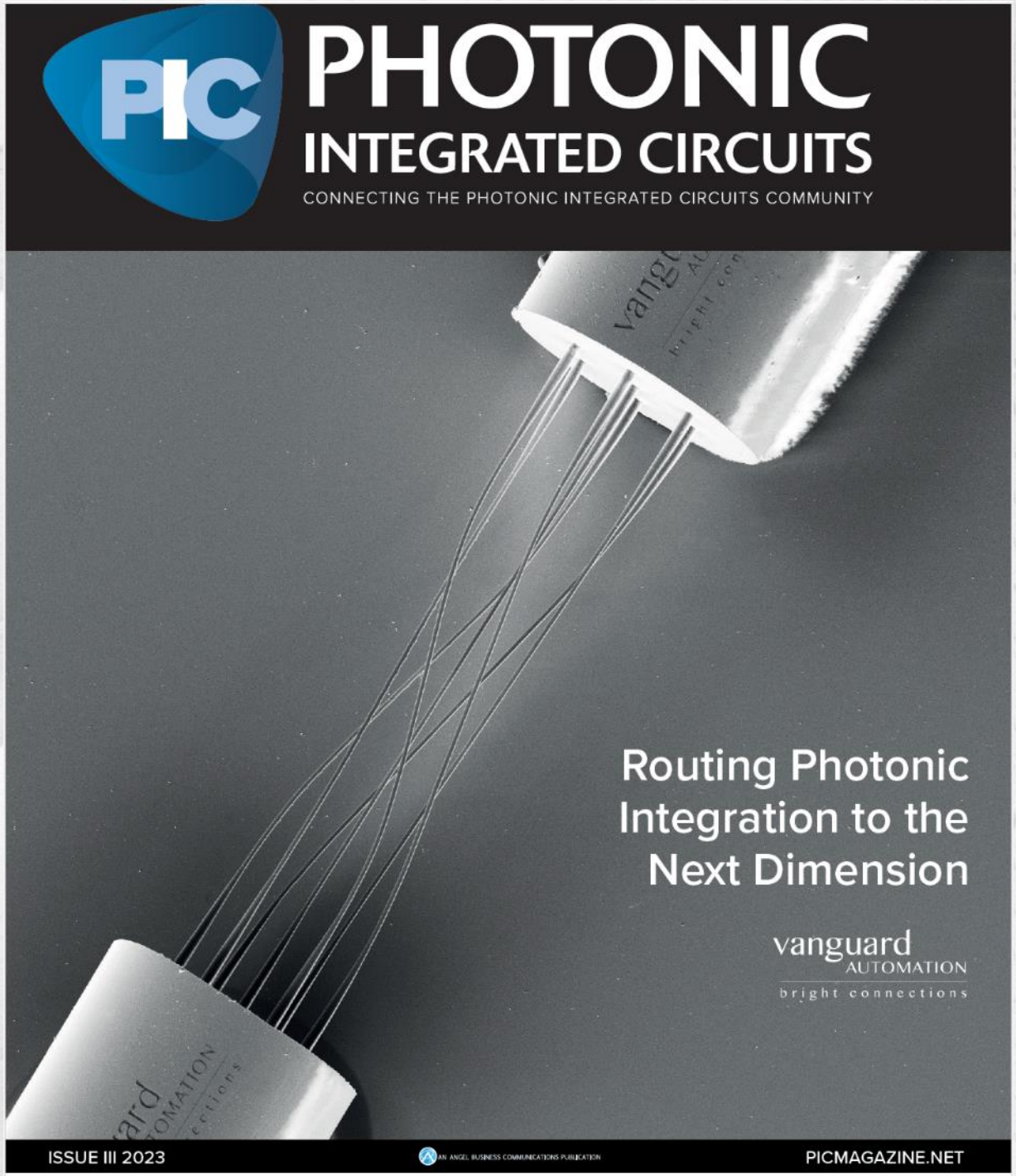


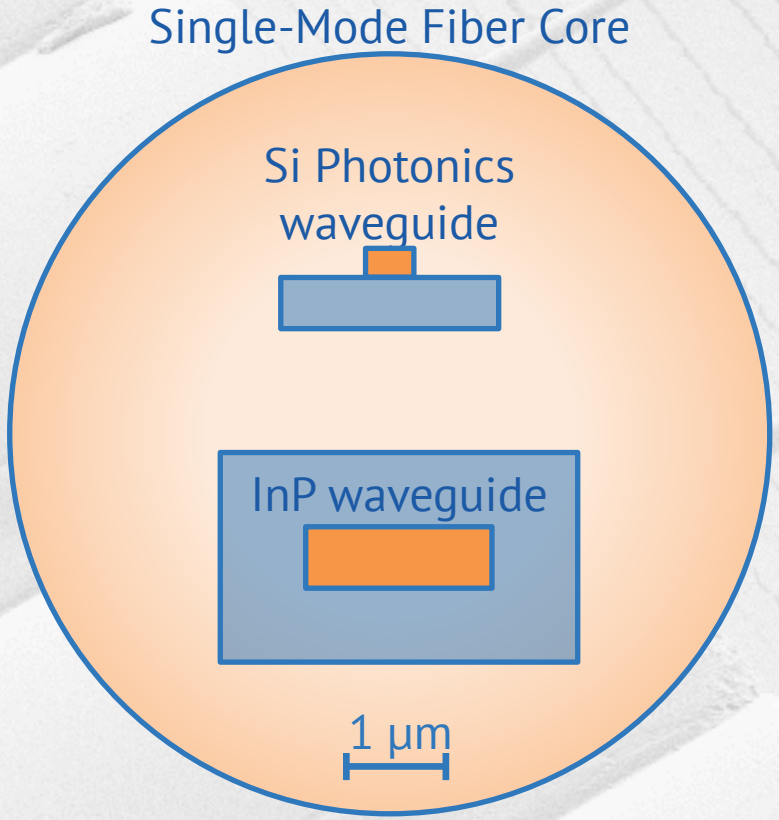
vanguard AUTOMATION

bright connections

Connecting and Packaging Multi-Core Fibers with **Photonic Wire Bonding (PWB)**

Today's Packaging and Assembly Challenges

Different Mode Field Sizes and Heterogenous Material Platforms



→ Mode field matching.

→ High-precision assembly alignment.

→ Fast and reproducible packaging.

→ Reliable under various conditions.

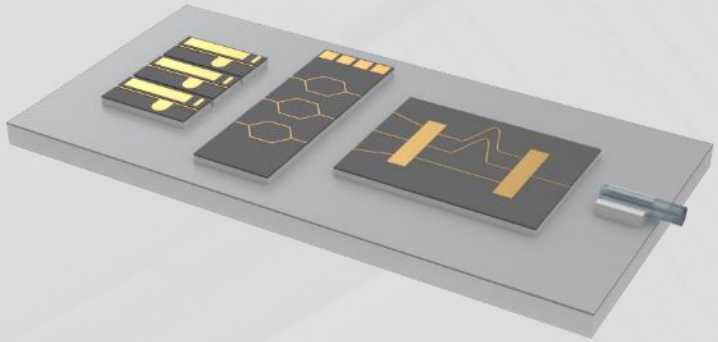
→ Over 70% of cost of photonic integrated systems are caused by the packaging process

Our mission

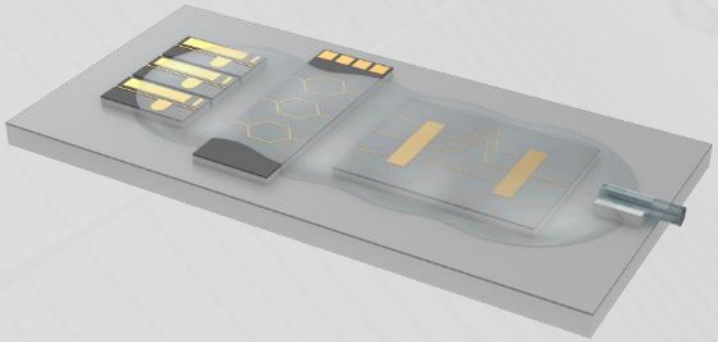
Advance Photonic Packaging and Assembly by providing scalable 3D nano-fabrication solutions from prototyping to high-volume production.

