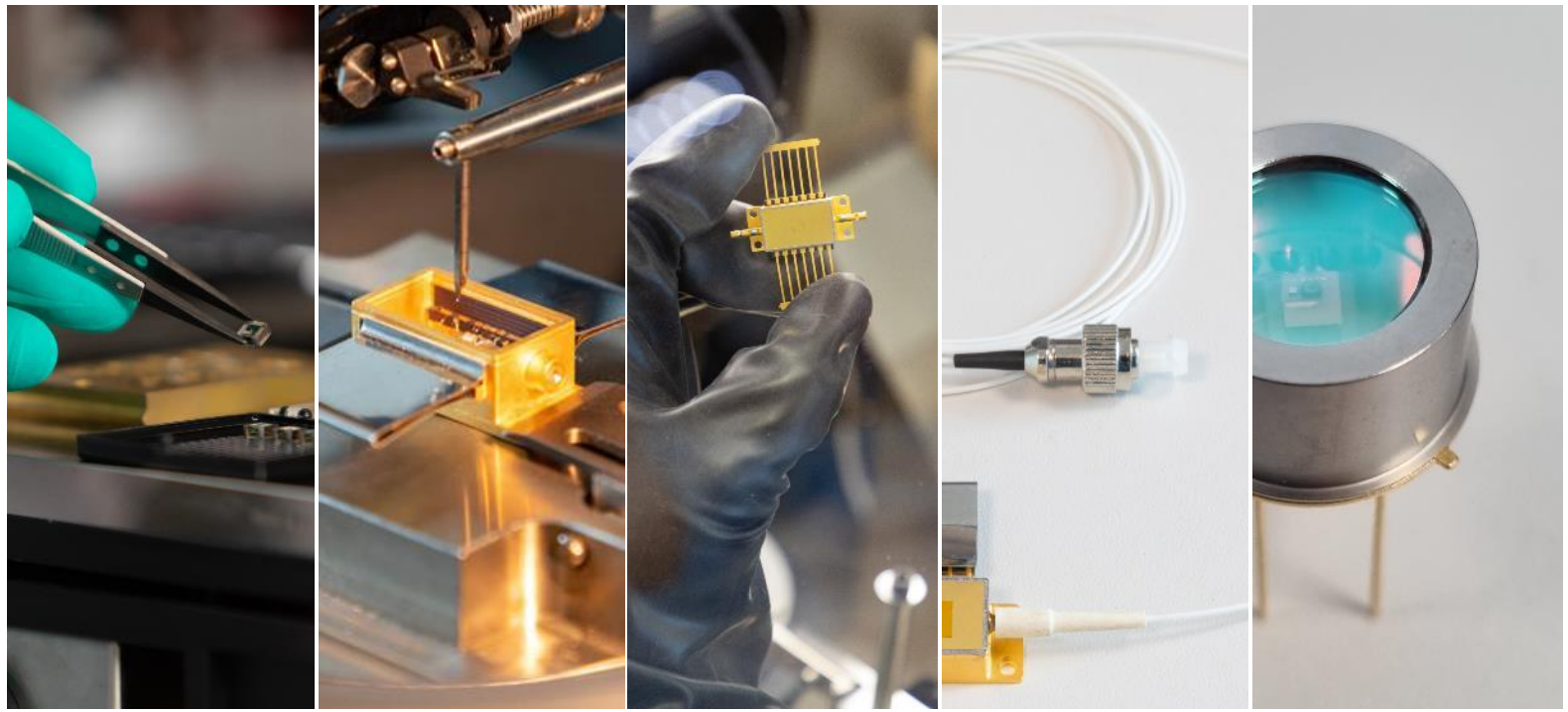
Bay Photonics

Packaging Photonic Components & PICs for Quantum Technology 2.0

Andrew Robertson

Nov 2022



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Advanced Photonics Assembly and Packaging

Bay Photonics Products & Services

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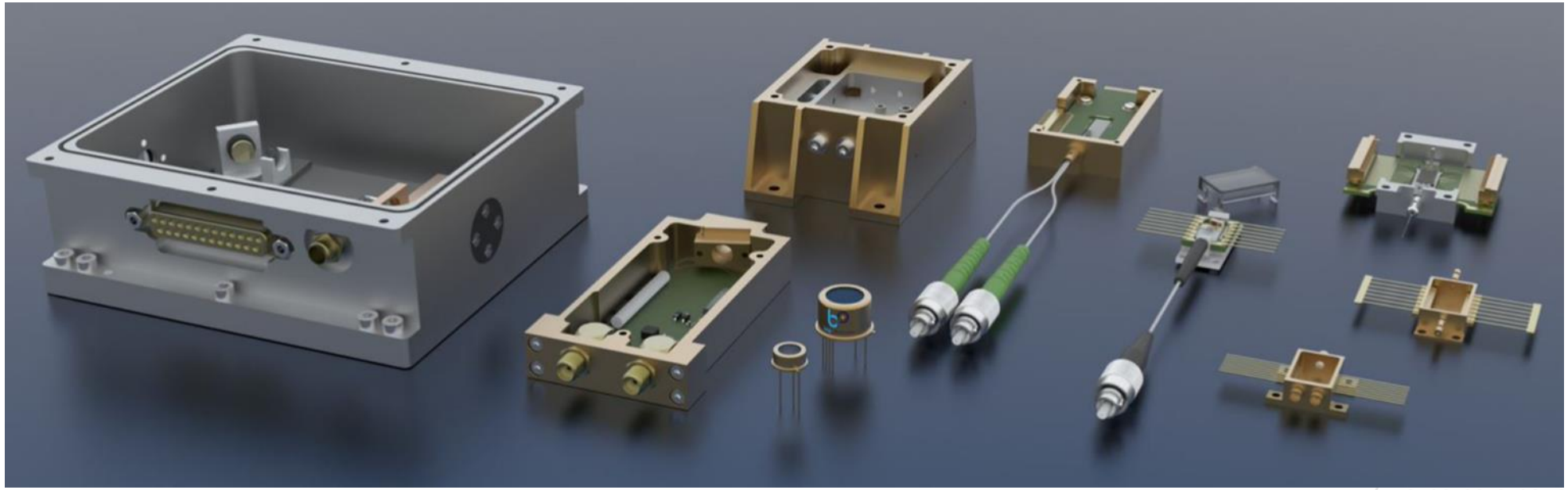
Advanced Photonics Assembly and Packaging

- Downstream photonic semiconductor (chip) processing
  - Die attach & wirebond, PIC packaging, co-packaging, hermetic (e.g. butterfly, TO)
  - Optical & electronic interface design & simulation, thermal control
  - Manufacturing process development to enable transfer to volume manufacturing
- Founded 2007, comprising former Nortel Networks & JDS Uniphase engineers
- Many decades of industrial optics & photonic packaging experience



Bay Photonics Location & Heritage

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TORBAY
Hi-TECH
CLUSTER

- 2020s EPIC Centre built Electronics & Photonics Innovation Centre

- 1950s STC builds factory
- 1980s worlds first fibre optic undersea cable systems
- 1990s Nortel Networks site employs 6000
- 2000s II-VI/Coherent, SIFAM, Lumentum, Spirent, G&H, Prior Scientific, Palomar

Manufacturing Process Development

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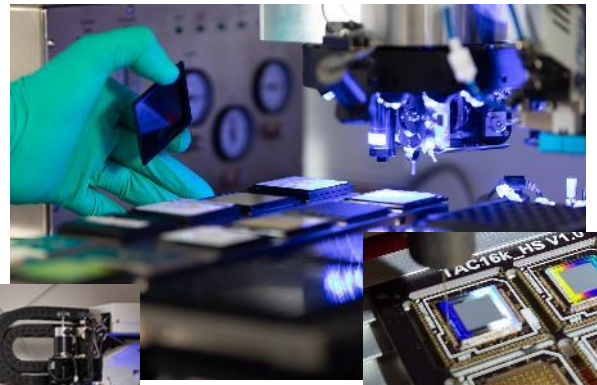

Palomar 3880 die bonder

Pyramid hermetic seam sealer

Palomar 9000 wedge bonder

AMADA Weld Tech hermetic seam sealer

Why does Quantum matter?

