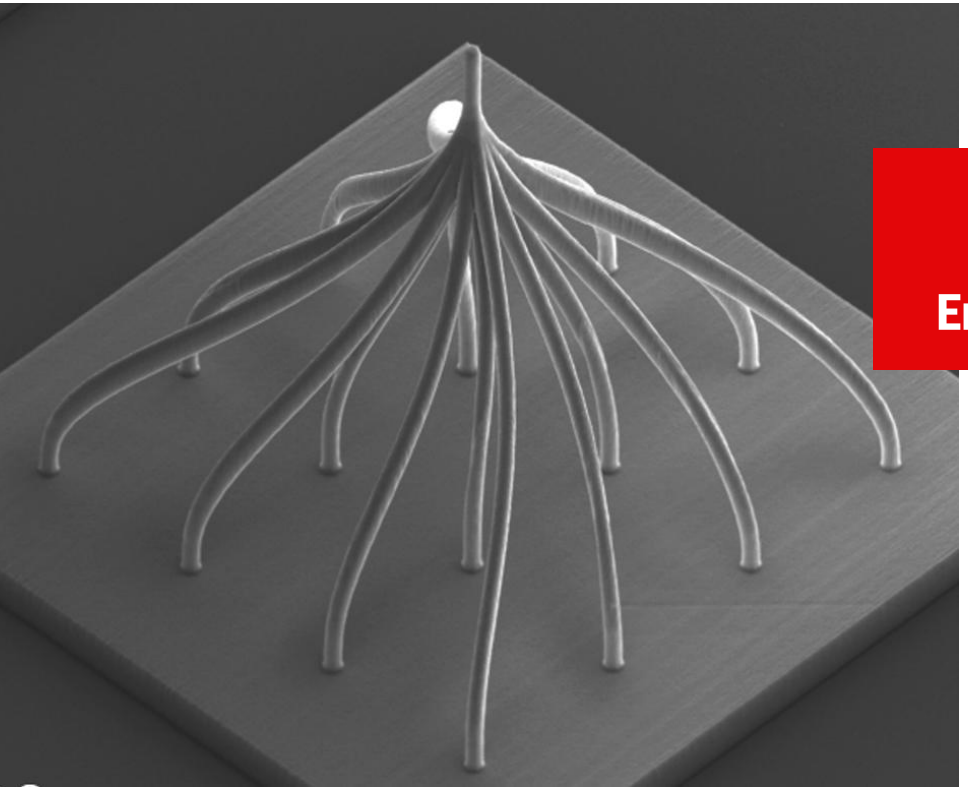


Optical Interconnects

Enabled by 3D-Printed Photonic Wire Bonding

Gang WANG

MICRO-722 : 3D Printing with light

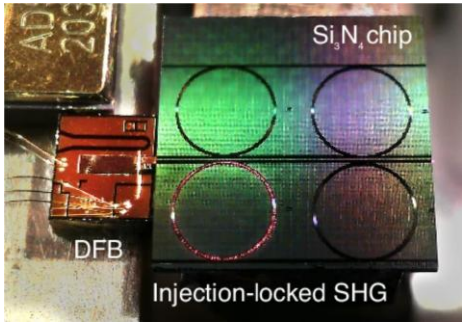
École
polytechnique
fédérale
de Lausanne

[1] Optical Materials Express **10**, 2952 (2020)

1 Dec 2025

Background of Optical Interconnects

- Definition:
  - Optical interconnects refers to any system of transmitting signals from one part of an integrated circuit to another using light

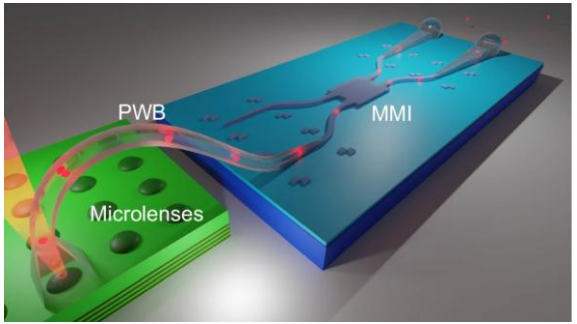


free space

- no waveguide required
- vibration sensitive
- satellite, LiFi, etc.

fiber based

- robust
- hard to miniaturize
- server interconnect

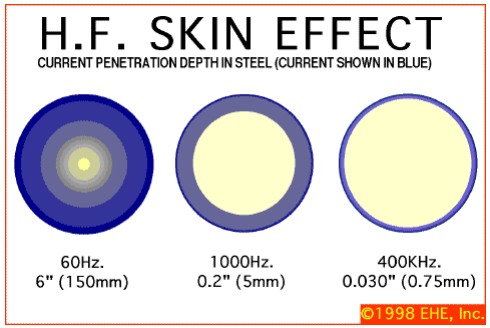


waveguide based

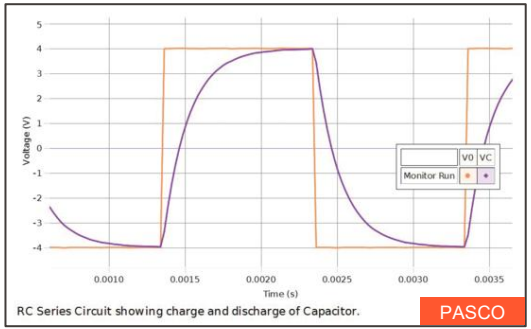
- compact
- fabrication
- chip-to-chip interconnect