3D Laser Lithography for Photonic Packaging – The Process

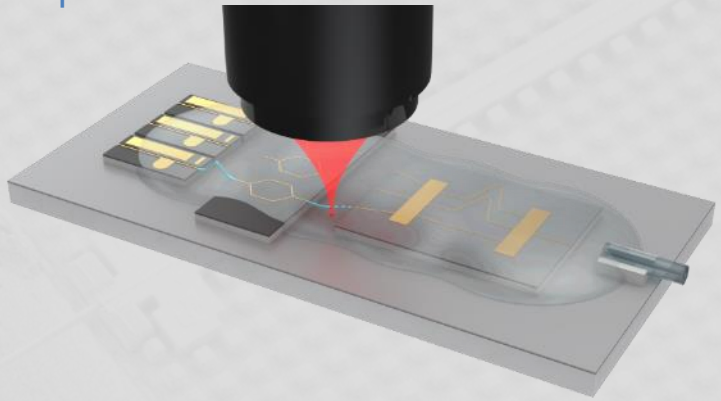
Step 1: Assembly Build-Up



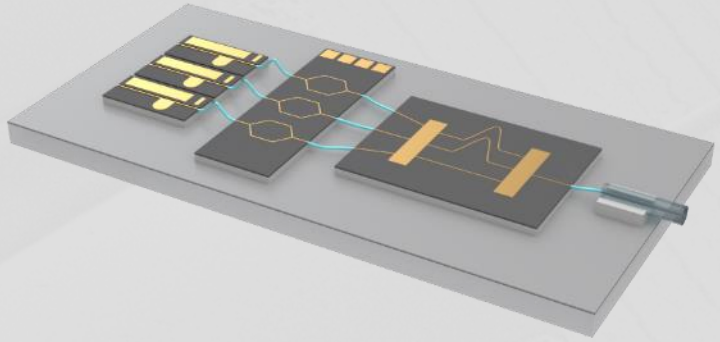
Step 2: Resist and Interface Detection



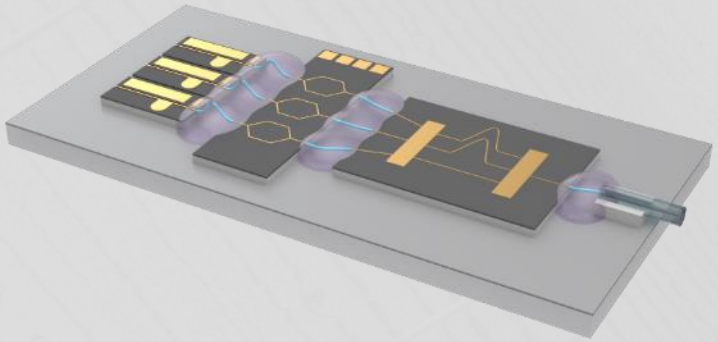
Step 3: Fabrication of PWBs



Step 4: Developing and Cleansing



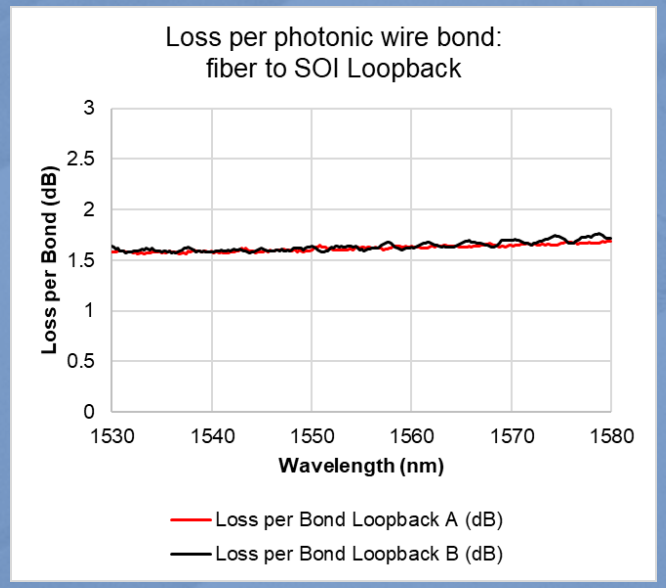
Step 5: Cladding (Encapsulation)



Compatibility with material platforms/foundries

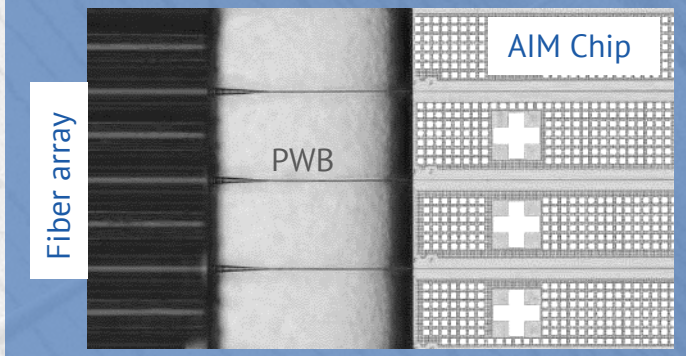
Silicon (AMF, Singapore)

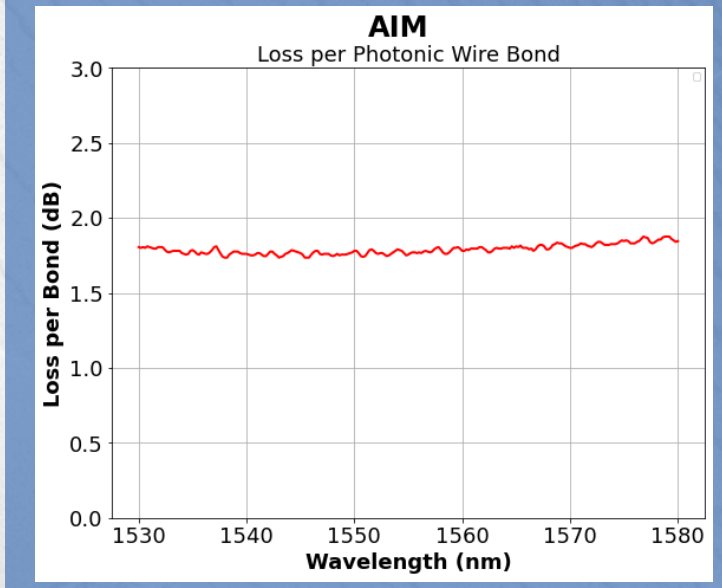
- ~1.5dB loss



Silicon nitride (AIM, USA)

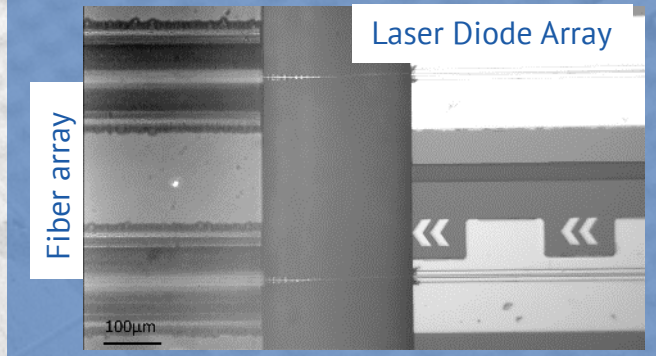
- ~1.7dB loss

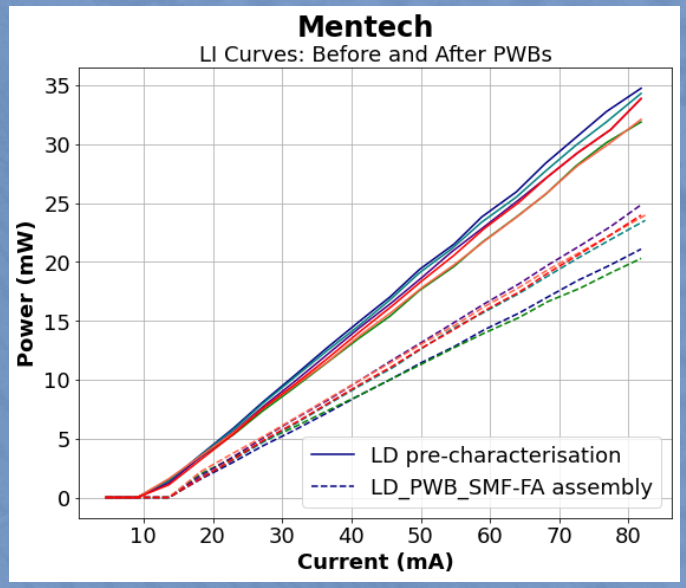




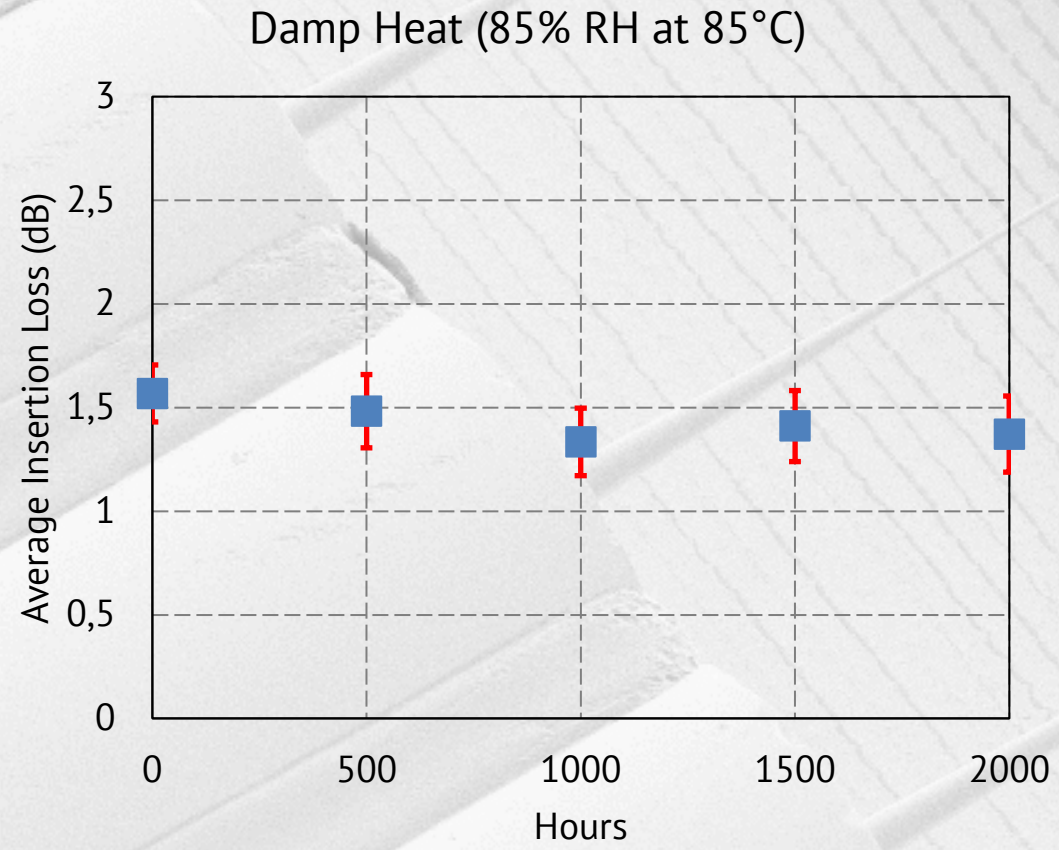
Indium phosphite (Mentech, China)