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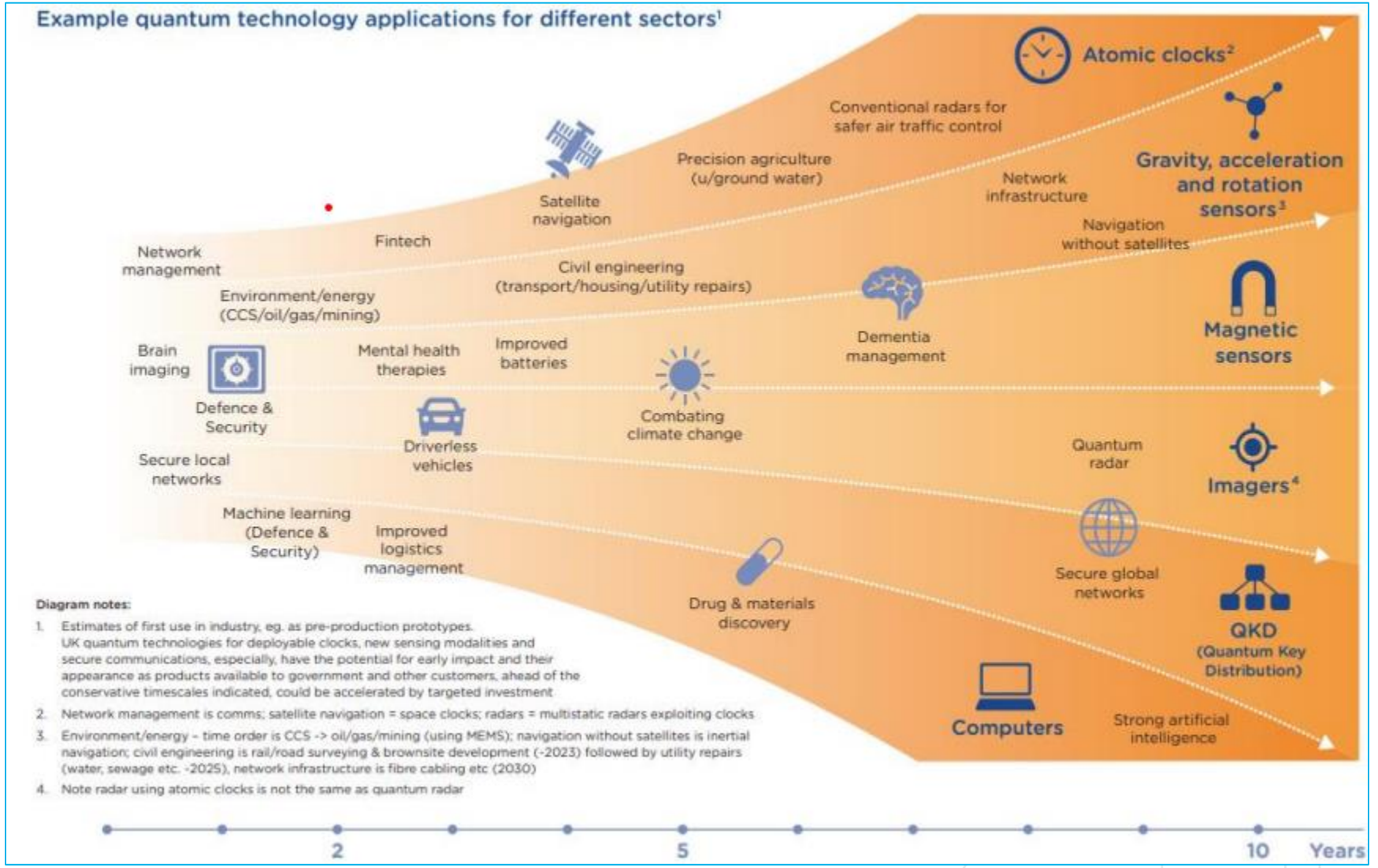
- Transformative change across multiple sectors
- Quantum Computing
- Quantum Secure Comms
- Quantum Sensing & Timing
- Quantum Imaging



Quantum & PIC Collaboration Partner

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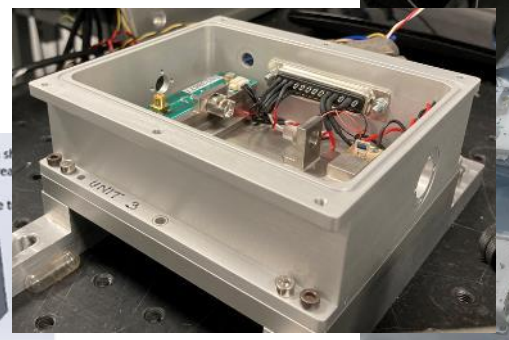
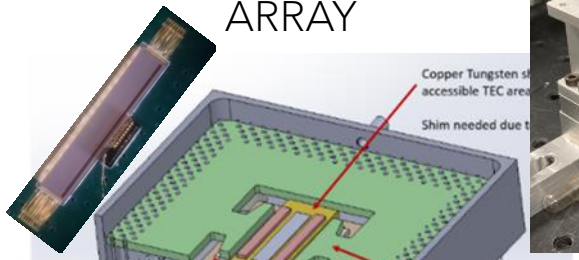
- Innovate UK
  - PACKABLE (IUK 104511)
  - AQUASEC (IUK 104615)
  - SIDEWINDER (IUK 133979)
  - SPLICE (IUK 106174)
  - QFOUNDRY (IUK 48484)
  - AIRQKD (IUK 45364)
  - SPIDAR (IUK 44835)
  - HIQED (IUK 10001572)
  - REDEEMA (EUROSTARS)
  - PADME (IUK 10031438)
  - Q-PODS (IUK 10032014)
  - Q3MD (IUK 10032009)

SIDEWINDER ECL

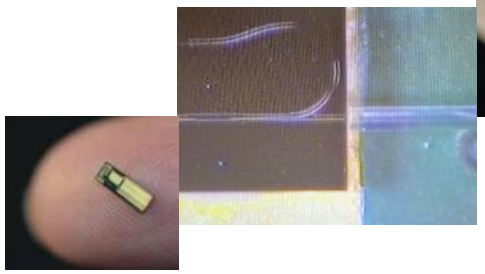


SPIDAR SPAD ARRAY



SPLICE LIDAR TRANSCEIVER

AIRQKD SPAD



PACKABLE PIC

Photonic Semiconductor Packaging

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- Mechanical (strength, mass, shielding, fixturing etc)
- Electronic (current, RF, ESD, etc)
- Thermal (high power, low temperature, temperature stability, cryogenic)
- Environment (N_2, vacuum, hermetic)
- **Optical (transparent material with characteristics to match other requirements!)**

Quantum semiconductor packaging "divergence"

Semiconductor Application	General Packaging Requirements			
	Wavelength	Environment	Heat dissipation	Minimum operating temperature
Computer CPU	non optical	Non-hermetic	High	-40C
Telco	"Colourless" Wideband	Non-hermetic	Low	-40C
LIDAR	Eye-safe	Non-hermetic	High	-40C
Quantum Technology	Narrow band (visible to IR)	Hermetic	High	-50C to cryo

Drive to Low cost

✗ "Leveraging Telco/Consumer Electronics"

✓ "Volume"

New optical Tx (*+ve*) margin only realised after 12 months of production and > 10000 units per month

Photonic Integrated Circuits

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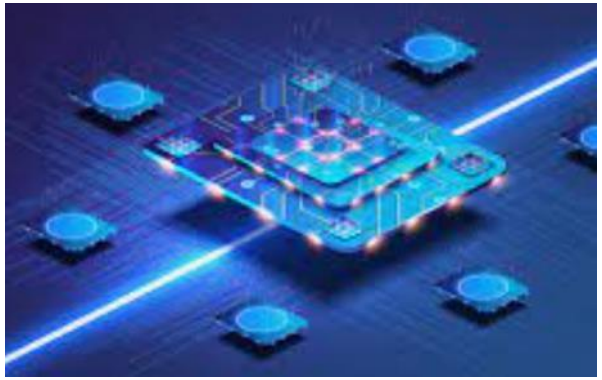
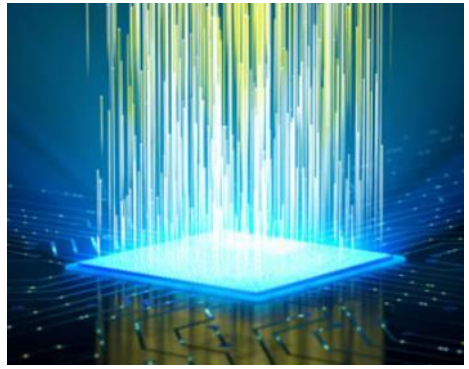
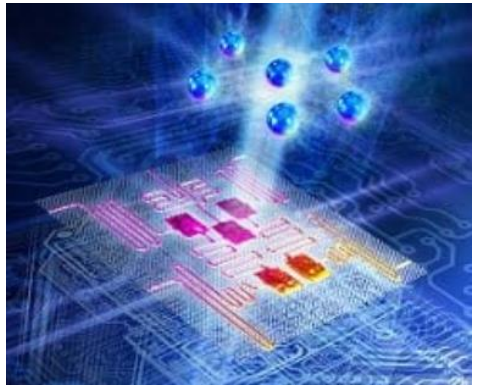
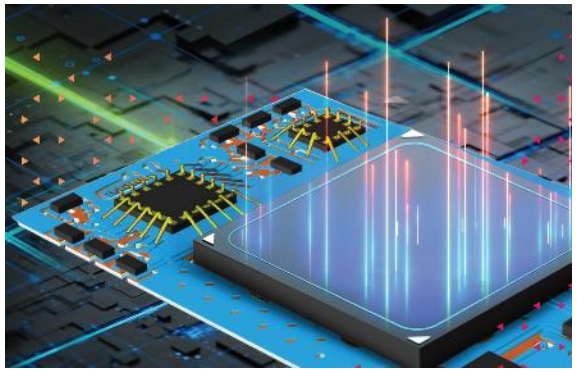
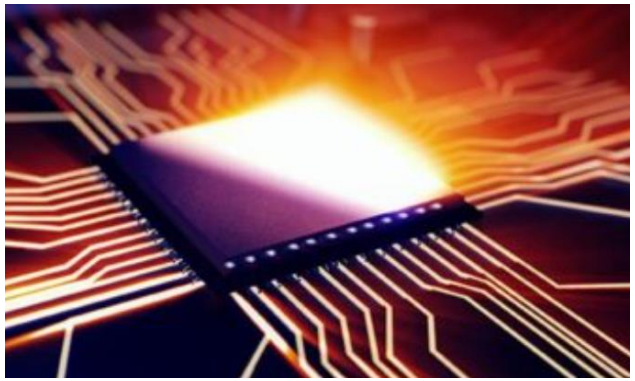
- Mainstream media view of “quantum chips”