Background of Optical Interconnects

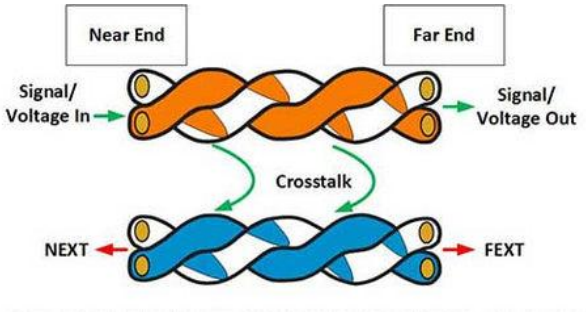
- Motivation:
  - exponential growth of AI accelerators, data centers, etc.
  - overcoming electrical interconnect limits: RC delay, crosstalk...



skin effect



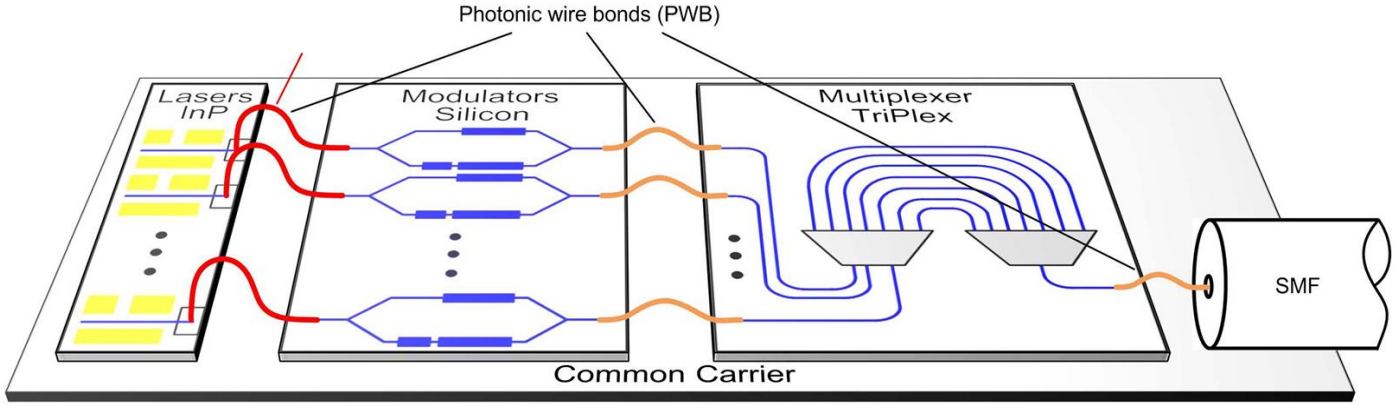
RC delay



crosstalk

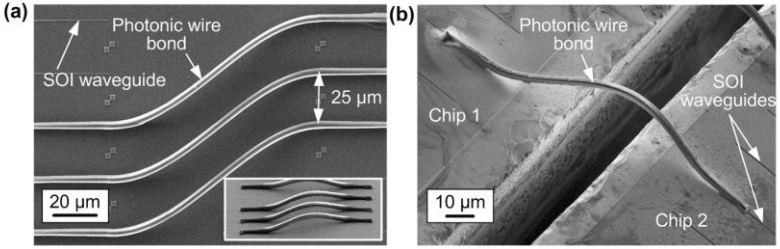
Background of Optical Interconnects

- Photonic wire bonding (PWB):
  - A **free-form 3D polymer waveguide**
  - Written directly between optical ports
  - Advantage:
    - 3D capability surpassing height and angle limits
    - no alignment needed
    - ideal for heterogeneous integration (silicon photonics, III-V, fiber optics, etc.)

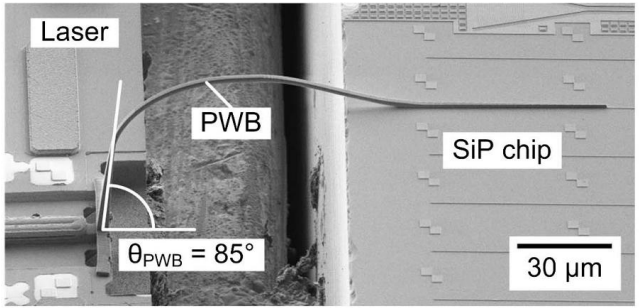


Development of PWB

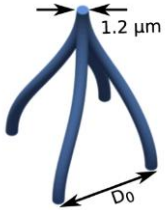
- **Single-mode waveguide interconnect**
  - Lindenmann, N., et al. "**Photonic wire bonding: a novel concept for chip-scale interconnects**." *Optics Express* 20.16 (2012): 17667-17677.