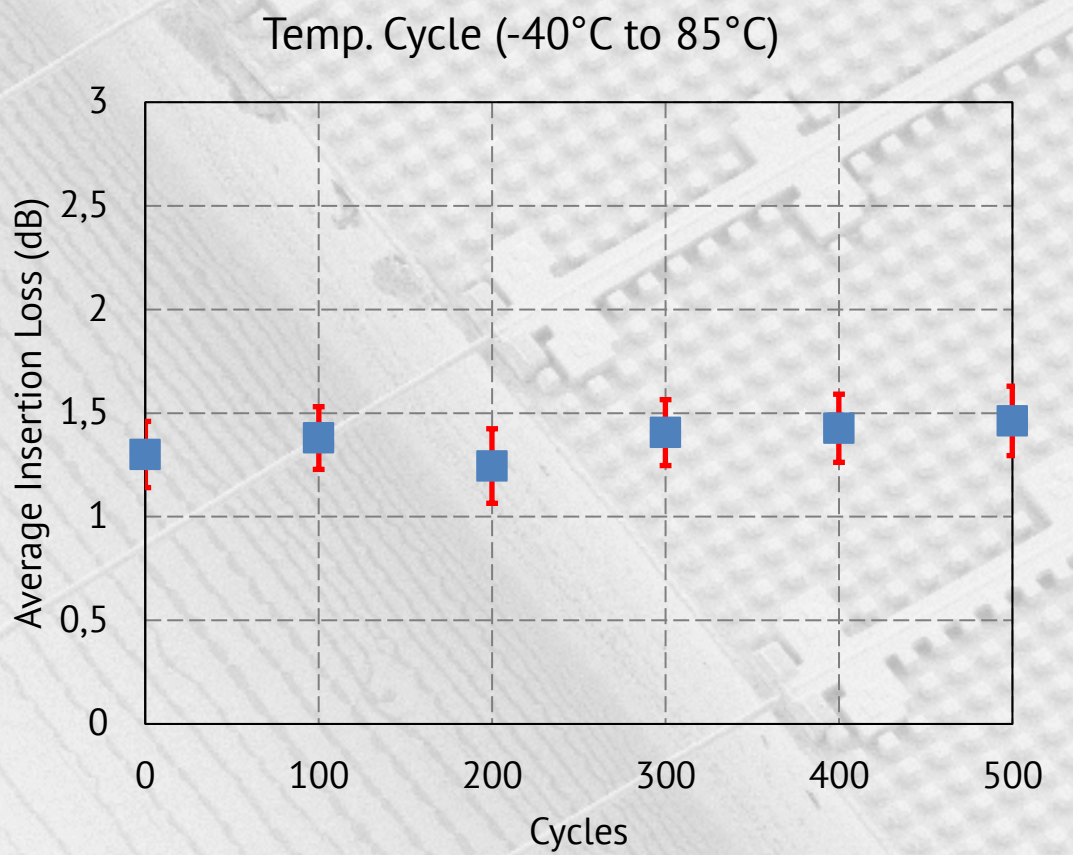
- ~1.5dB loss





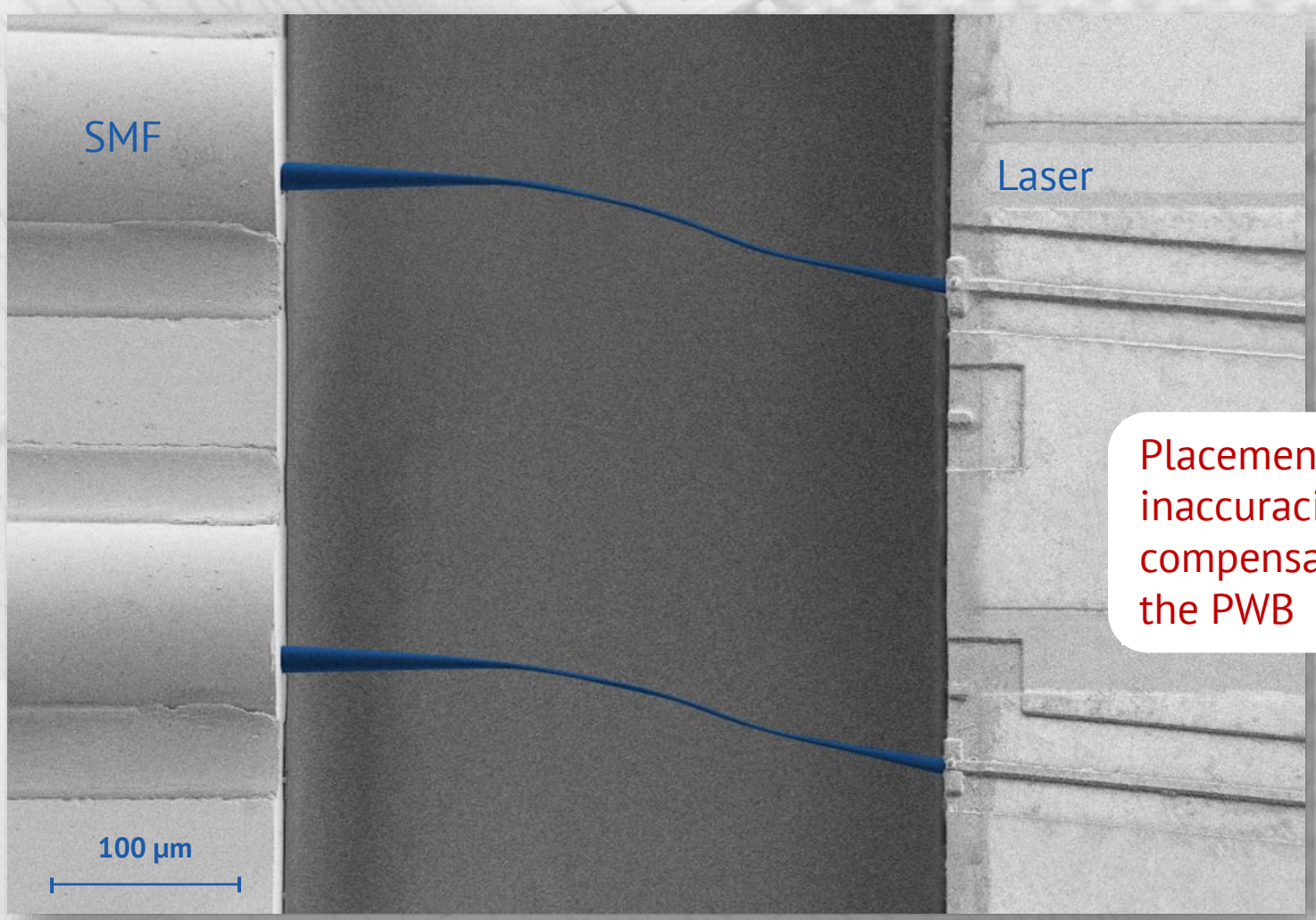
Passing Standard Reliability Tests for Tele/Datacom





Photonic Wire Bonding: The Benefits

- Low loss connection to arbitrary mode fields
- Automatable, reproducible and fast processes
- Reliable connections under various conditions
- High interconnect density (compact modules)
- High degree of design flexibility for hybrid multi-chip integration
- C-Band and O-Band

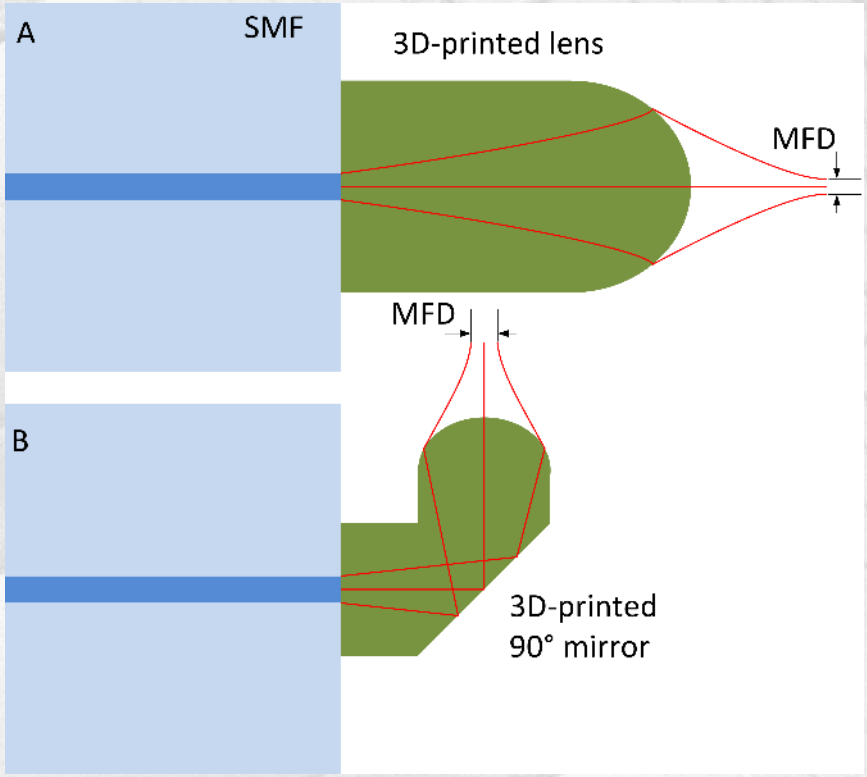


Placement inaccuracies are compensated by the PWB

Laser by Freedom Photonics LLC

Facet-attached micro-lenses

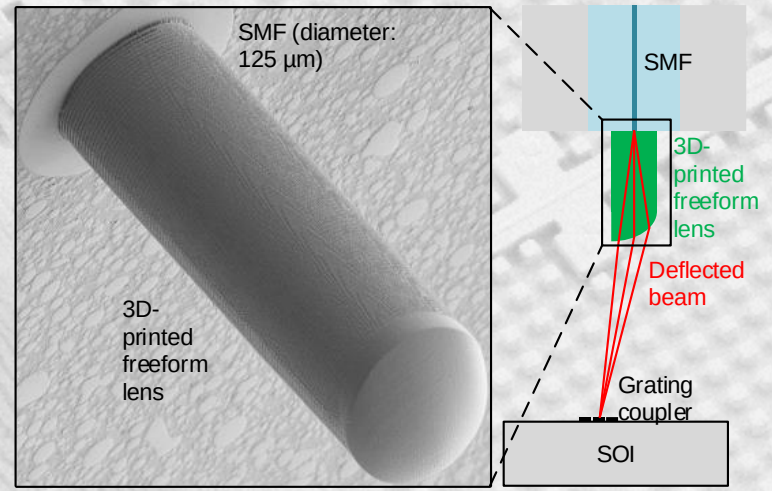
Standard optics on fiber arrays



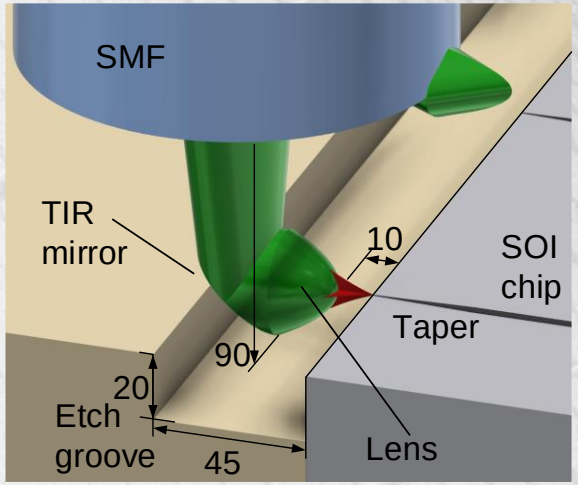
Various fiber array pitches, MFDs, wavelengths, and sizes