PIC Reality

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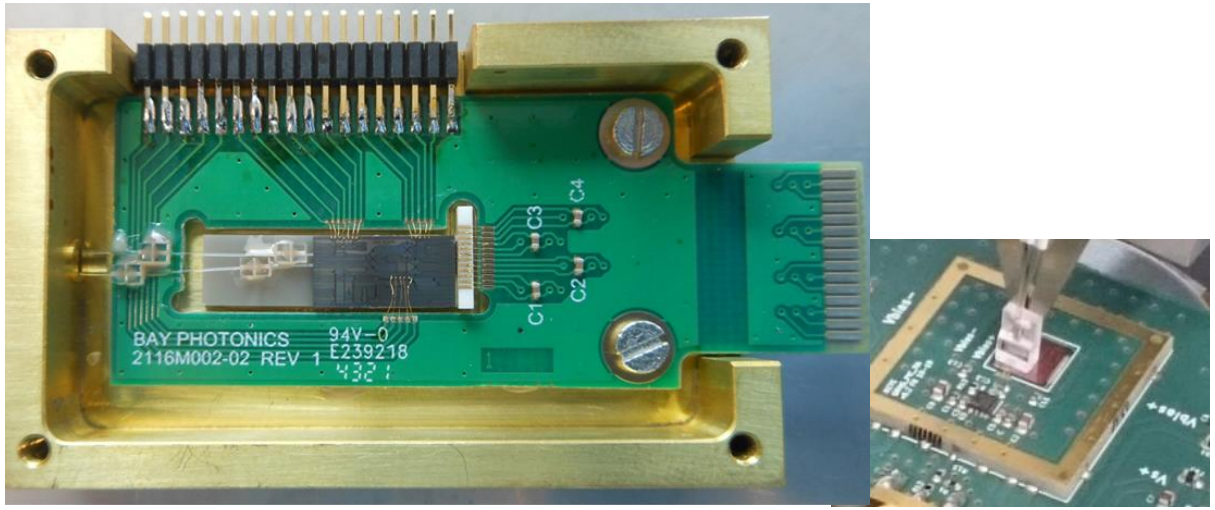
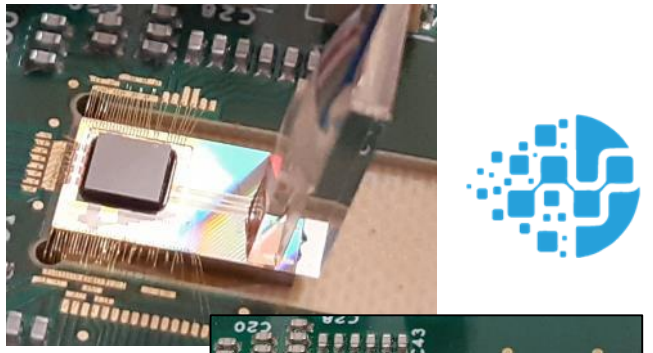
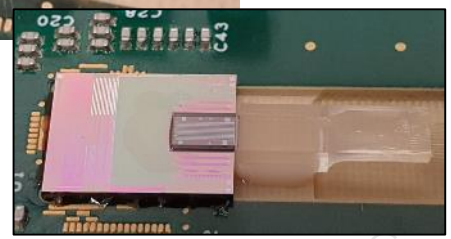
- No one material will do all functions
  - Need chip-to-chip optical interface
    - Not fibre
  - Electrical & optical chips need interfacing
- Low temperature operation
  - Vacuum
  - Cryogenic
- Higher & higher electrical I/O count
  - 10s of thousands for processors
- Light needs to get out of package
  - Transparent packaging
  - Mode field conversion, fibre optics





RESOLUTE PHOTONICS



Photonic considerations

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- Wavelength
- Optical performance expectations (IL, WDL, TDL, PDL)
- Number of optical I/O
- Edge vs surface coupling
  - Surface coupling allows wafer level testing
- Mode conversion waveguide tapers
  - Optical model?
  - Mode field measurements, far field measurements?
- Fibre array
  - Made up of “strands” consisting of 12 fibres, not arbitrary!
- Optical feedback restrictions
  - AR coatings, fibre lens designs, optical windows
- Power vs stability trade off

SPAD (QFOUNDRY)

FOUNDRY

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- Quantum emitters & detectors for fibre communication
- Fibre coupled SPADs
- Low temperature, -50C operation
  - Optimum TEC performance in vacuum
    - Standard telco is N_2
    - Standard welding machines do not seal in vacuum
    - Bay developed vacuum process for butterfly type packages

BT and Toshiba launch first commercial trial of quantum secured communication services .

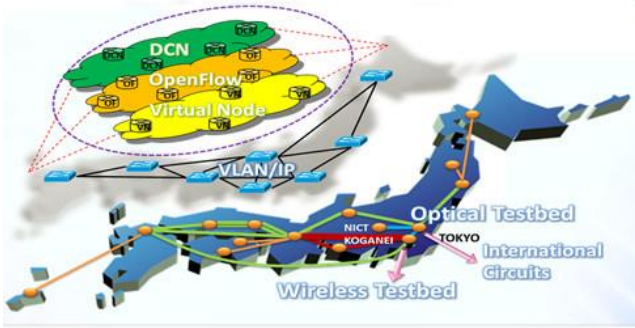
Written by BCCJ
April 28, 2022
Member News

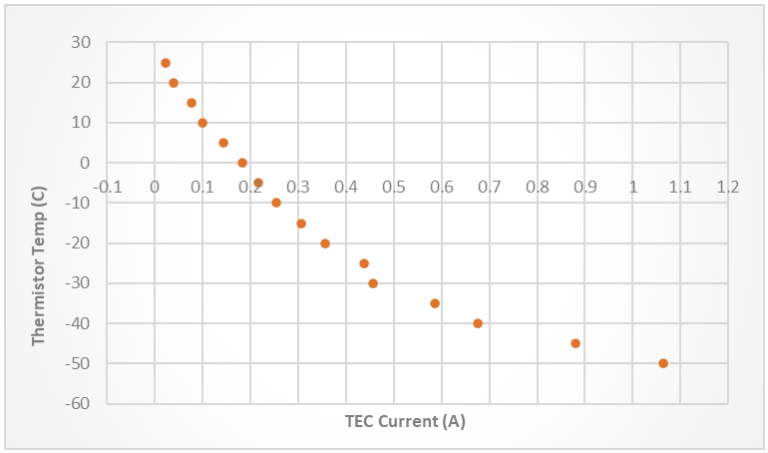
TOSHIBA | BT

EY becomes first commercial customer to connect quantum secure data transmission between its major London offices.

