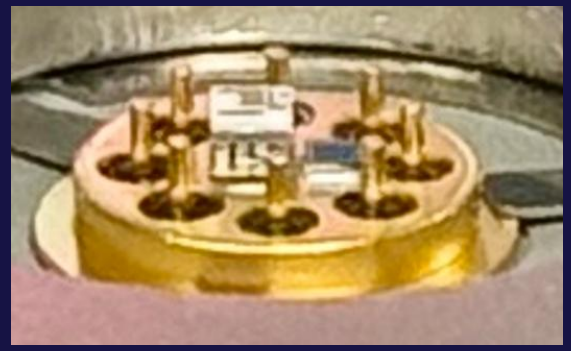
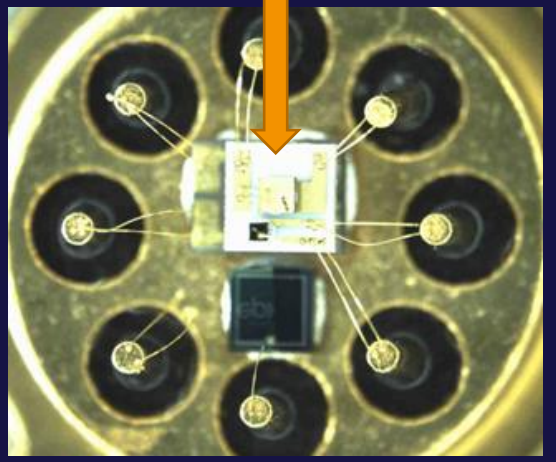
Quantum Packaging - VCSELs

- Narrow linewidth VCSELs for quantum and spectroscopic applications









VCSEL Manufacture

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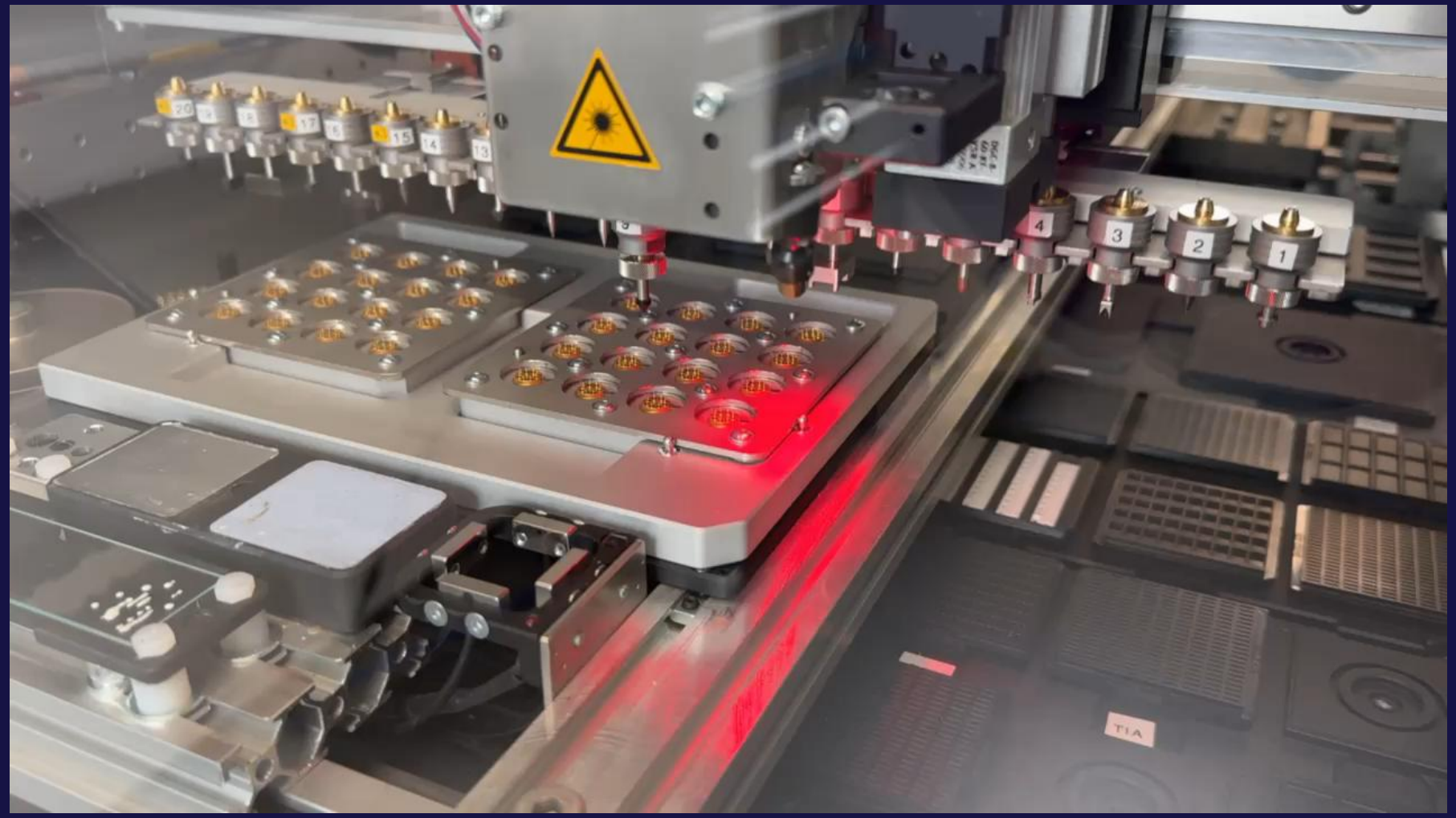