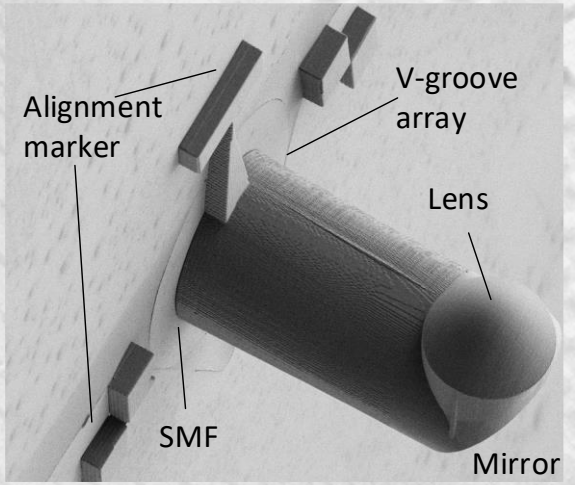
https://keystone-photonics.com/

Development of customer specific micro-optics



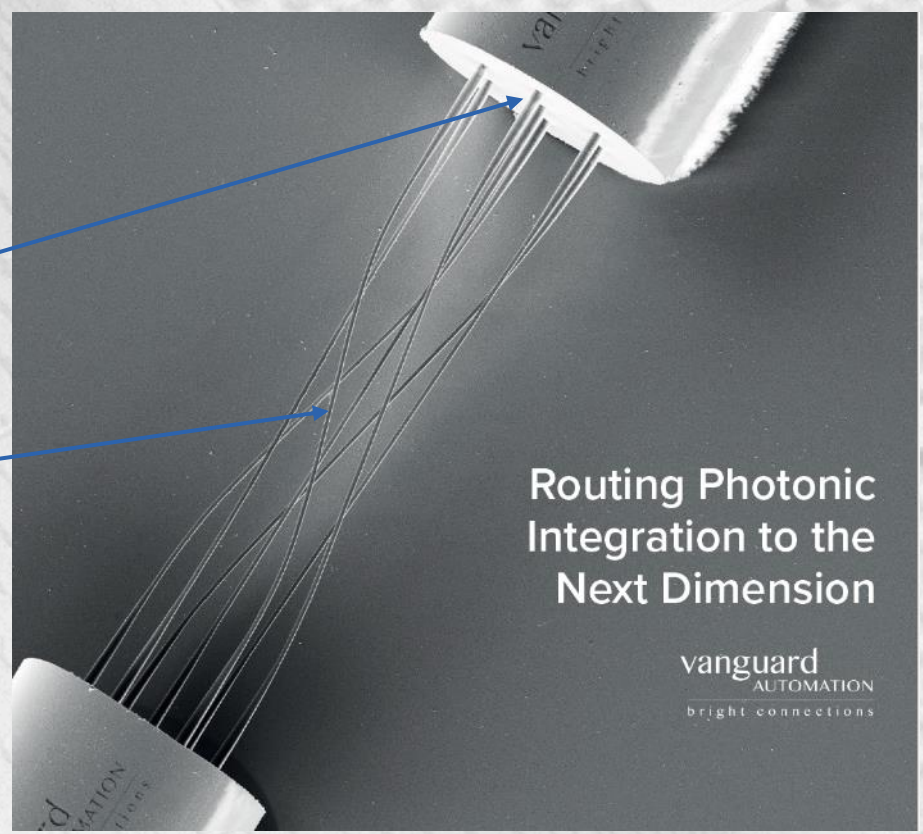
Application specific, e.g. for Wafer-Level Probing





PWB Connections to Multi-Core Fibers

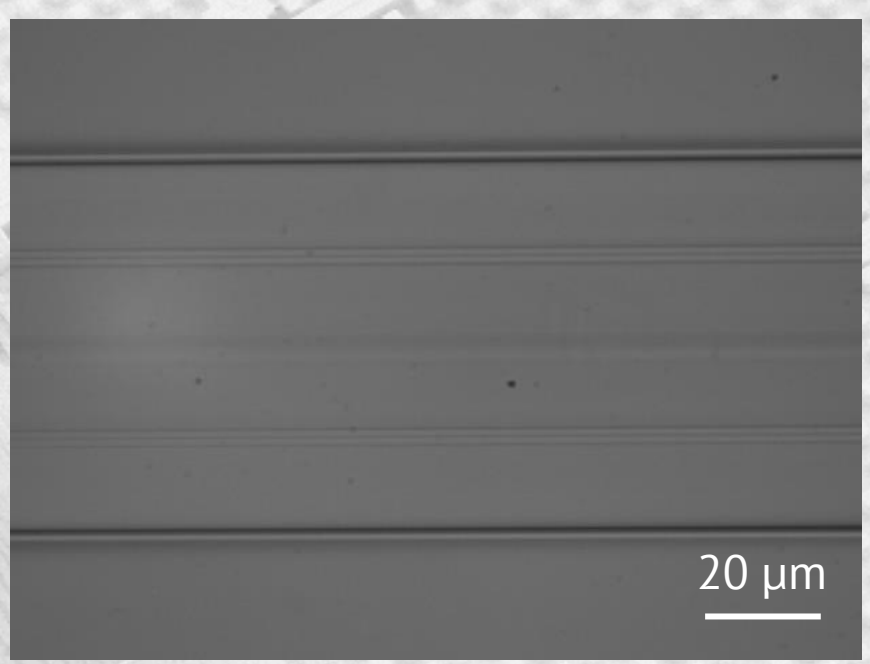
- No fundamental difference between PWBs on MCF and standard PWBs
  - Same hardware + software + process
- Only two extensions required:
  - Detect fiber core positions
  - Channel mapping

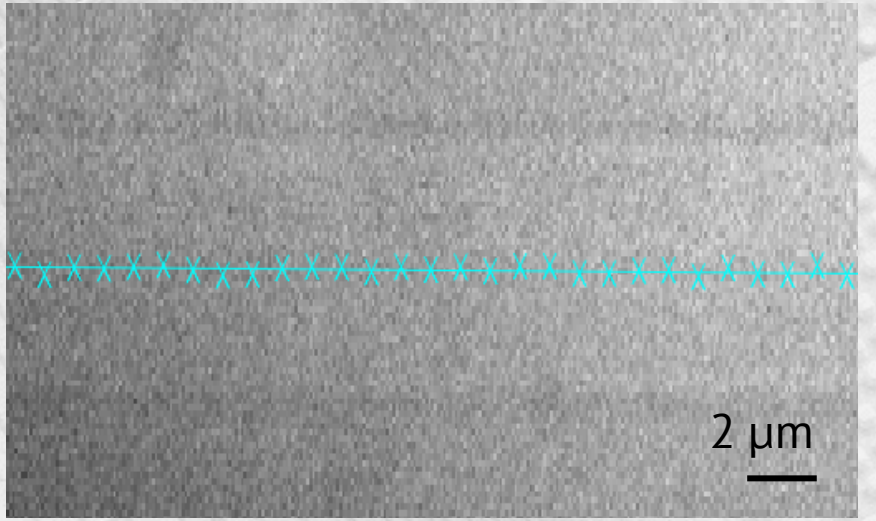


Detecting Cores in the Side-View

- Optical axis of each core is detected “on-the-fly” by 3D scan
  - Rotational alignment of fibers not necessary!

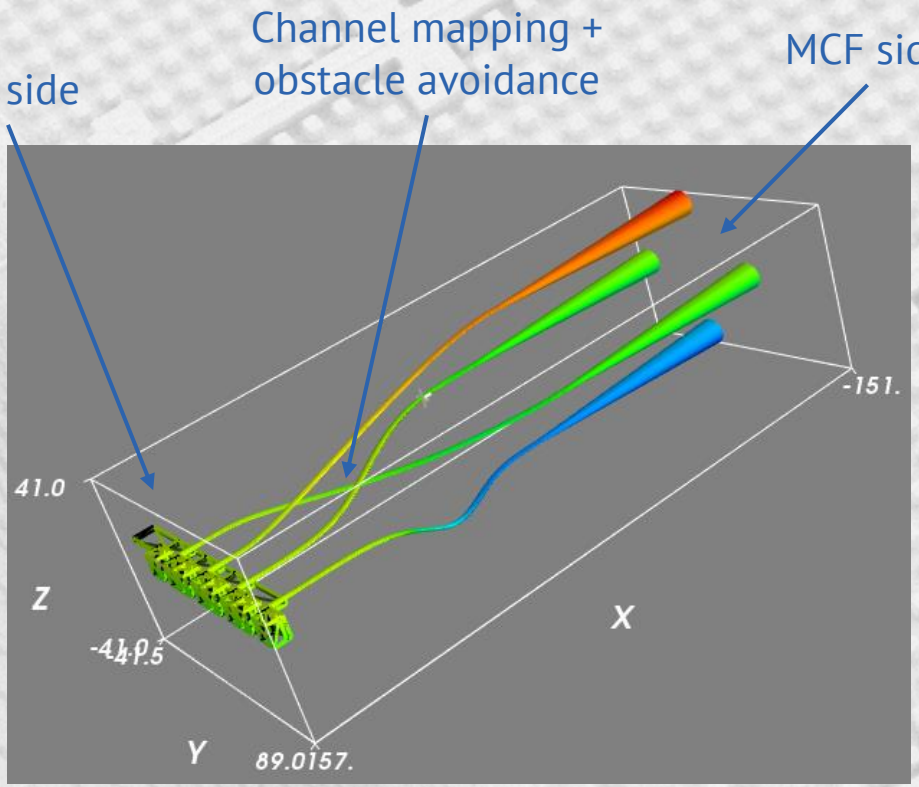
- < 0.5 µm deviation of detected position to achieve ~2 dB loss



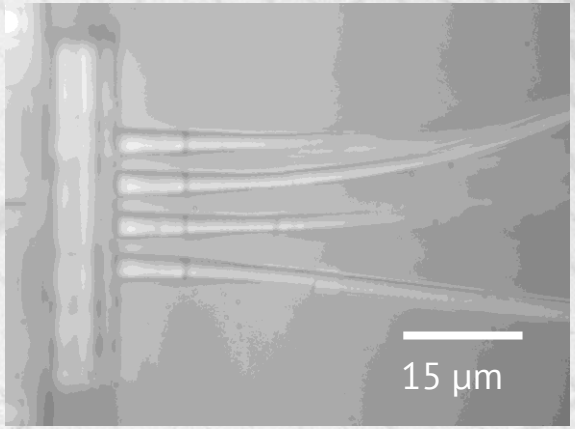


Routing PWB Connections

- Arbitrary mappings between PIC-waveguide and fibercore
- Obstacle avoidance to eliminate crosstalk
- Model generation “on-the-fly”
- PIC side: channel spacing of down to 5 µm