Wednesday April 27, 2022

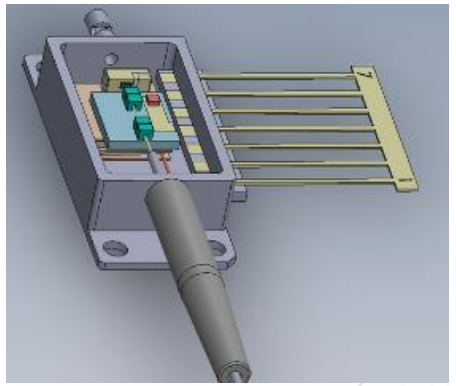
London, England and Japan – At an event held at BT Tower yesterday (Tuesday 26th April), BT and





QFoundry SPAD QFE1A4 vacuum butterfly package

Vacuum Performance
- Average reduction in temp 5C to 7C
- Efficiency of TEC increases by ~15%



SPAD (AIRQKD)

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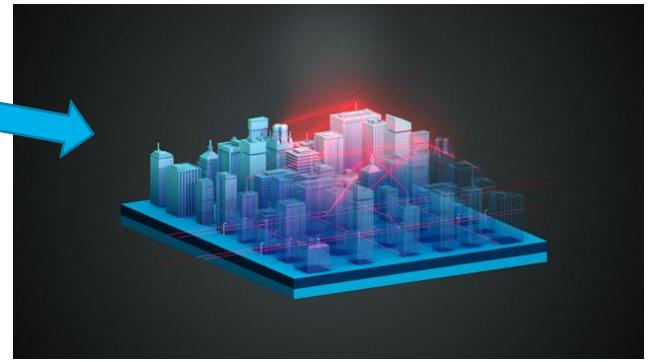
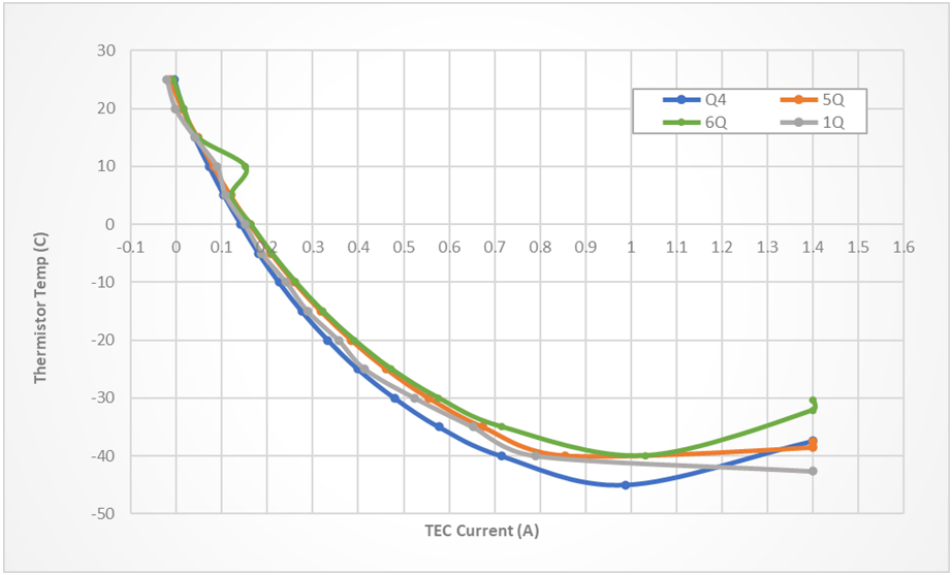
- Line of site communications (city landscape)
- "Standard" packaging
- Low temperature -40C operation
  - Optimum TEC performance in vacuum
    - Projection welding machines do seal in vacuum

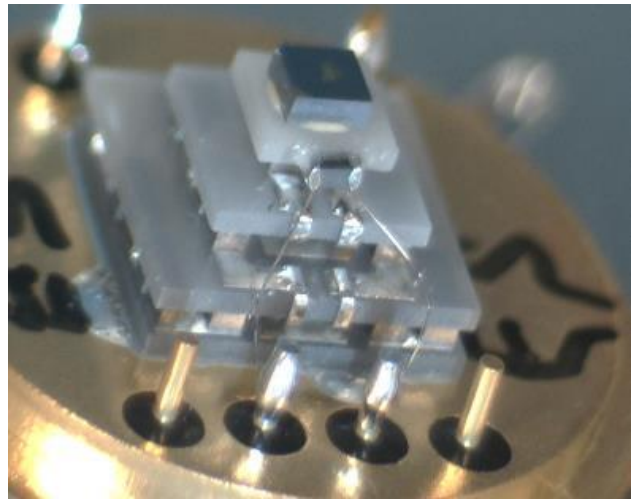


AIRQKD CONCEPT



AIRQKD package performance

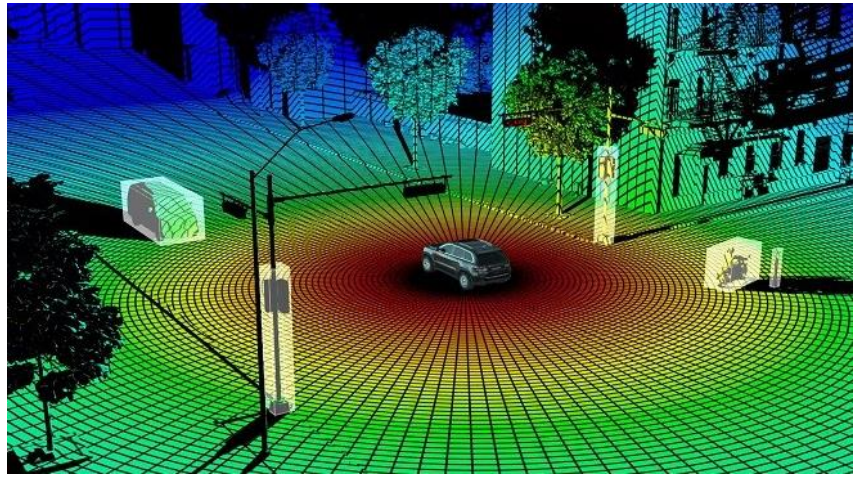
- Devices reached -40C
- Best performance -45C

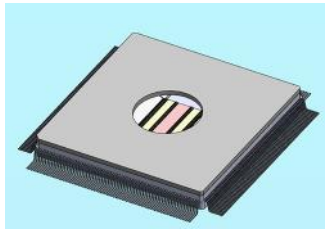


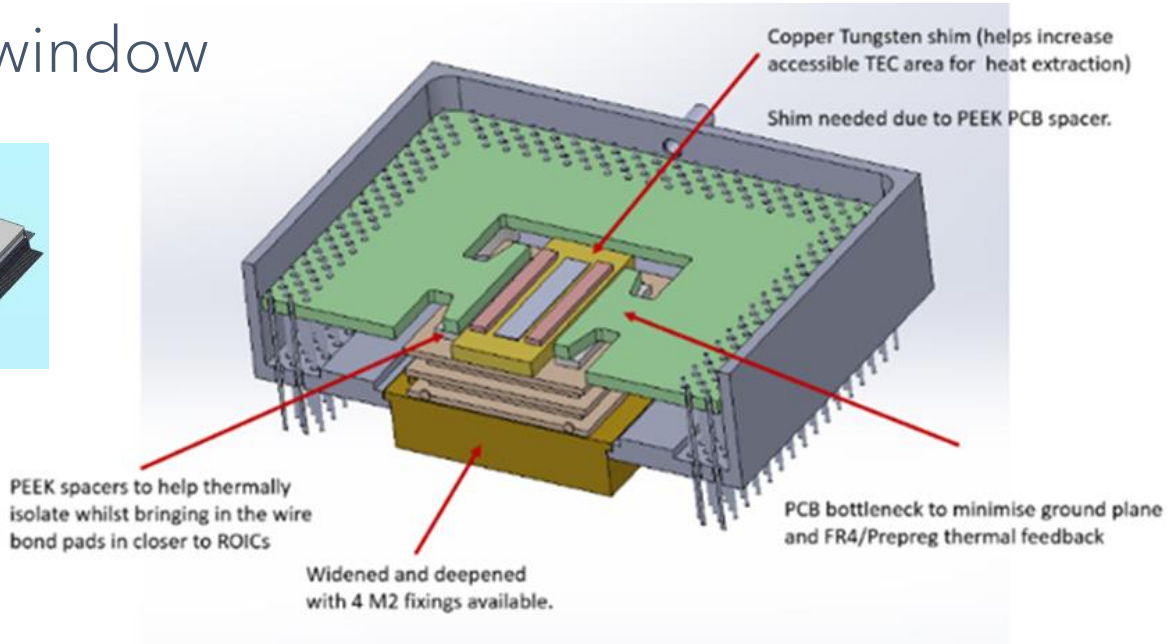
AIRQKD SPAD TO8

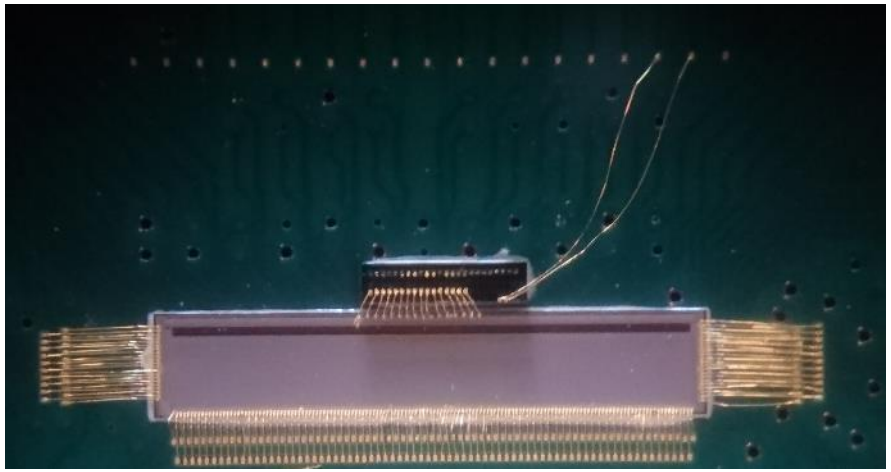
SPIDAR SPAD Array

- Quantum based LIDAR
- Needs electrical connection ROICs
- To achieve performance, -40C to -50C
  - Sealed under vacuum, hermetic
  - Hybrid housing – TEC on high thermal conductivity material brazed insert
- 300+ pin out electrical connections
- Optical window