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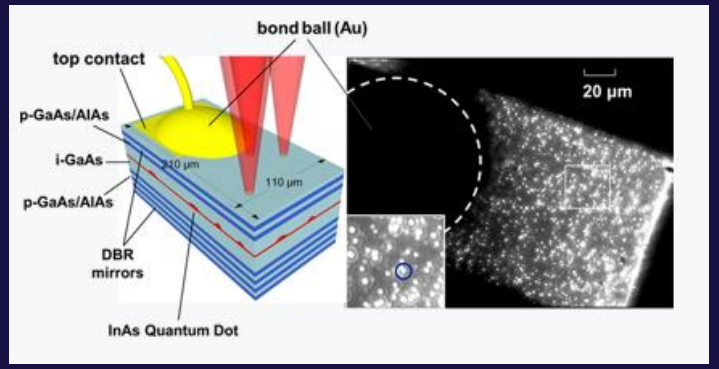
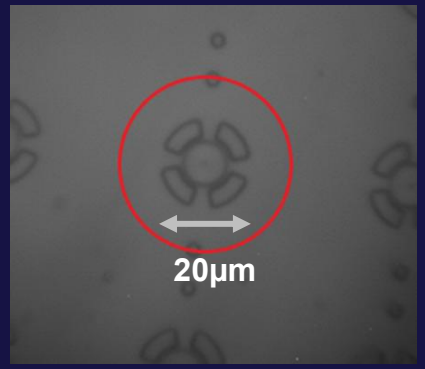
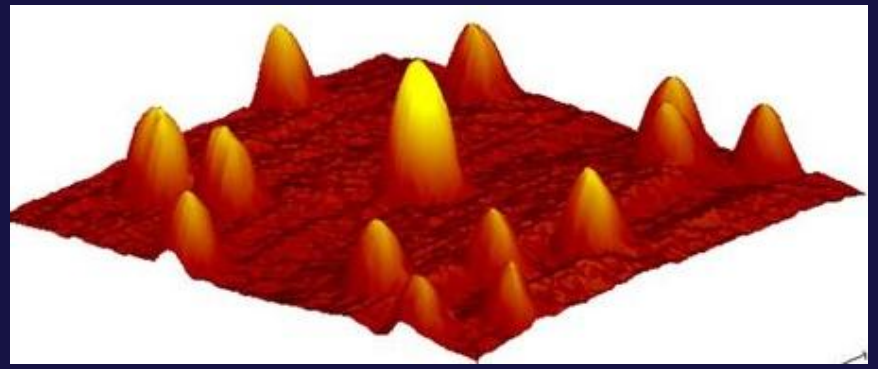
Packaging cryo – QLE - SPARQLE

- Requirement for fibre coupled Quantum light emitter (QLE)
- QLE only emits at <4K, so optical alignment "in the dark"
- Material properties at cryo-temps complex and non-linear
- Post-attach alignment accuracy needs to remain within +/-200nm