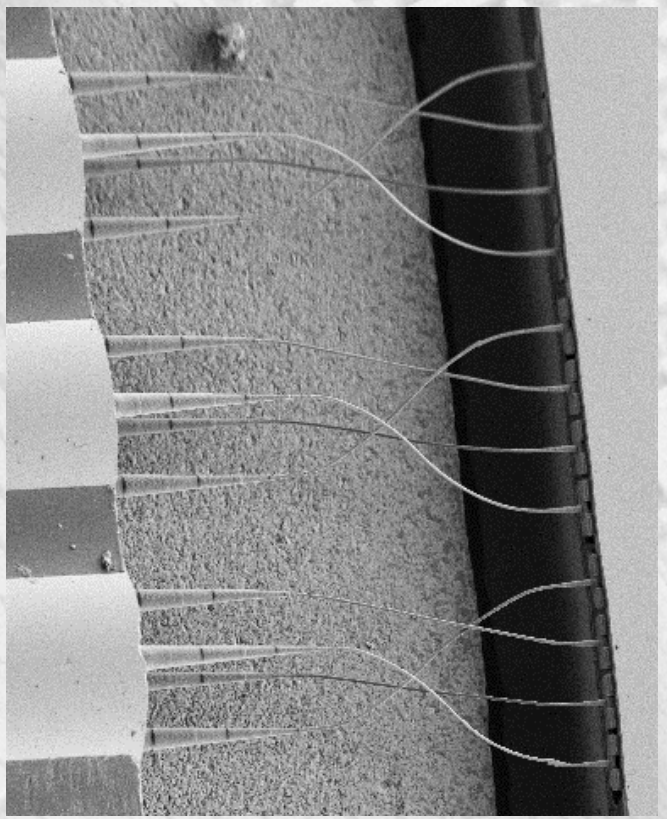
Screenshot from Vanguard’s system software

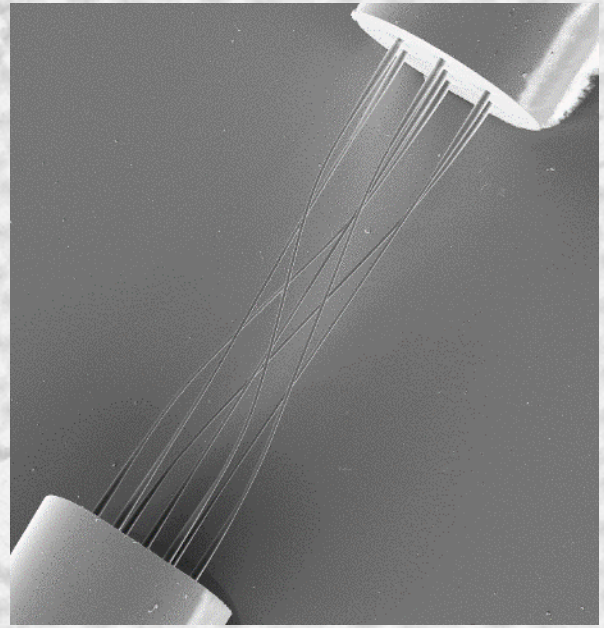


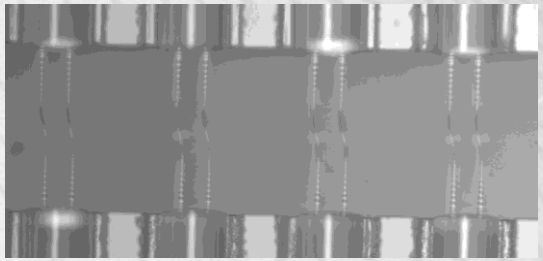
PWB Connections to Multi-Core Fibers

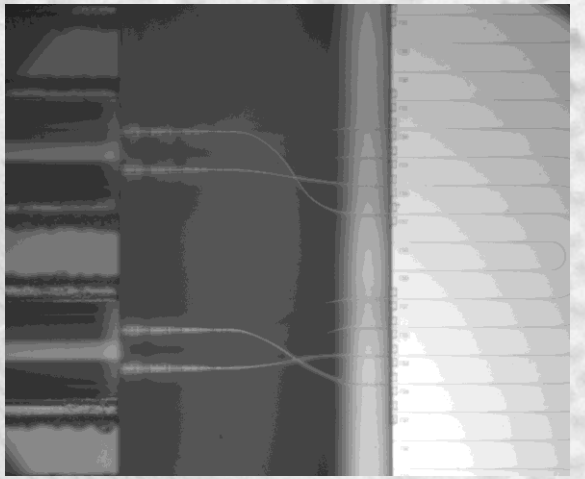
- Demonstrated connections between:
  - Two single Multicore Fibers
  - Two Multicore-Fiber Arrays
  - A Multicore-Fiber and a Silicon PIC

- Losses (Fiber-to-Fiber): ~2 dB
- Losses (Fiber to Chip) To reach < 2 dB with >90% yield in 2024









Vanguard SYMPHONY 1000

Software-Defined Fabrication of PWBs and Mirco-Optical Lenses

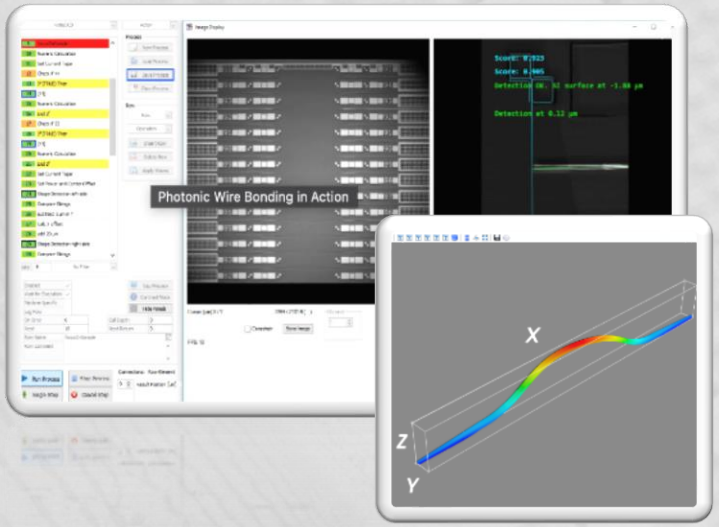
Automated 3D Lithography Based Nano Fabrication

SONATA 1000

Automated Pre- and Postprocessing (Development and Encapsulation)

REPRISE 1000

Software for Machine Control, Process Development and Management



Composer and BrightWire3D

Standard Fabrication Processes | Material | Product Support and Services

"Photonic integration and packaging with Photonic Wire Bonding and facet-attached micro-optical elements", PIC Magazine, September 2023

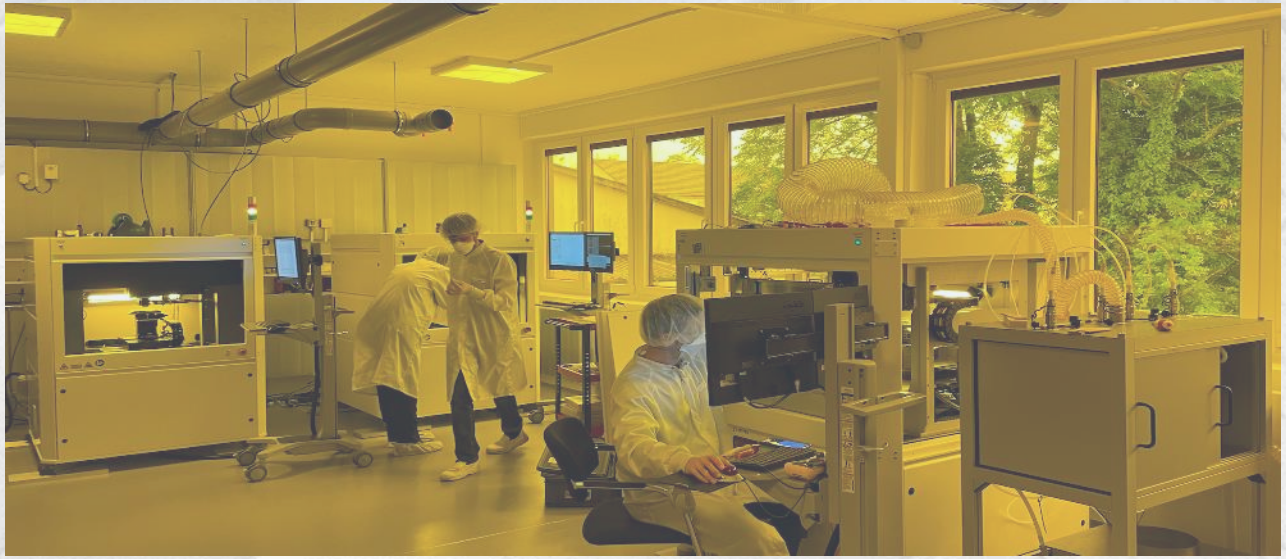
"As PIC Production Ramps Up, Fabricator Eye Alignment Options", Photonics Spectra, June 2022

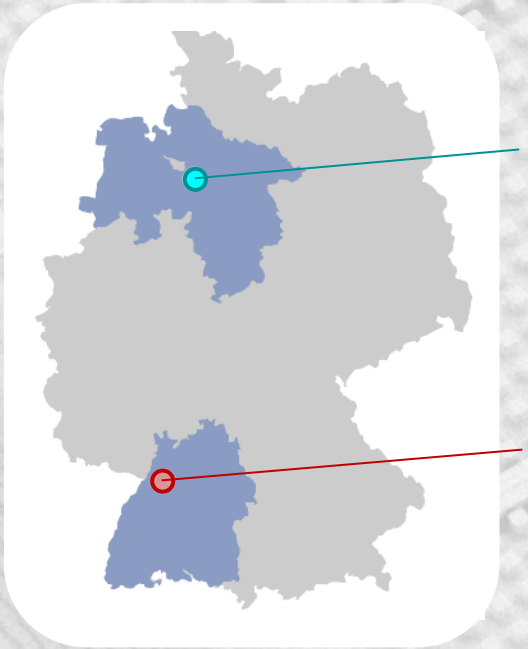
"Photonic Wire Bonding: Using Lasers to Integrate Lasers", Photonics Spectra, August 2022