2x16 test SPAD array with ROIC

PIC flexibility is packaging challenge

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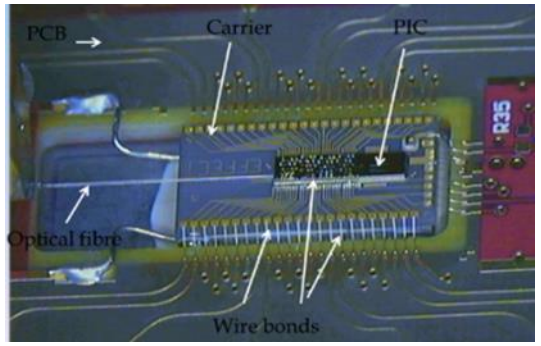

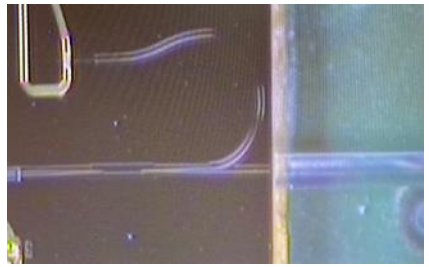

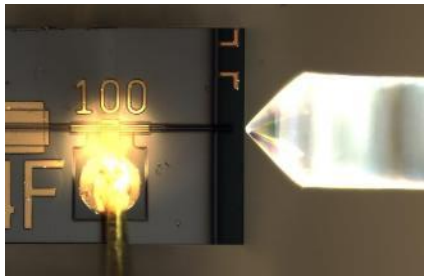

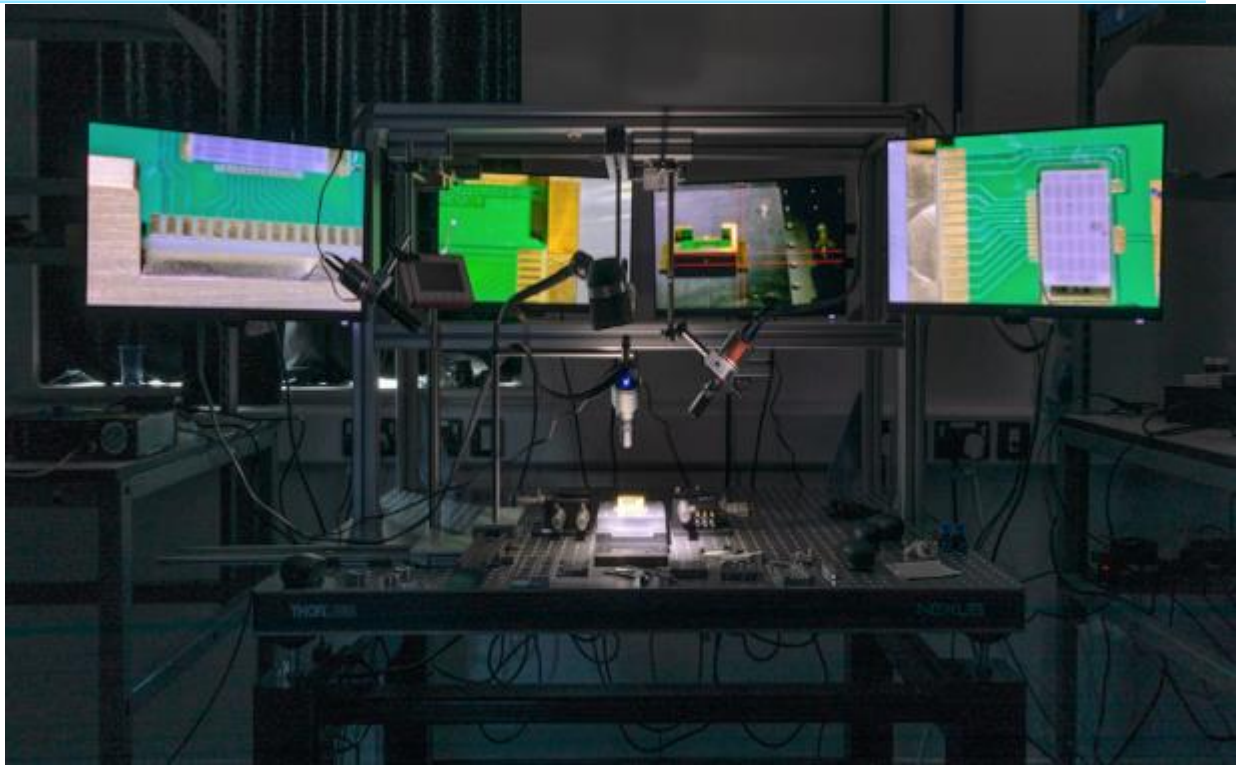

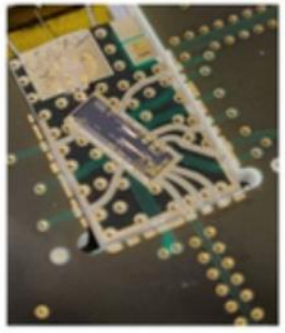

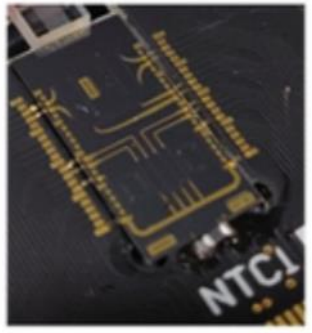

Images from TOSHIBA AQUASEC project

- Manual die & wire bonders
- Piezo controlled sub-micron alignment stages
  - Pitch & yaw
  - Rotation (PM)

QUANTUM PROBLEMS

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- Test, measurement & assembly
  - How do you test the performance of a single photon emitter?
  - How do you measure the wavelength of a single photon emitter?
  - How do you optimise transmission in a system with single photons?
- Optical component performance
  - Interact with the real telecoms network and your single photons will be lost! Even optical fibre has a loss.
  - To date QKD demonstrators are point-to-point
- The classical world
  - How do you filter out the sun in free space quantum comms?