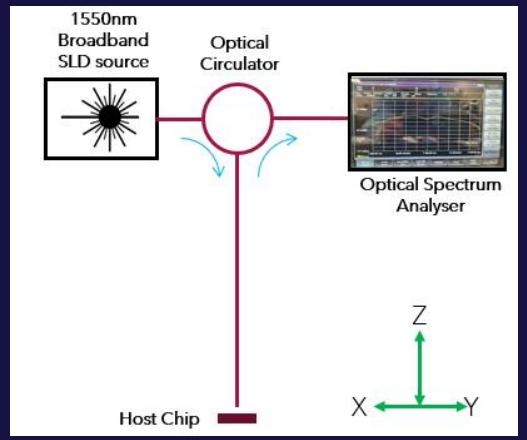


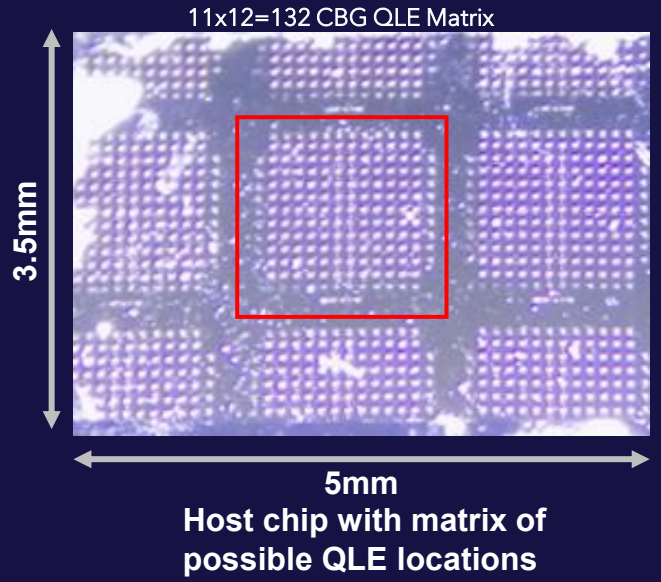




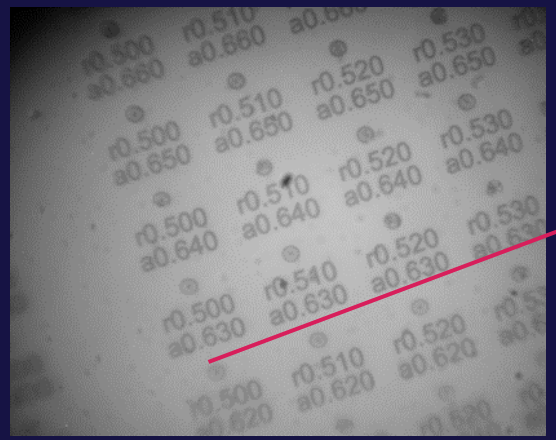
Packaging cryo QLE - SPARQLE

- Fibre to be aligned is used as imaging probe to identify QD
- Probe for Optical Coherence Tomography (OCT)
- Create 3D image of chip surface identifying key features

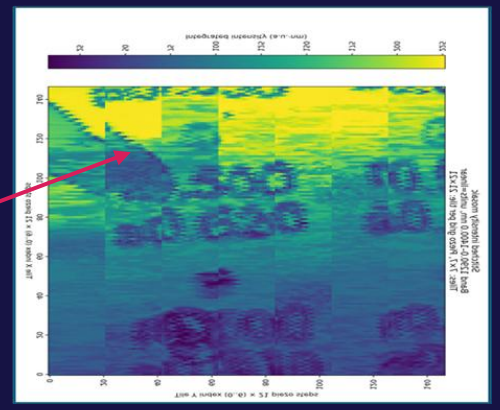




Host chip with matrix of possible QLE locations



Magnified image of CBG QLEs and ID Coordinates



OCT Mosaic of CBG QLE and ID Coordinates
(7x7 20um square scans, resolution 1um)