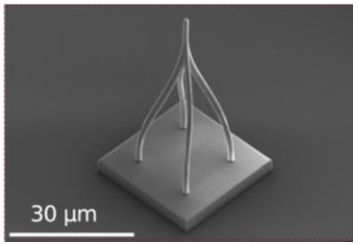


- **Laser-to-waveguide interconnect**
  - Billah, Muhammad Rodlin, et al. "**Hybrid integration of silicon photonics circuits and InP lasers by photonic wire bonding**." *Optica* 5.7 (2018): 876-883.



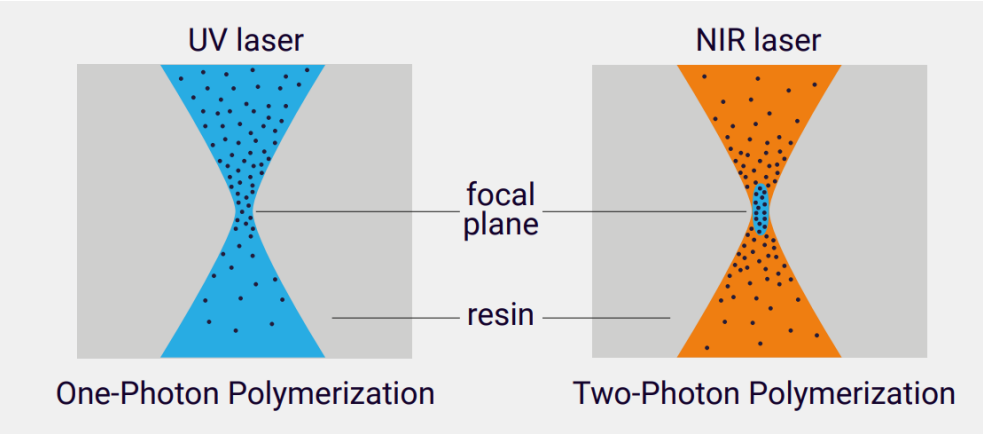
- **Multimode splitters for photonic interconnect**
  - Moughames, Johnny, et al. "**3D printed multimode-splitters for photonic interconnects**." *Optical Materials Express* 10.11 (2020): 2952-2961.