Future enabling tech - optical

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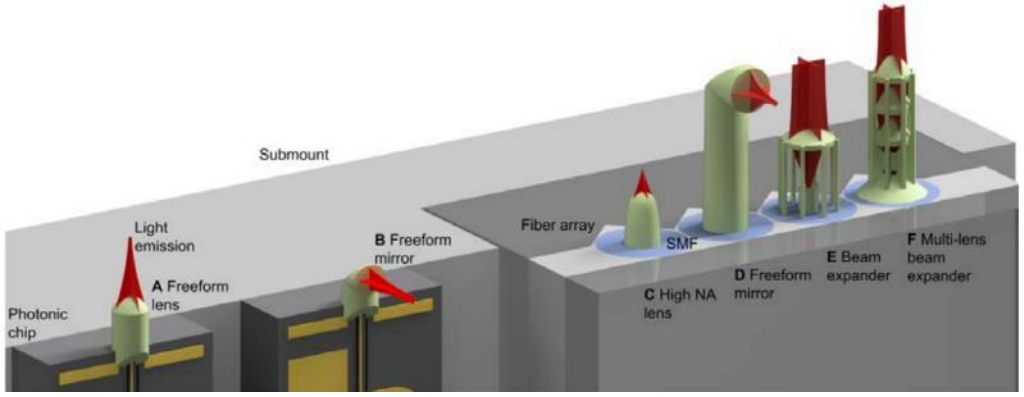
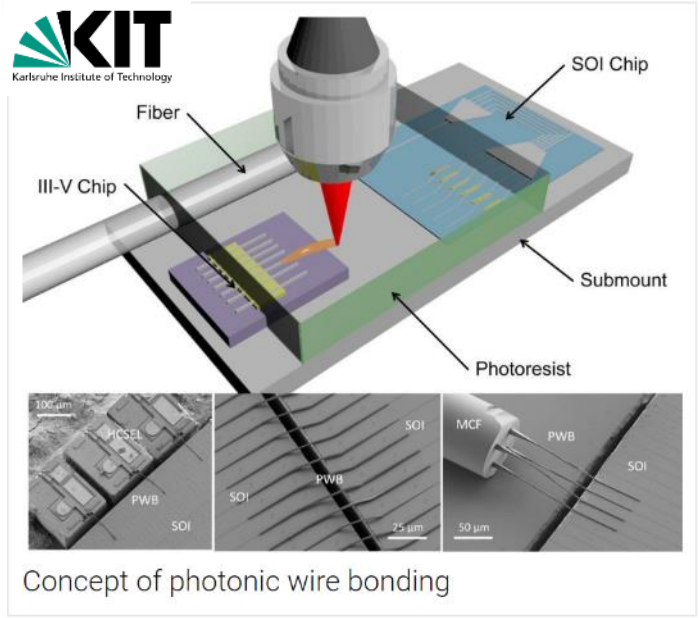
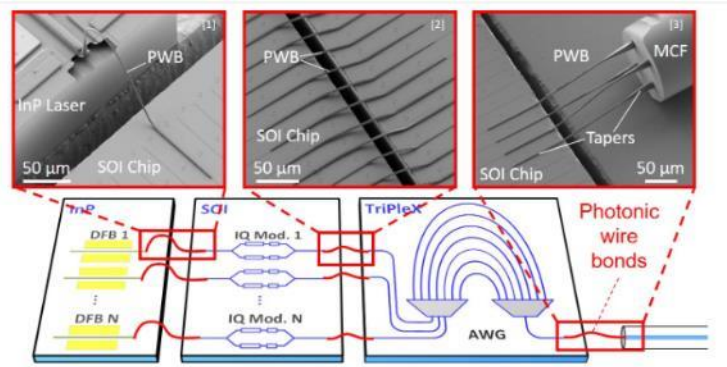
- Additive 3D Nanofabrication
  - Two-photon polymerization (TPP)
  - Inter-chip connectivity
  - Optical componentry
    - Free form lenses & mirrors
  - Several companies developing workstations



Source: KIT/Vanguard Photonics



Concept of photonic wire bonding



Future enabling tech

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KSOP Karlsruhe School of Optics & Photonics (KSOP)
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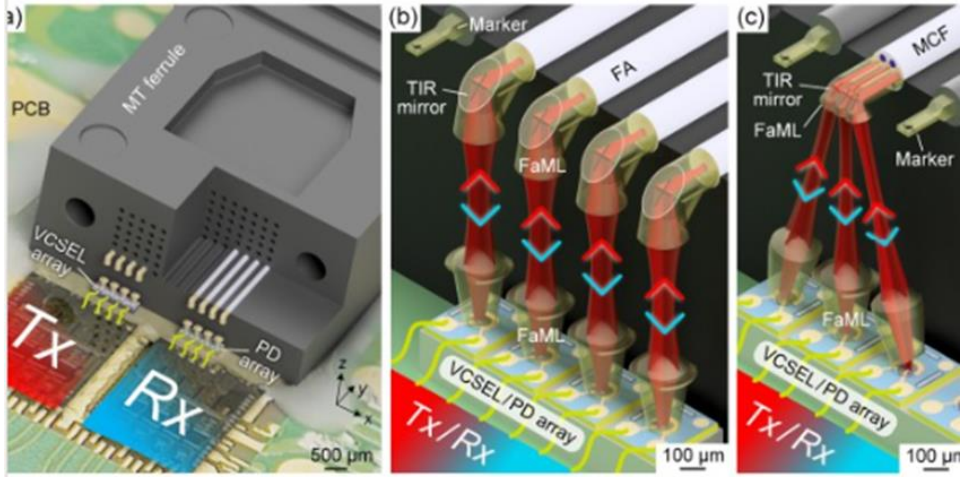
KSOP members Yilin Xu, Christian Koos and their colleagues wrote a paper about 3D-printed facet-attached optical elements for connecting VCSEL and photodiodes to fiber arrays and multi-core fibers. In their paper they d ...see more



3D-printed facet-attached optical elements for connecting VCSEL and photodiodes to fiber arrays and multi-core fibers - Multicore optical fibers and...
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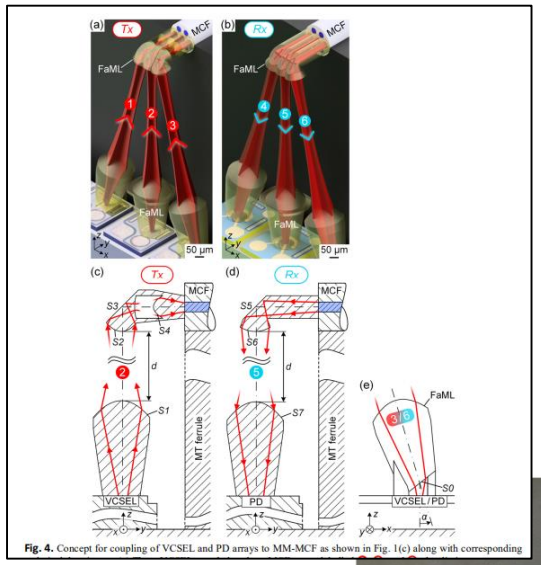

Fig. 4. Concept for coupling of VCSEL and PD arrays to MM-MCF as shown in Fig. 1(c) along with corresponding

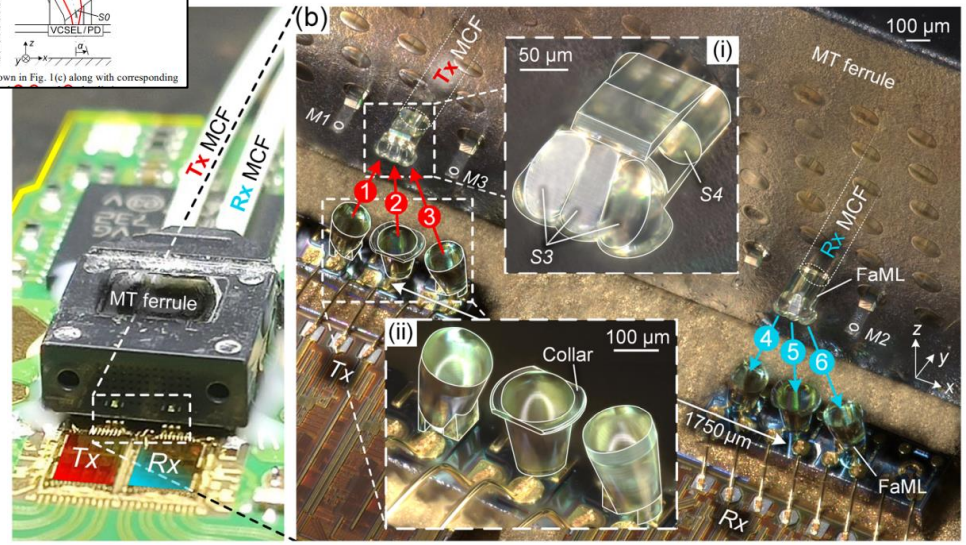

Fig. 5. Three-channel transceiver module implemented on a small form-factor pluggable PCB. Three Tx VCSEL ❶, ❷, and ❸ and three Rx PD ❹, ❺, and ❻ are connected to three cores of the associated MM-MCF.