"Integrated photonics for quantum applications", Laser Focus World, September 2022

Appendix

Vanguard Automation





Bremen **Manufacturing**

ficontec
photonics assembly & testing

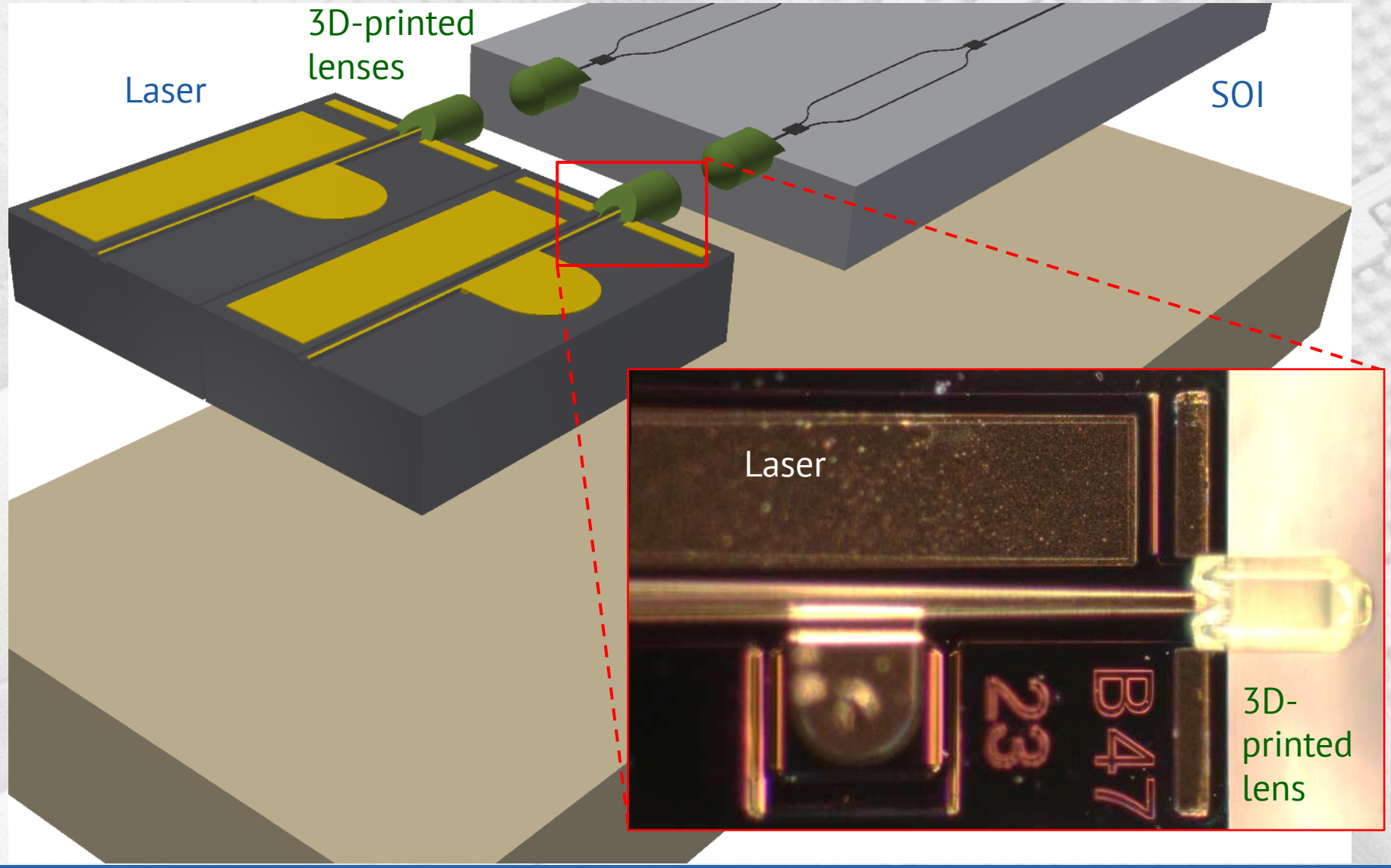
Karlsruhe

vanguard
AUTOMATION
bright connections

Mission

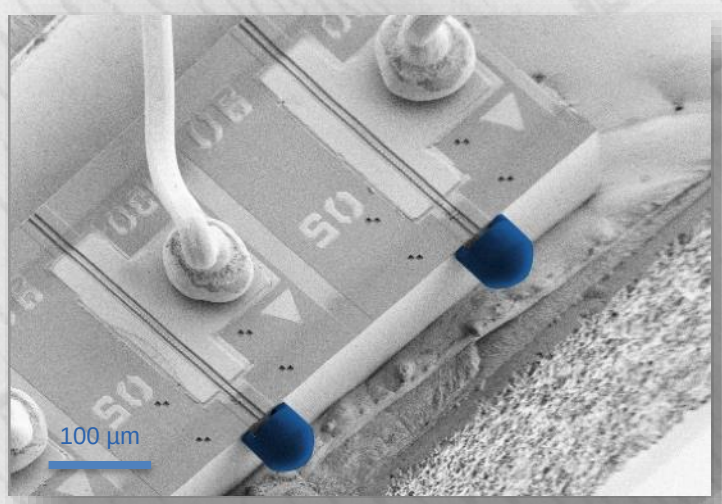
Advance Photonic Packaging and Assembly by providing scalable 3D nano-fabrication solutions from prototyping to high-volume production.

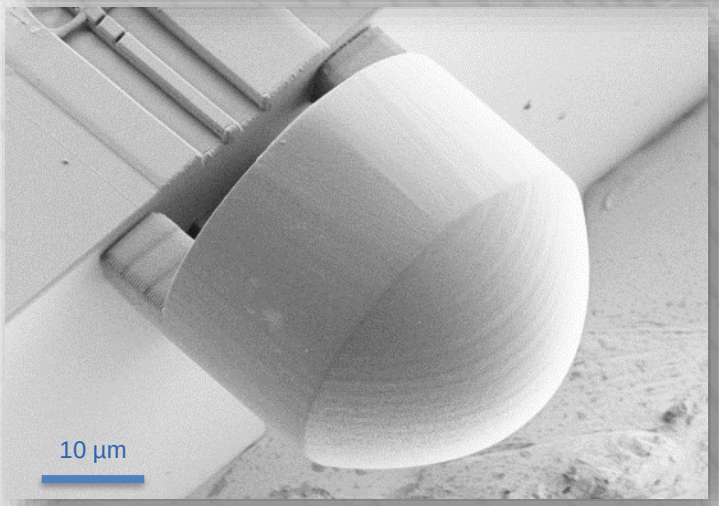
Facet-Attached Micro-Optical Elements



Micro-Optical Elements for industrial applications

- **Compatible components**
  - Laser (DFB and other)
  - PIN and APD diodes
  - SMF, PMF and MMF fiber arrays
  - PIC: SOI, SiN, InP, LiNb and more
- **Standard building blocks:**
  - Lenses with focal length up to centimeters and mode-field diameters of 2.0 µm to 100 µm (@1/e² intensity)
  - Total-internal-reflection mirrors
  - 3D-printed mode-size converter
- **Coupling**, depending on laser and chip
  - **Laser-to-Chip:** 0.6 to 2.5 dB
  - **Chip-to-Fiber:** 1.5 to 2.5 dB,
- **Alignment tolerances @ 1 dB penalty:**
  - ±1.5 µm (single lens on one component) to ±15 µm (beam expander)
- **Tested operational range**
  - 530 nm to 2000 nm

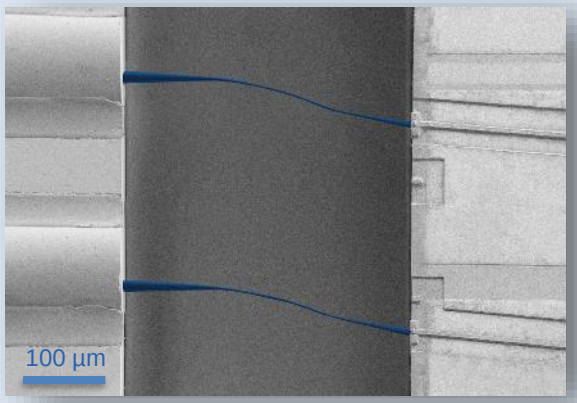




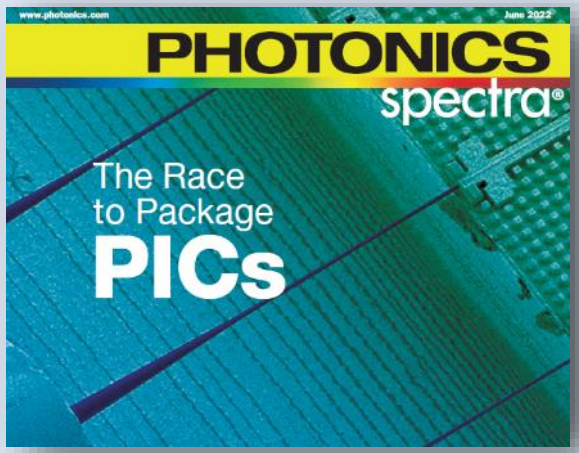
- **Reproducibility**
  - Below σ = 0.2 dB coupling variation
  - Below 10% mode-field and focus length variation/deviation
- **Accuracy**
  - Below σ = 50 nm detection accuracy
  - Below ±100 nm shape accuracy
  - Less than 10 nm RMS-roughness
- **Reliability testing**
  - > 4000 h 85°C/85% rel. hum
  - > 250 cycles -40°C to 85°C
  - Reflow soldering, 3 cycles, 270°C
  - Die bonding, 310°C
- **Shock testing**
  - Acceleration of up to 1500 g
  - Vibration, 20g, all axis
- **High power operation**
  - >1 W @ 1550 nm
- **Cryogenic operation**
  - > 10 cycles 4K to room temperature