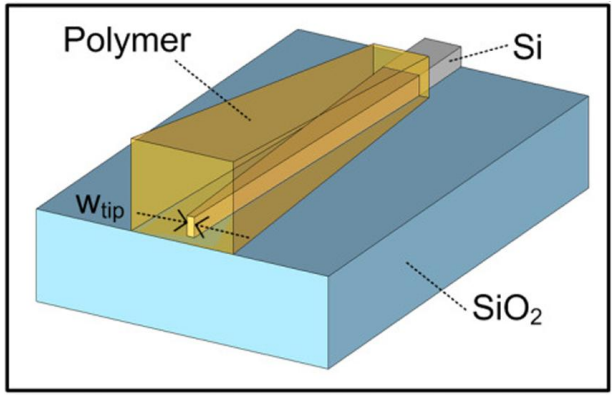


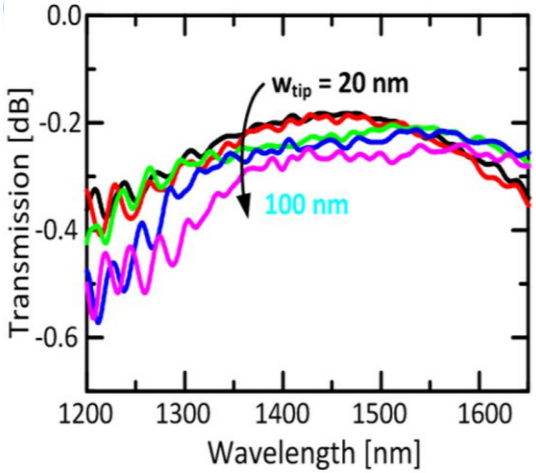
Mechanism of PWB

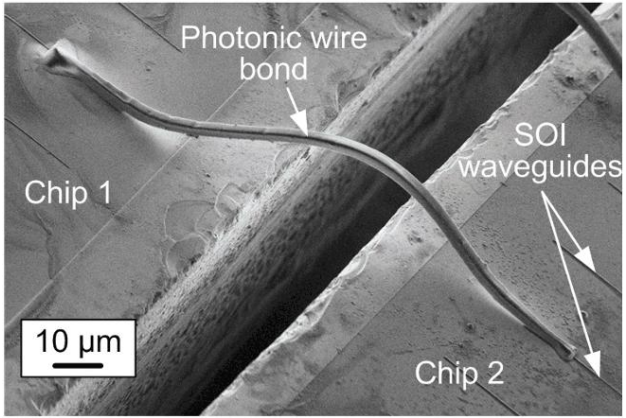
- **Sample fabrication**
  - Laser: 780 nm central wavelength, ~100 fs pulse duration, ~100 MHz repetition rate (commercial Nanoscribe)
  - PWB core material: SU-8 (n@1550 = 1.57), IP-Dip (n@780 = 1.52), etc.
  - cladding: Cytop (n@1550 = 1.34), Cargille Laser Liquid 3421 (n@1550 = 1.3), etc.



PWB-waveguide coupling







Inverse-taper transition from PWB interconnect to waveguide

PWB WG: 1.4 µm × 1 µm
PWB taper: 0.76 µm × 0.45 µm

Si WG: 0.5 µm × 0.22 µm

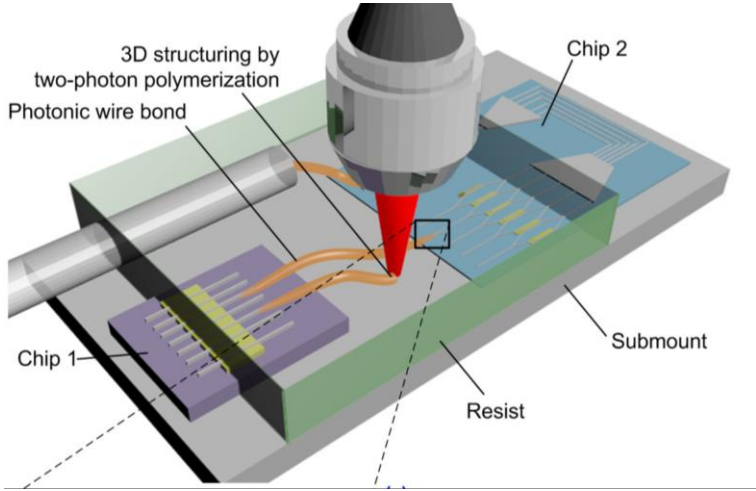
Simulated transition loss spectrum

PWB chip-to-chip interconnect

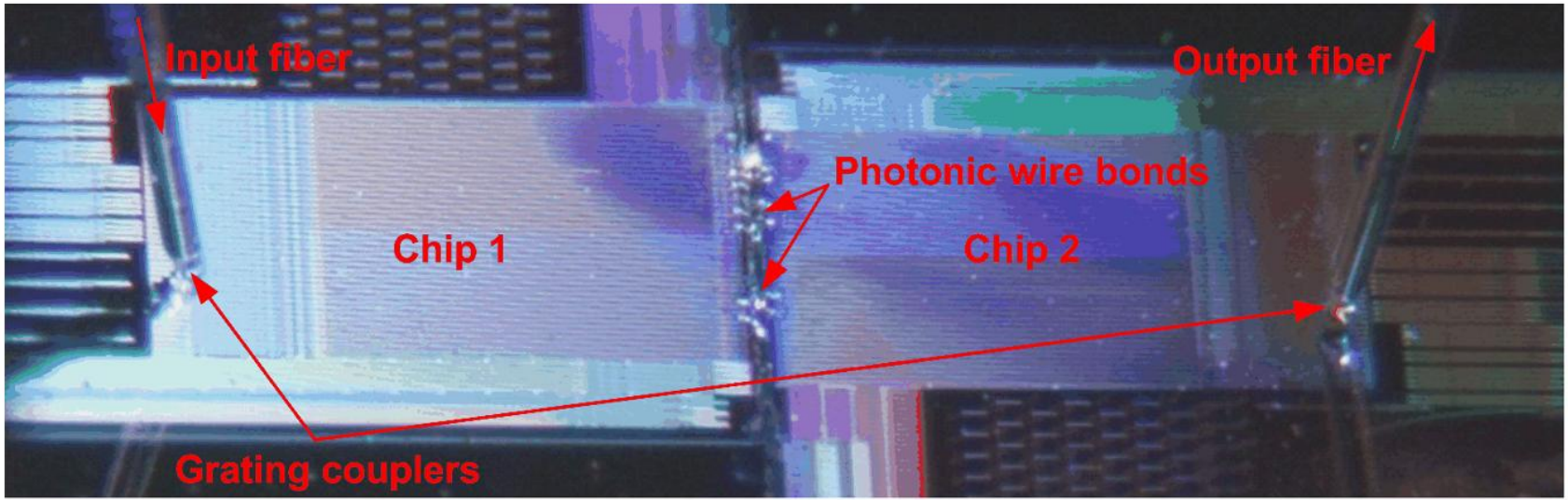
Optics Express **20**, 17667 (2012)