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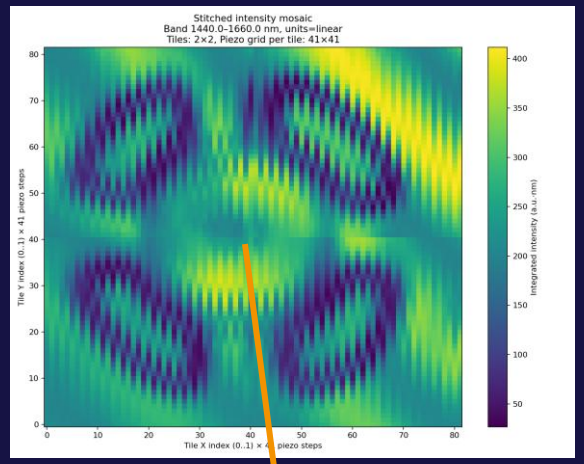
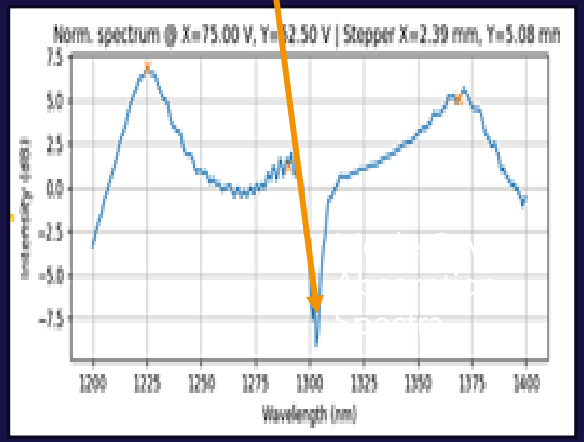
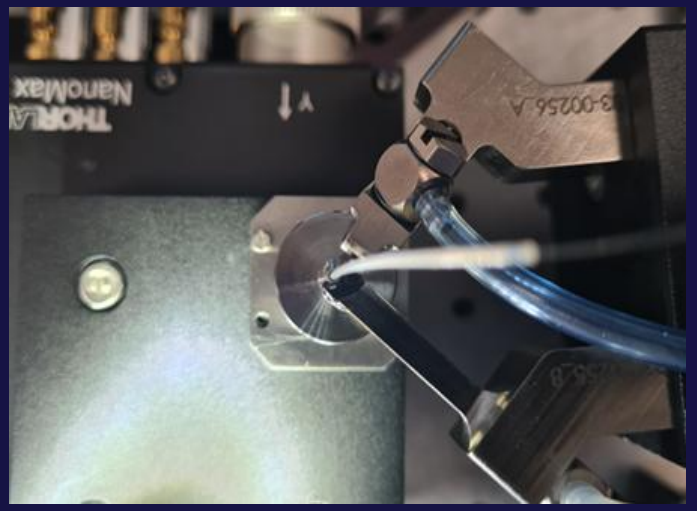
Packaging cryo QLE - SPARQLE

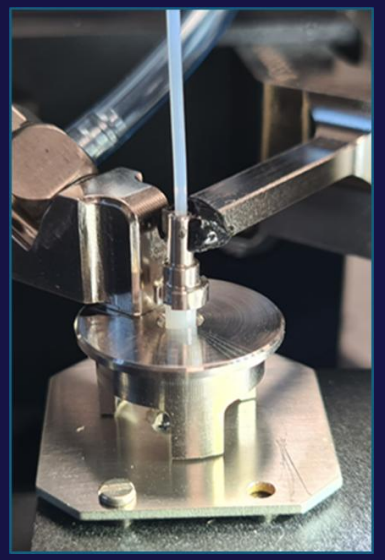
0.5um X&Y step resolution
80 steps => 40um in X&Y,80*80=6400 measurements





- Z-axis: Use OCT measurement to fix distance between fibre & chip
- X&Y: CBG identified by OCT image
- QLE mode centre identified using relative absorption spectrum for final alignment
- Attach





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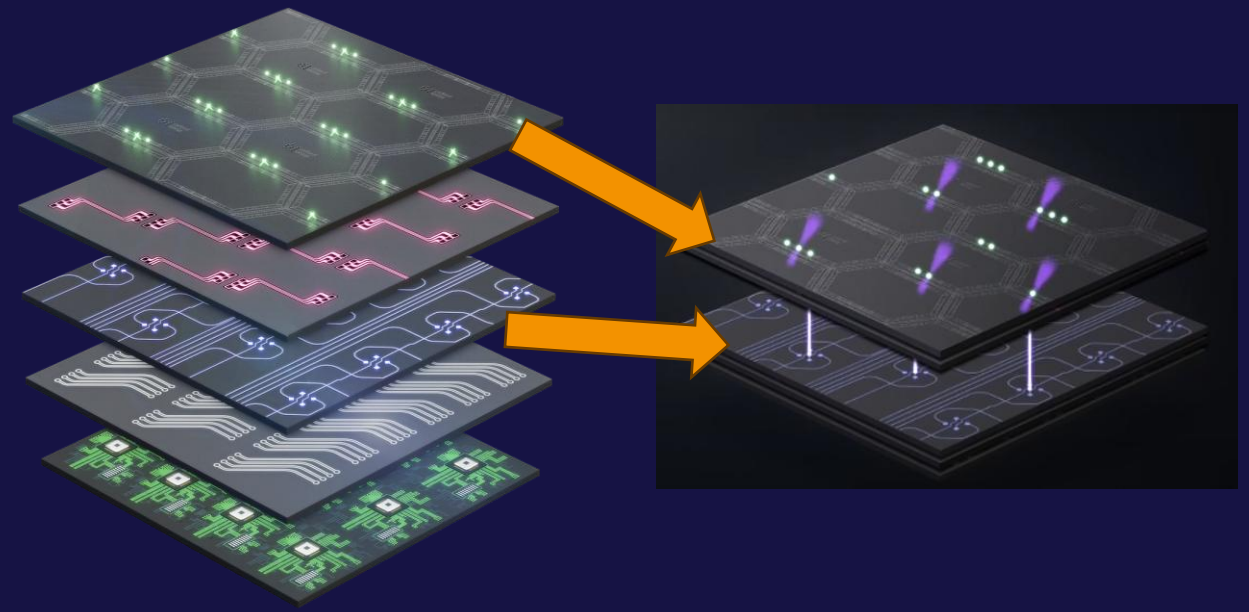
Packaging cryo 2D atom trap – Q-TATA