Next Generation Photonic Integration and Packaging Solutions

Photonic Wire Bonds

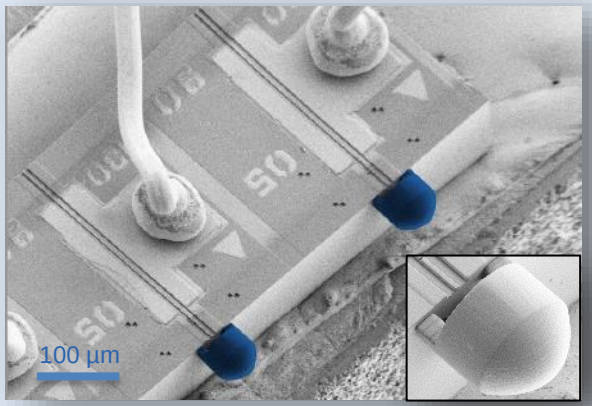


Laser by Freedom Photonics LLC

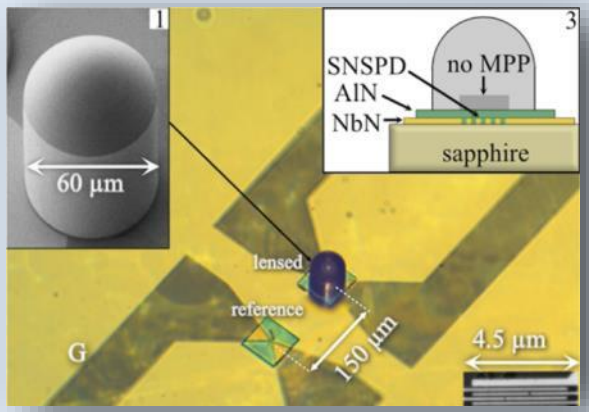


PIC by Institut für Mikroelektronik Stuttgart

Micro-Optical Elements

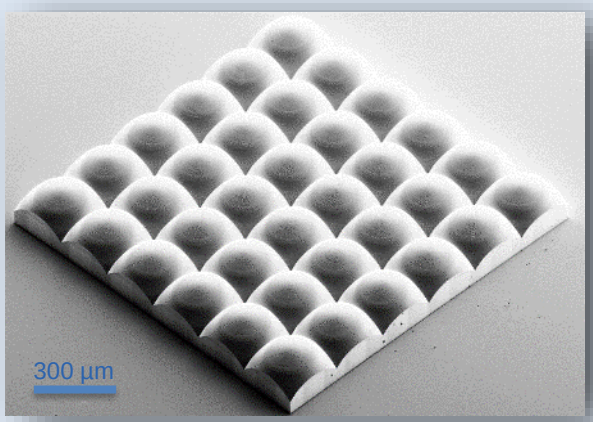


Samples by PIXAPP (Photonic Packaging Pilot Line)



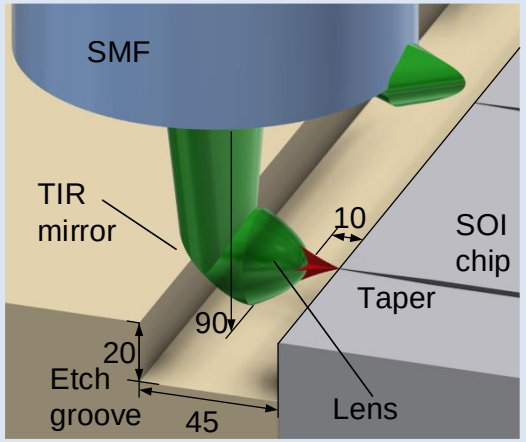
Xu et al., Superconducting nanowire single-photon detector with 3D-printed free-form microlenses, Opt. Expr. 29, 27708-27731 (2021)

Write Field Extension

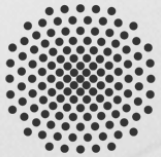


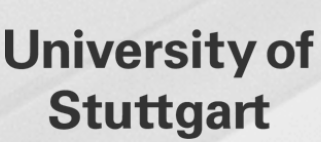
Design by Moveon Technologies Pte Ltd.

Wafer-Level Probing



Ecosystem Partners, Academic and Industrial Users

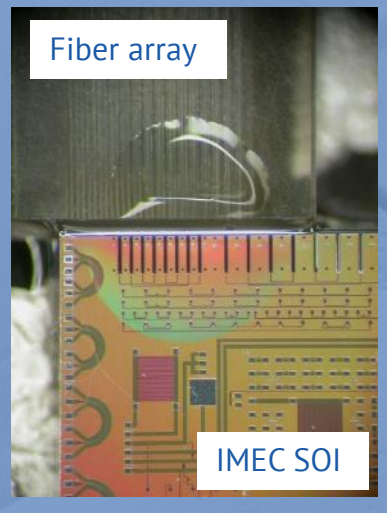


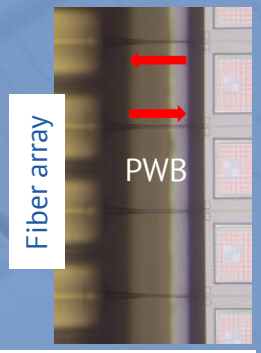


Compatibility with material platforms/foundries

Silicon (IMEC, Belgium)

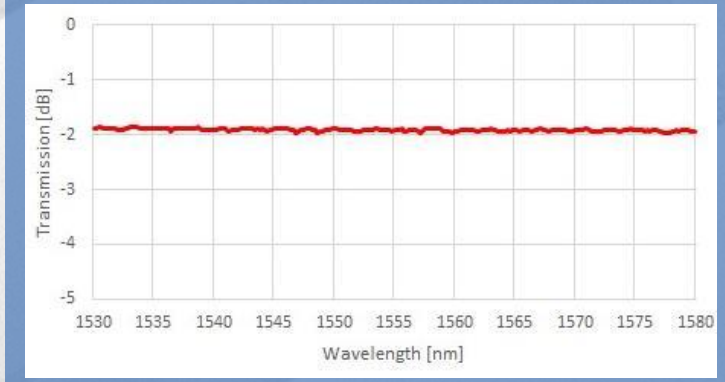
- ~2dB Loss





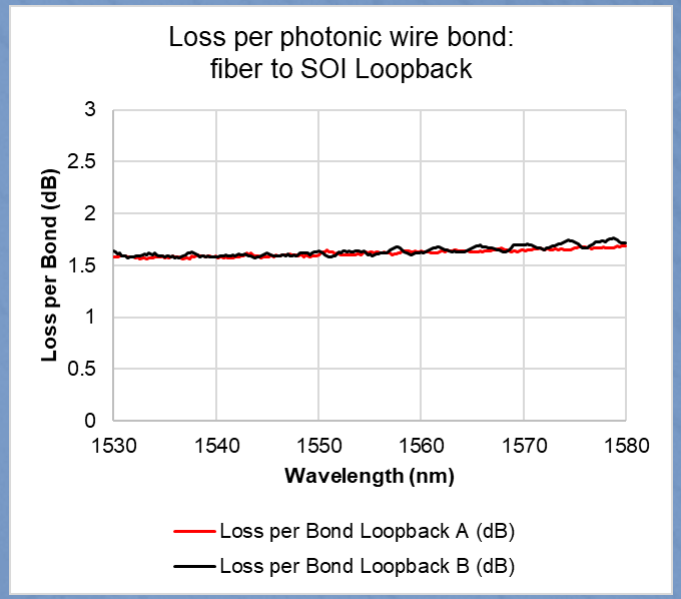
Building-block of

PIXAPP Photonic Packaging Pilot Line



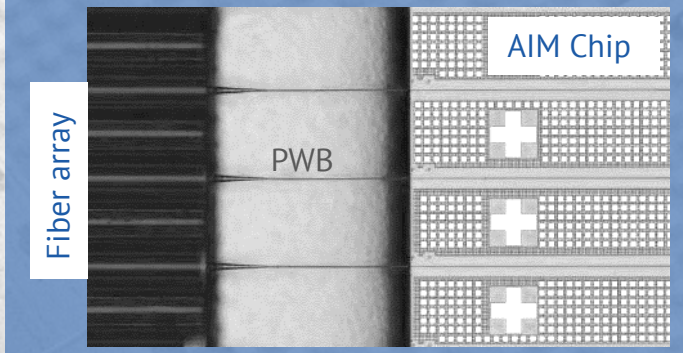
Silicon (AMF, Singapore)