PWB fabrication process

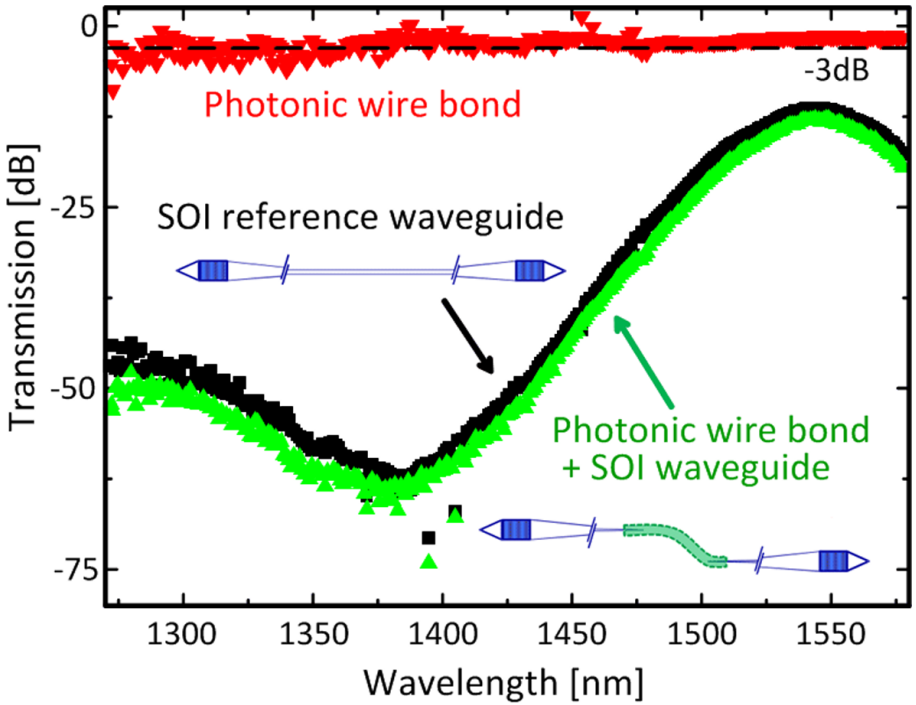
- Mount the components on a common carrier
  - accuracy of ~10 μm
- Drop-cast photoresist
- Detect the positions of the coupling interfaces inside the photoresist
- Define the start and end points of the PWB (4-order polynomials can be used to define the 3D trajectory)
- Fabricate the PWB by exposing the photoresist using two-photon polymerization
- Drop-cast a low-refractive-index matching liquid onto the assembly to act as the PWB cladding