- To enable scalable & commercially-useful quantum processor
- 2D atom ion trap with integrated photonics eliminating free space laser alignment



- Lasers still needed for ion cooling & state preparation
- Quantum logic gates are microwave driven enhanced by integrated photonic/EM control, NOT BY PHASE-STABLE LASER HITTING ION
- Electronic QBIT Control (EQB) reduces reliance on free space optics & complex laser systems

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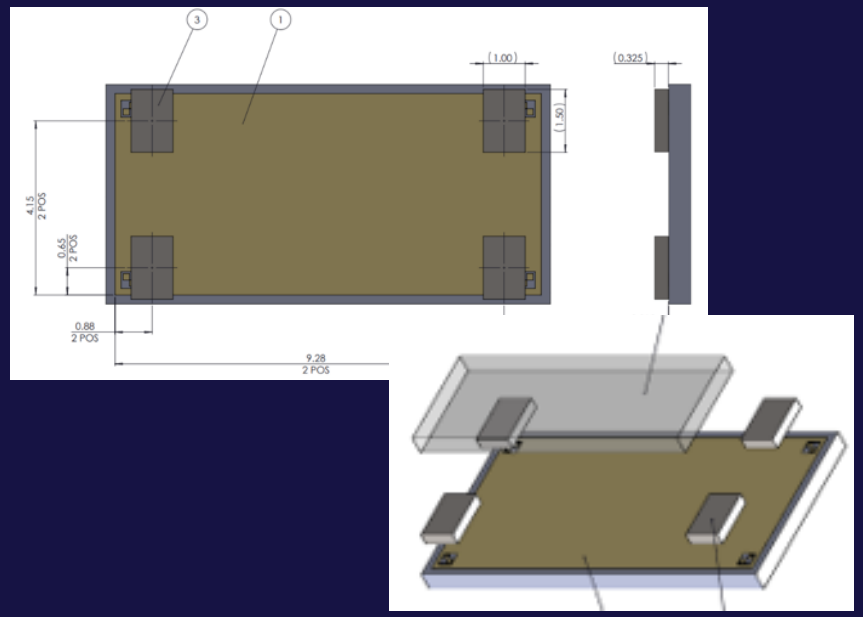
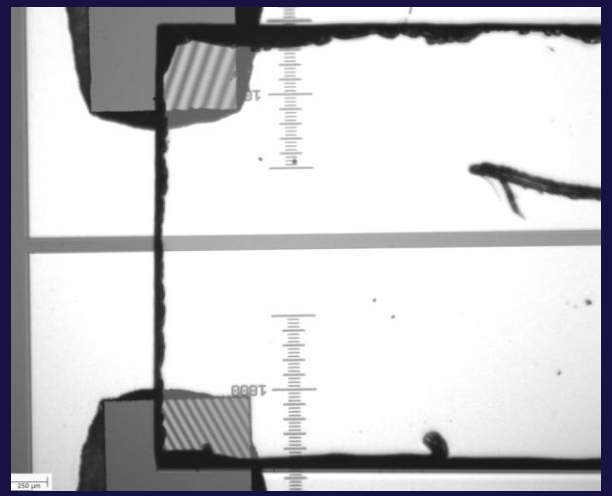
Packaging cryo 2D ion trap – Q-TATA