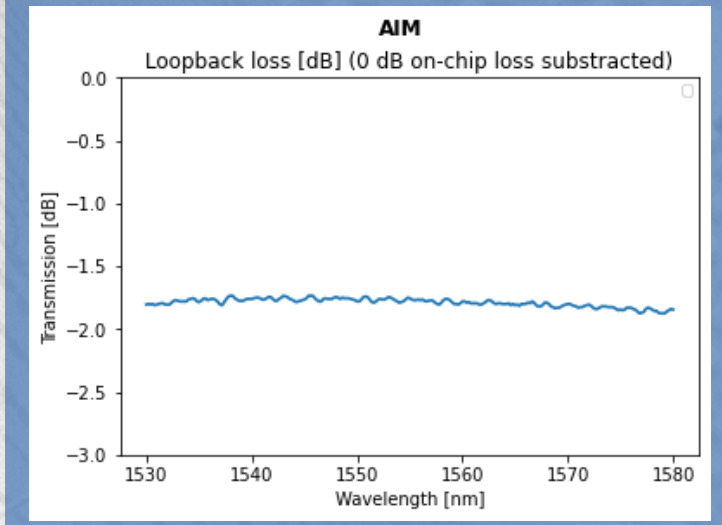
- ~1.5dB loss



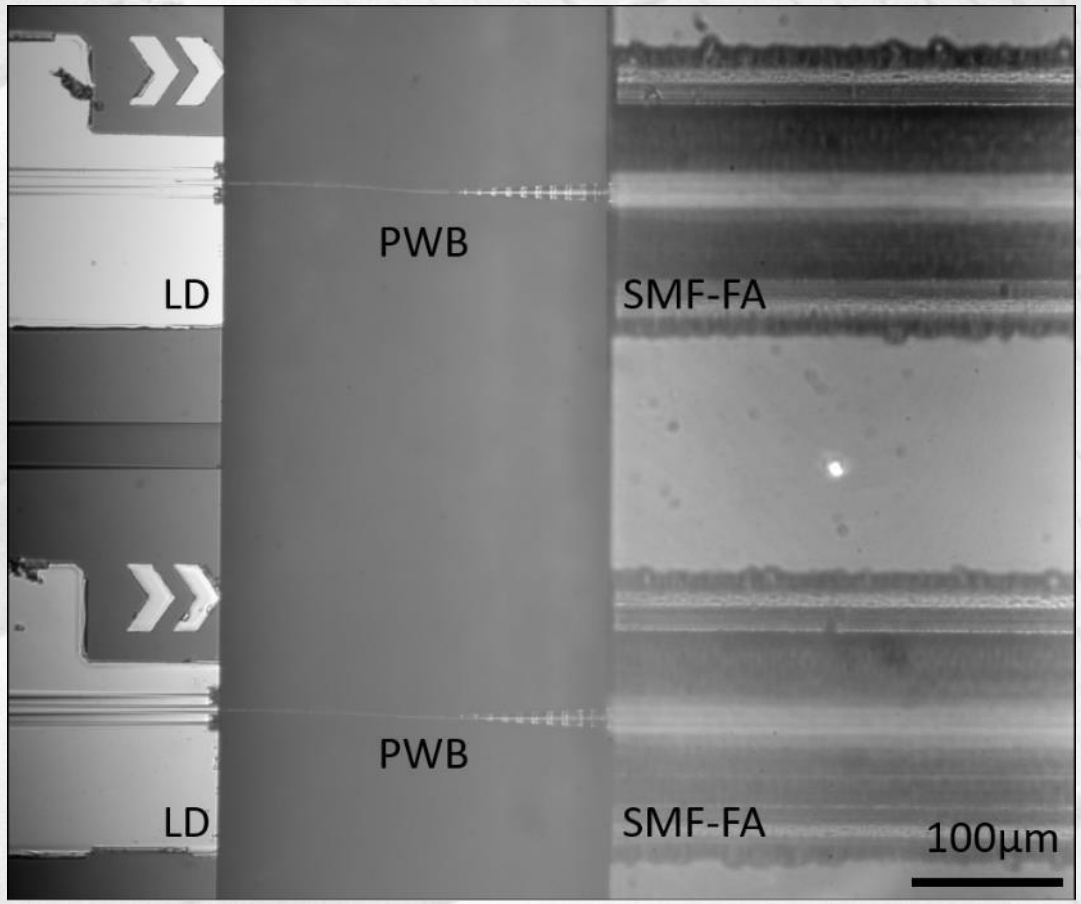
Silicon Nitride (AIM, USA)

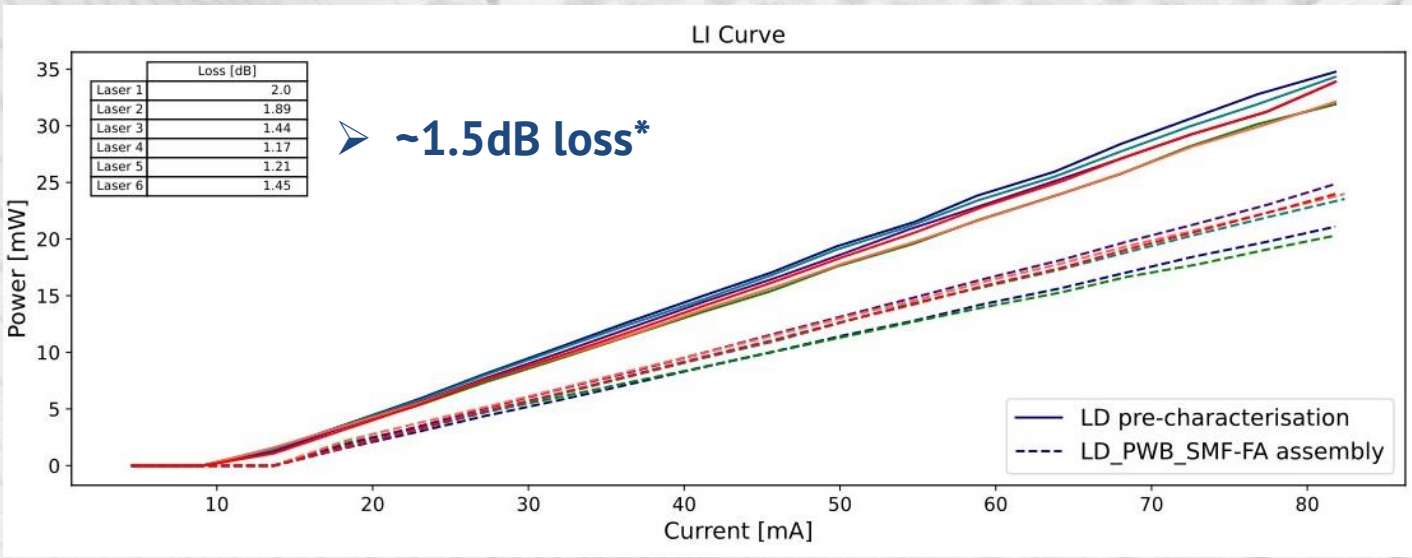
- ~1.7dB loss





Compatibility with material platforms/foundries





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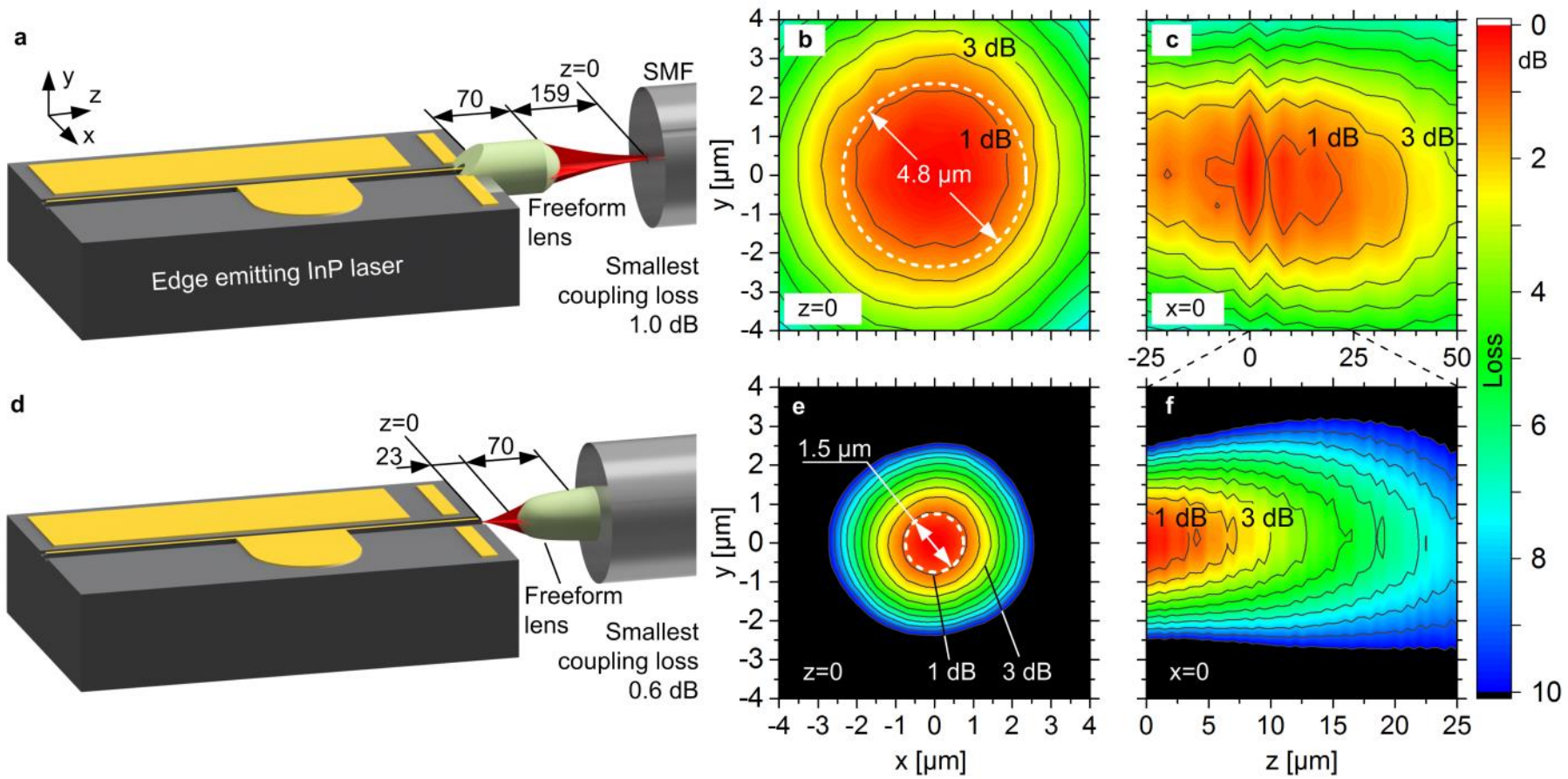
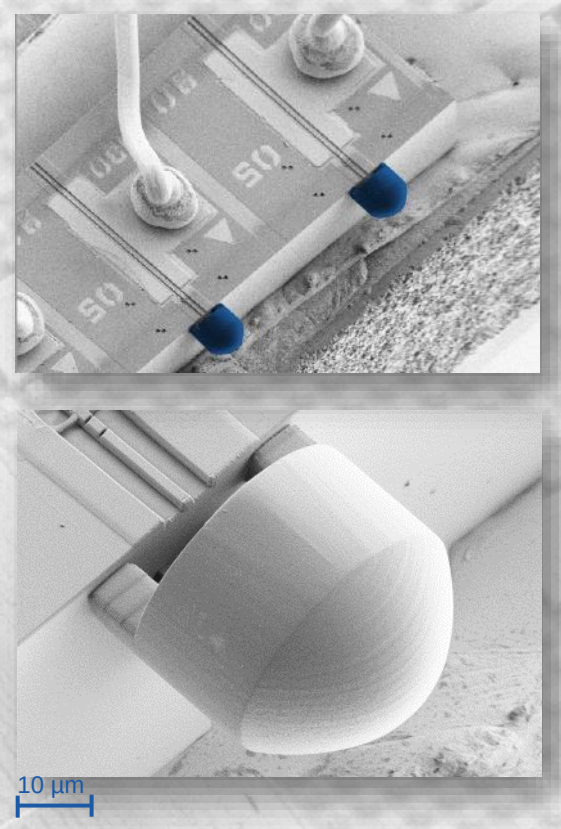
Coupling from laser to SMF





Samples bx PIXAPP
(Photonic Packaging Pilot Line)

Mode-field adaption of a DFB-laser with 3 µm MFD at 1590 nm to a SMF.