Chip-to-chip interconnect

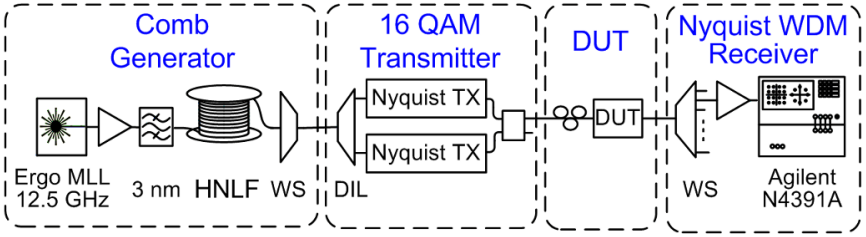


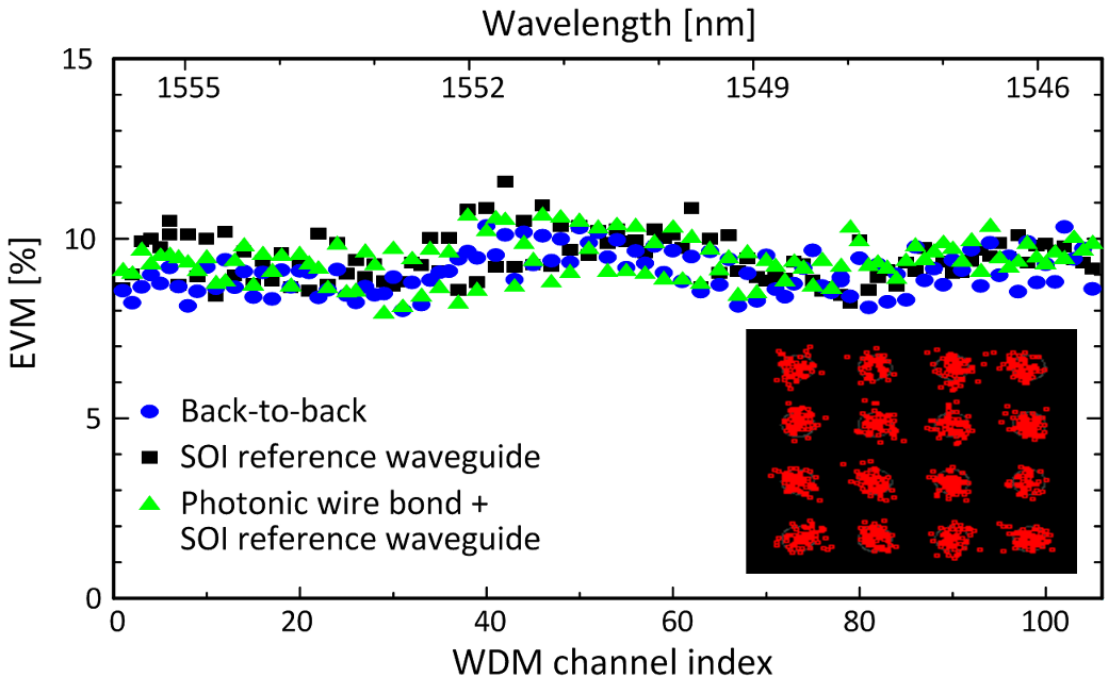
Performance



- (1.6 ± 0.4) dB loss within C band
- (2.5 ± 1.2) dB loss within the measured wavelength range from 1240nm to 1580 nm

Performance



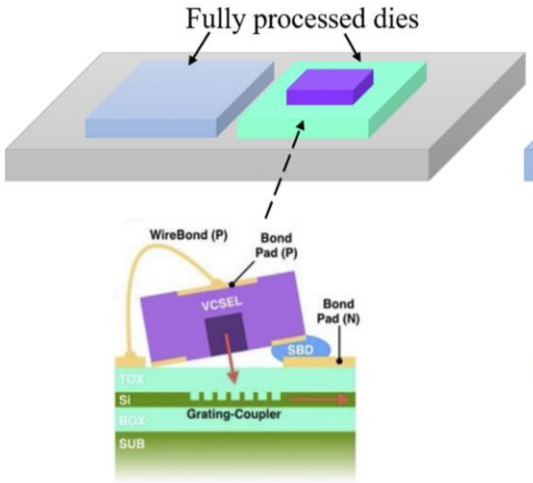


Mechanical and chemical stability

- No special protection against oxygen or humidity
- No degradation in transmission loss after repeated testing over several weeks at optical powers up to 100 mW
- Free-standing waveguide arches with diameters below 2 μm can span distances greater than 100 μm
- Structures remain mechanically intact during manual handling with tweezers
- Waveguides withstand intensive water rinsing
- Strong adhesion to the silicon surface is maintained with no detachment after oxygen plasma treatment and immersion in acetone
- PWB structure remained intact after sample dropped from a height of about 1 meter to the ground
- Explanation: $F \propto V$, $F_{th} \propto S$, stability increases as size decreases

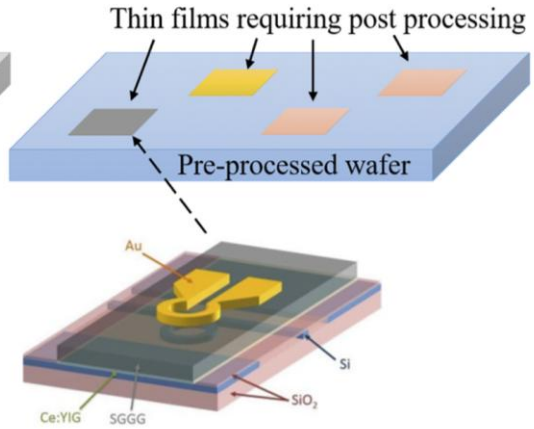
Laser to waveguide interconnect

Hybrid integration



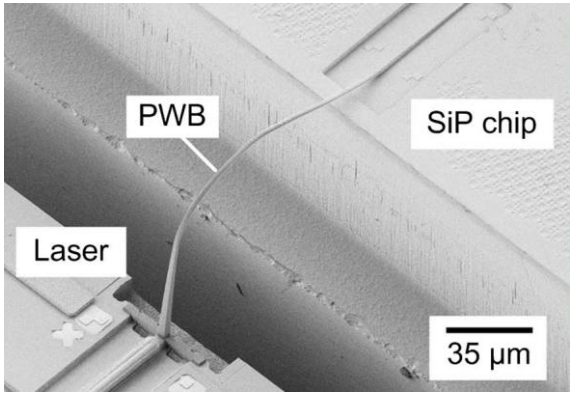
- packaging complexity
- alignment required