Wafer level PIC fabrication

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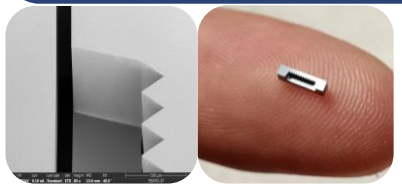
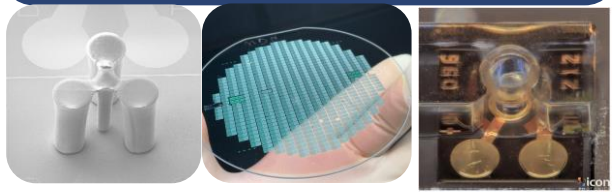
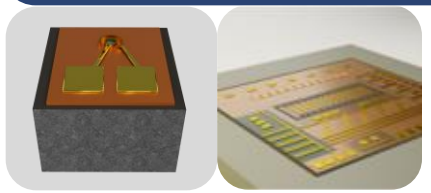
- Mechanical fixture for Fiber array self-alignment and attachment

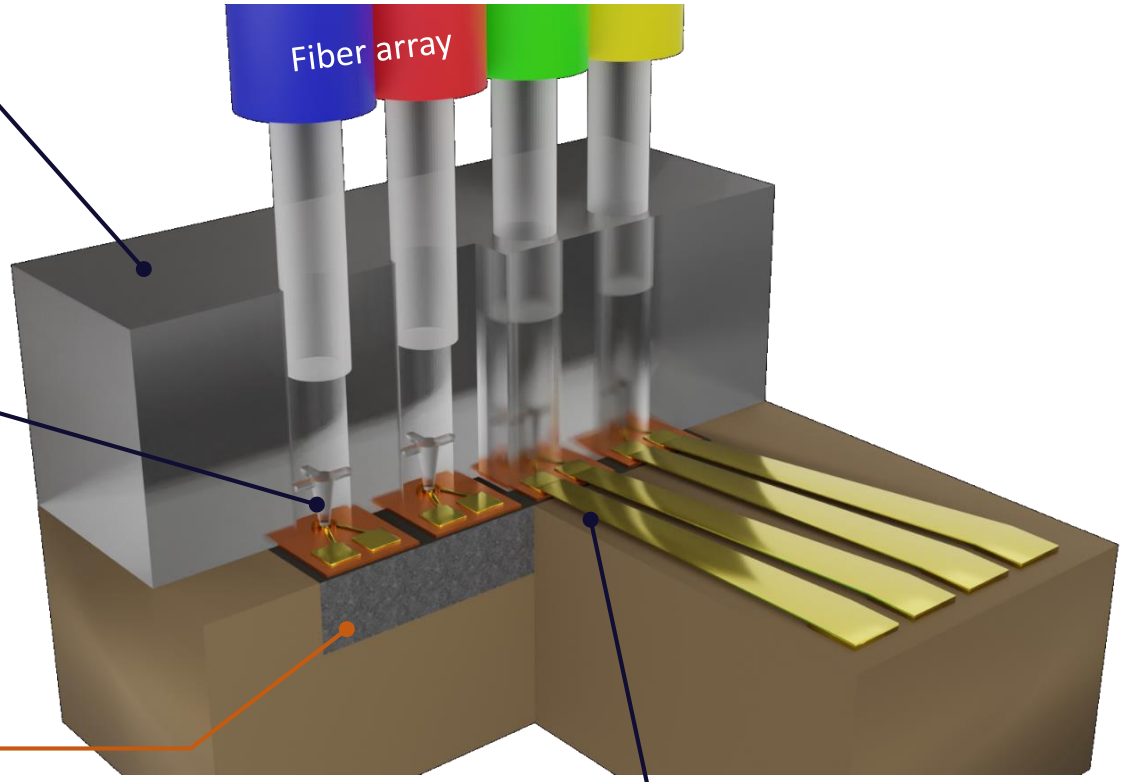


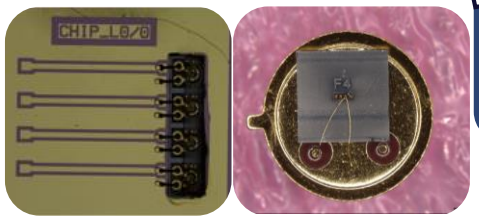
- Polymer micro-optics for low-loss light coupling



- Active device embedding: PIC, Detector, SNSPDs , VCSEL, Laser







- Silicon Electrical interposer
- RF and mmW transmission lines

Cryogenic compatibility !

icon PHOTONICS

Bay LoCoPack "Concept"

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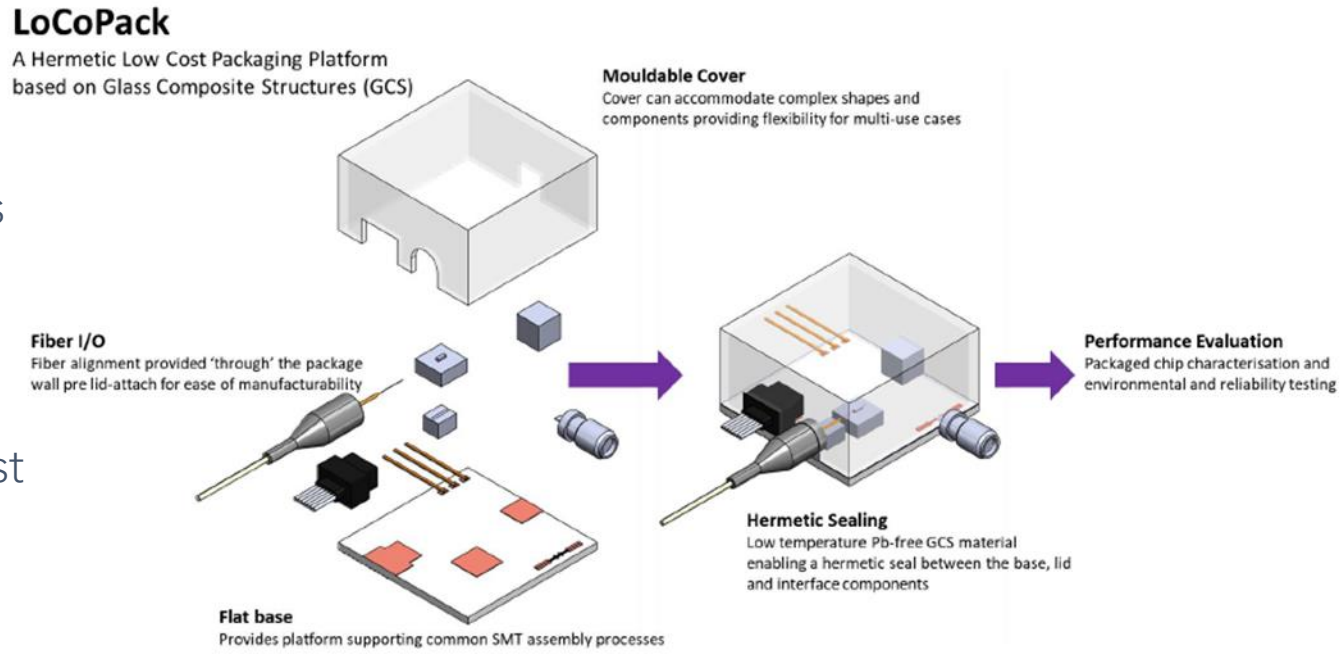
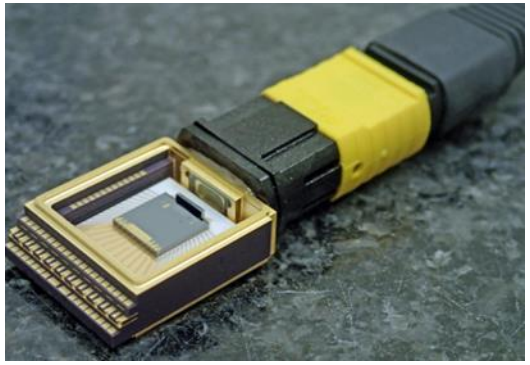
- Product platform designed for automation compatibility from day 1
- Open carrier allows access for P&P machines
- Glass Composite Structure enables new designs to be supplied in low volumes at far lower cost compared to metal packages
- High volumes can also be produced at a low cost
- Reduced development time and faster New Product Introduction as same package can be used for prototypes & volume
- Sustainable photonics packaging material

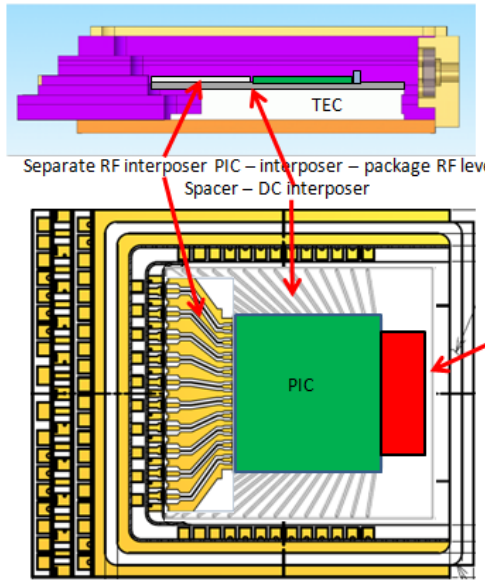


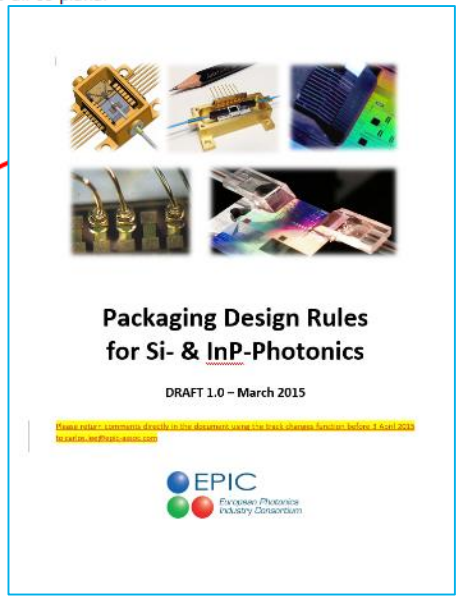
- Completely transparent package interface offers interesting options for LIDAR

Standardization

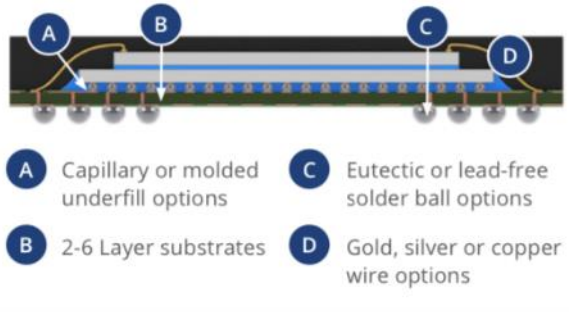
In 2010 the PARADIGM (FP7 EU project) partners were taking their first steps to define generic, InP-based, process platforms which could be run in industrial fabs, in an initiative which was unique in the world.