- Processor built from a number of layers with different functionality
- Critical that integrated optics & trap layers are precisely aligned, with surfaces parallel, Bay investigating practical limitations





- Traps built on die-bonder
- Monitoring interference fringes through contacted optical layers to estimate how parallel surfaces are

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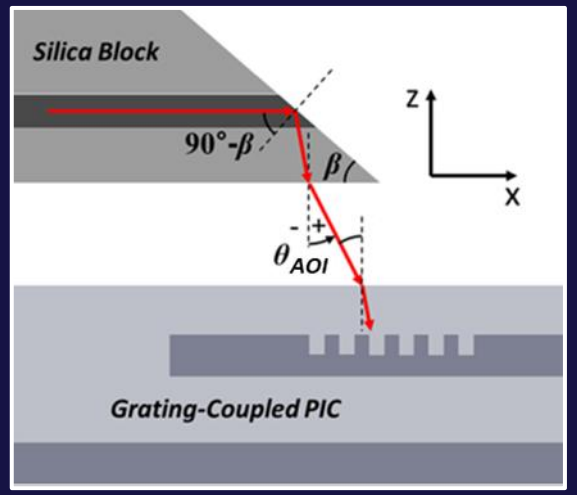
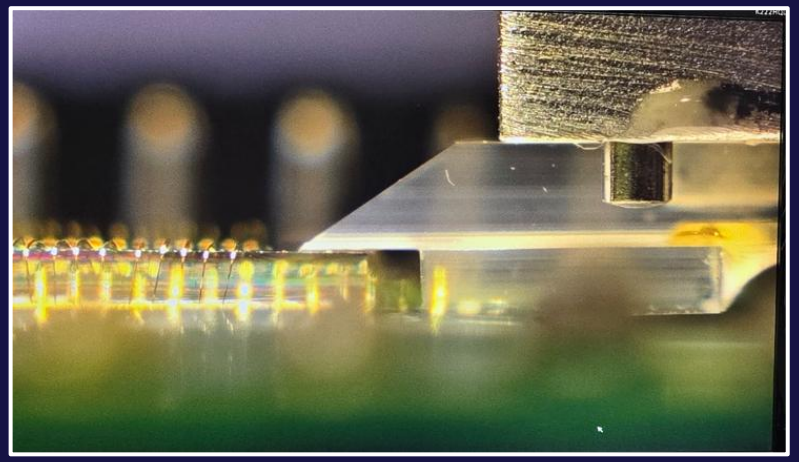
Packaging cryo 2D ion trap – Q-TATA

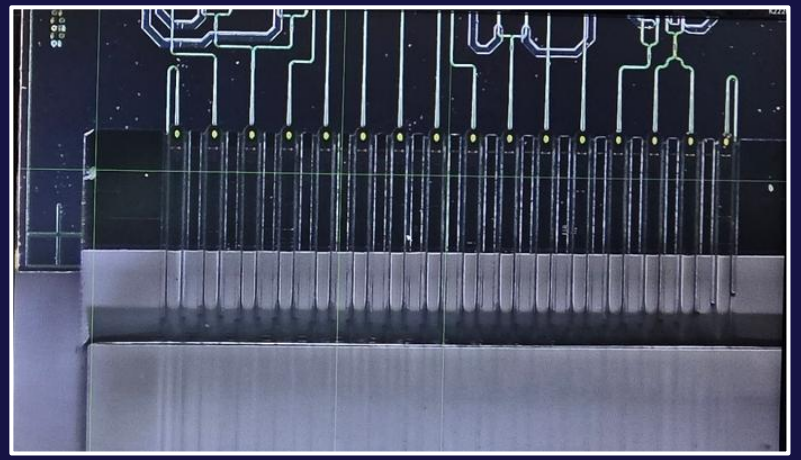
- Integrated optic layer uses quasi planar coupled fibre array
- Challenging wavelengths (lossy in current waveguide technology)



PIC Grating AOI



Side View – Horizontal FA⇔ PIC Alignment



Top Down – PIC Gratings Visible

Key Takeaways

- Photonics is the foundation for quantum technologies
  - Secure communications, sensing, computing
- Photonic packaging for cryogenic temperatures is a no longer a physics challenge but a manufacturing challenge
  - Scalable, repeatable processes for packaging components at 4K and below is crucial for moving quantum technologies out of the lab
- Integrated photonics is reducing complexity and enabling scale
  - Integrated optics is the route to commercial quantum processor systems with hundreds or thousands of qubits

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