Heterogeneous integration



- fabrication complexity
- pre-test impossible
- heat dissipation

Photonic wire bonding



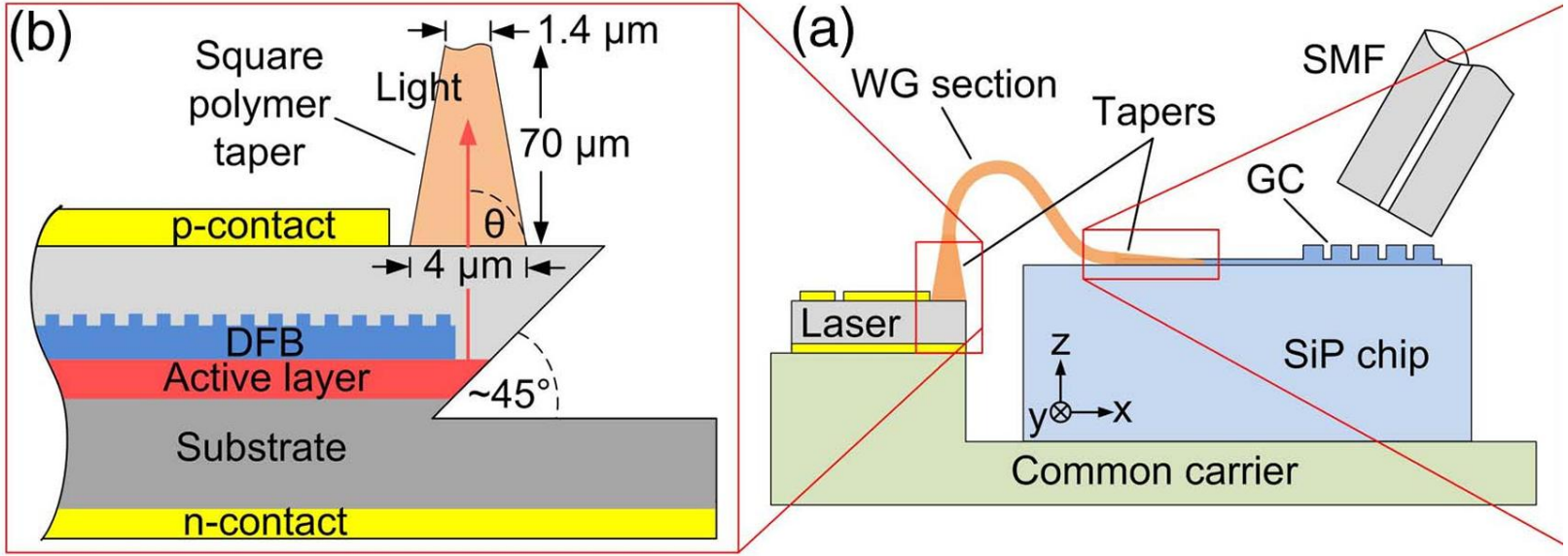
- no alignment required
- low loss
- flexibility

APL Photonics **6**, 061102 (2021)

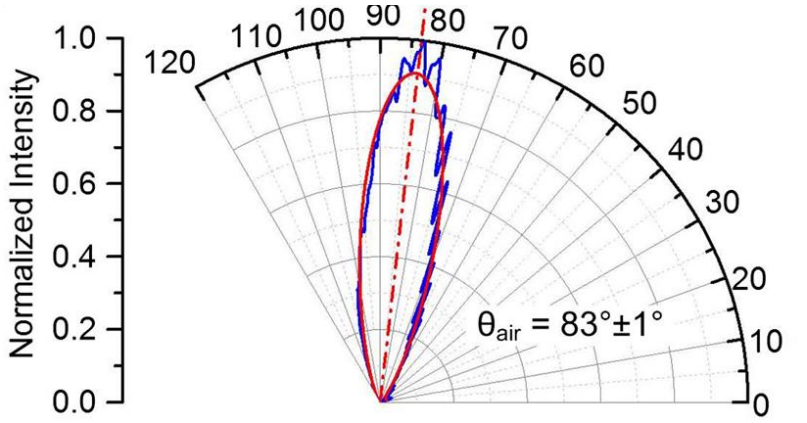
Optica **5**, 876 (2018)

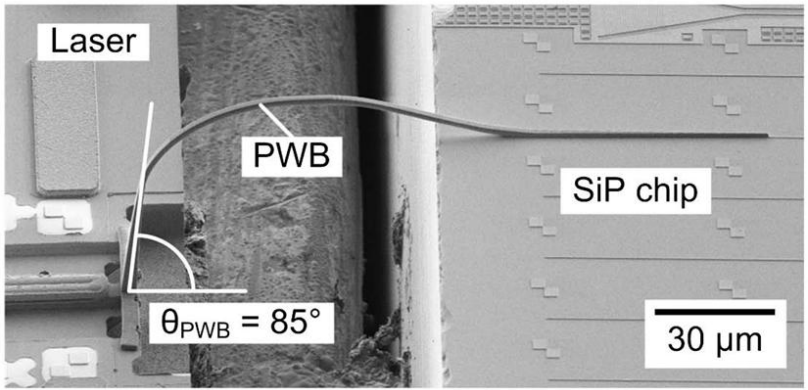
III–V source to silicon photonic circuit interconnect