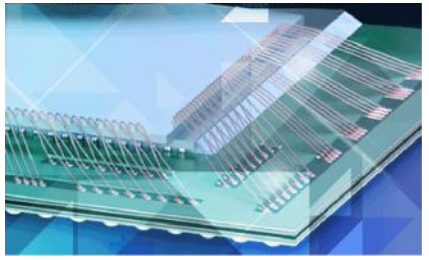


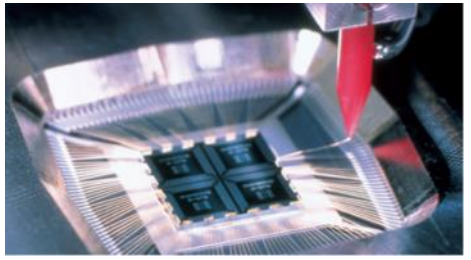




- Some standards exist
  - Low I/O componentry
  - TO, butterfly, DIL
- These were designed many years ago
  - E.g. TO standards 1950s!
- Some "de facto" standards appearing for PIC design
- Clear standards exist for electrical design
- Align with workstation capability







Don't Panic…

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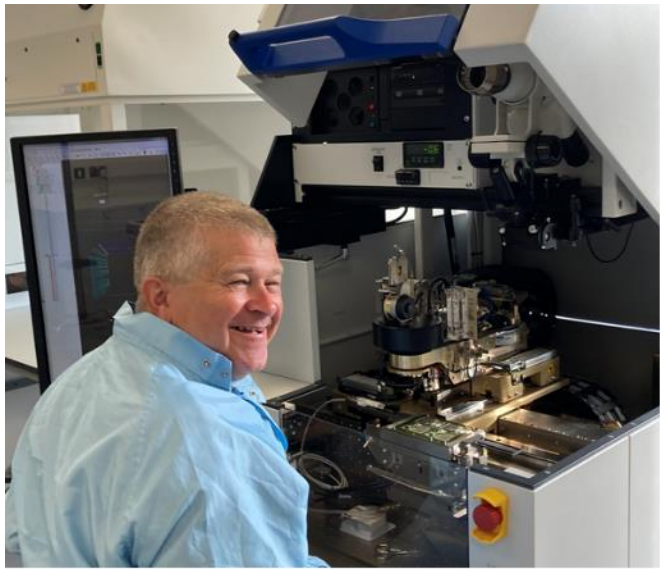
Scalable qubits Microsoft is developing hardware, such as this semiconductor–superconductor heterostructure device, and software for its scalable quantum computer based on topological qubits.

- We understand the need for proof of concept prototypes
- Manual die & wire bonders can be used to break the rules



Contact Details

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Future enabling tech – I/O

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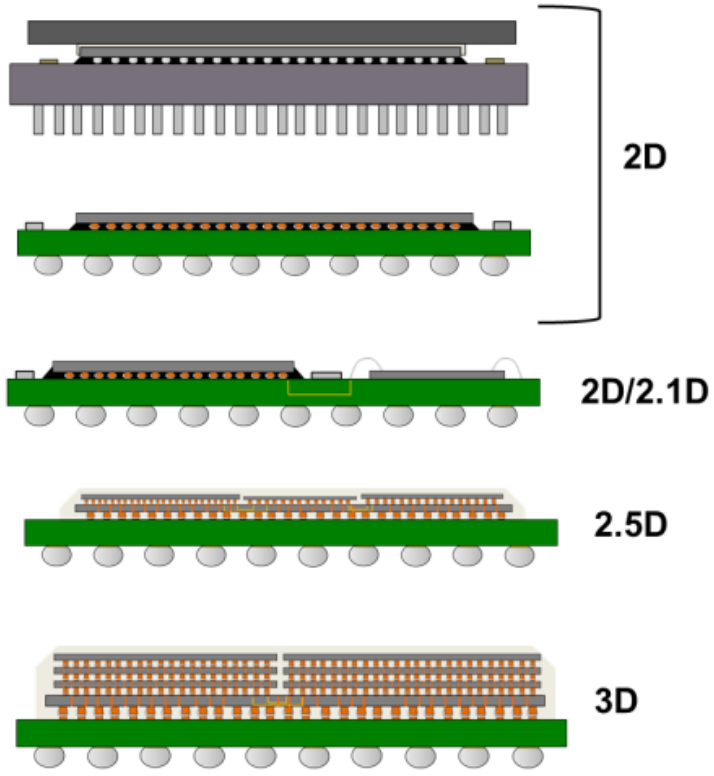
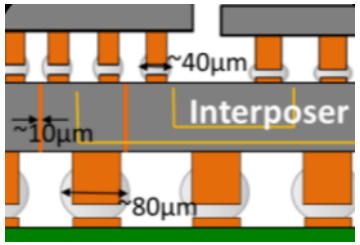
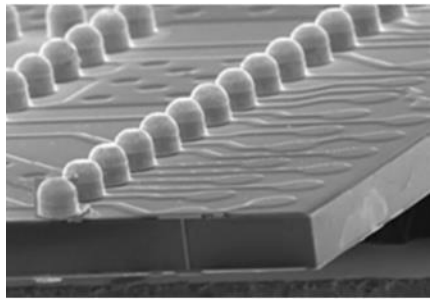
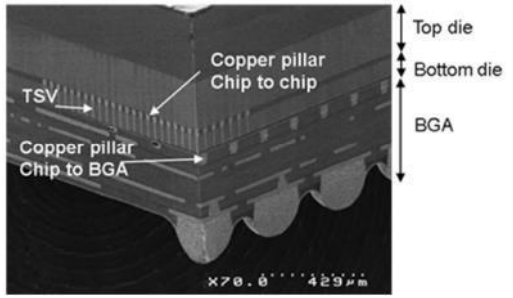


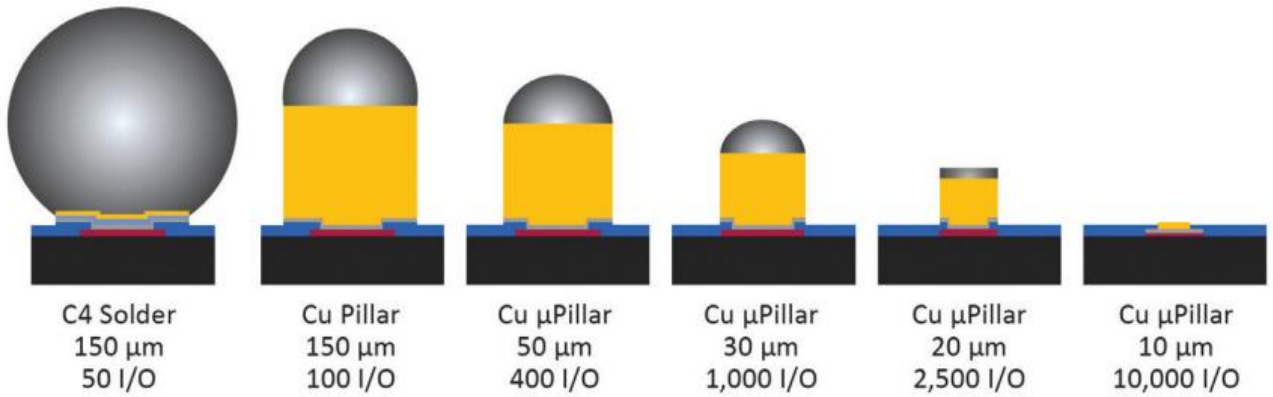


- Flip chip
- Cu micropillar
- TSV (through silicon via)
- 2.5D & 3D protocol





Source: CEA LETI



I/O per mm^2