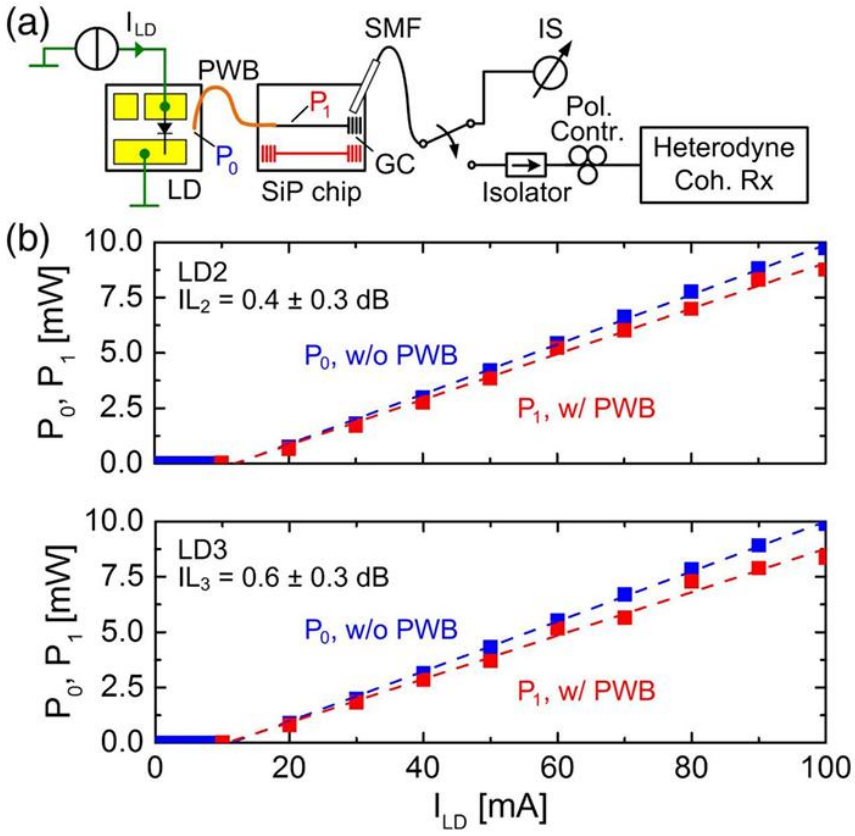
Gang Wang



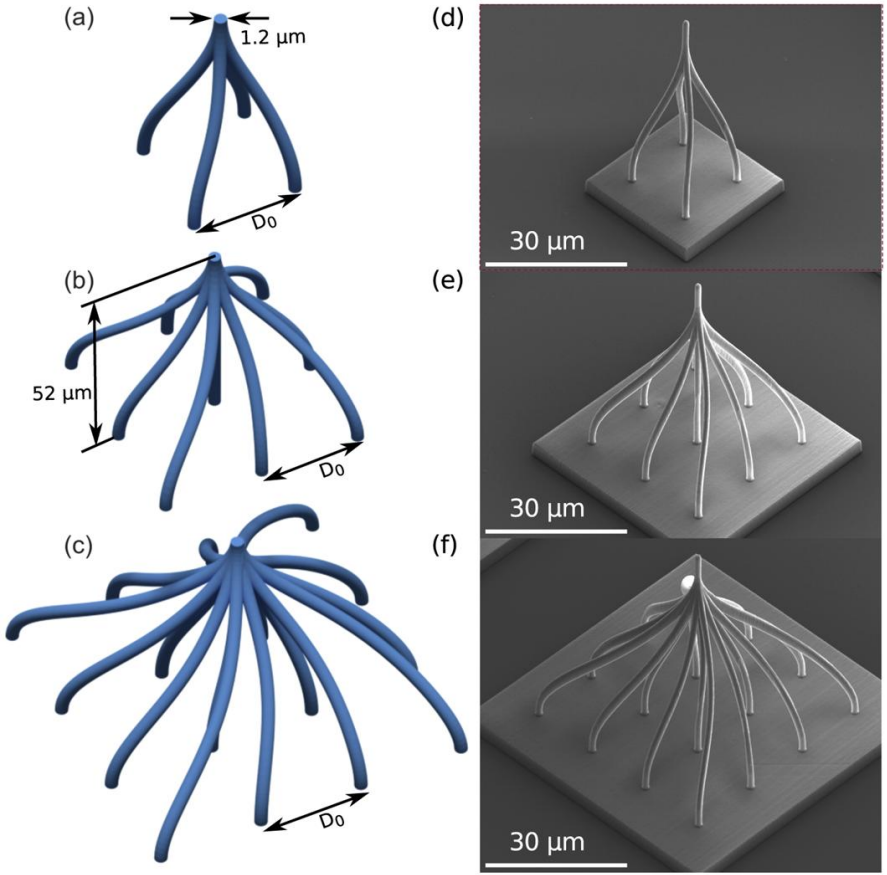
III–V source to silicon photonic circuit interconnect





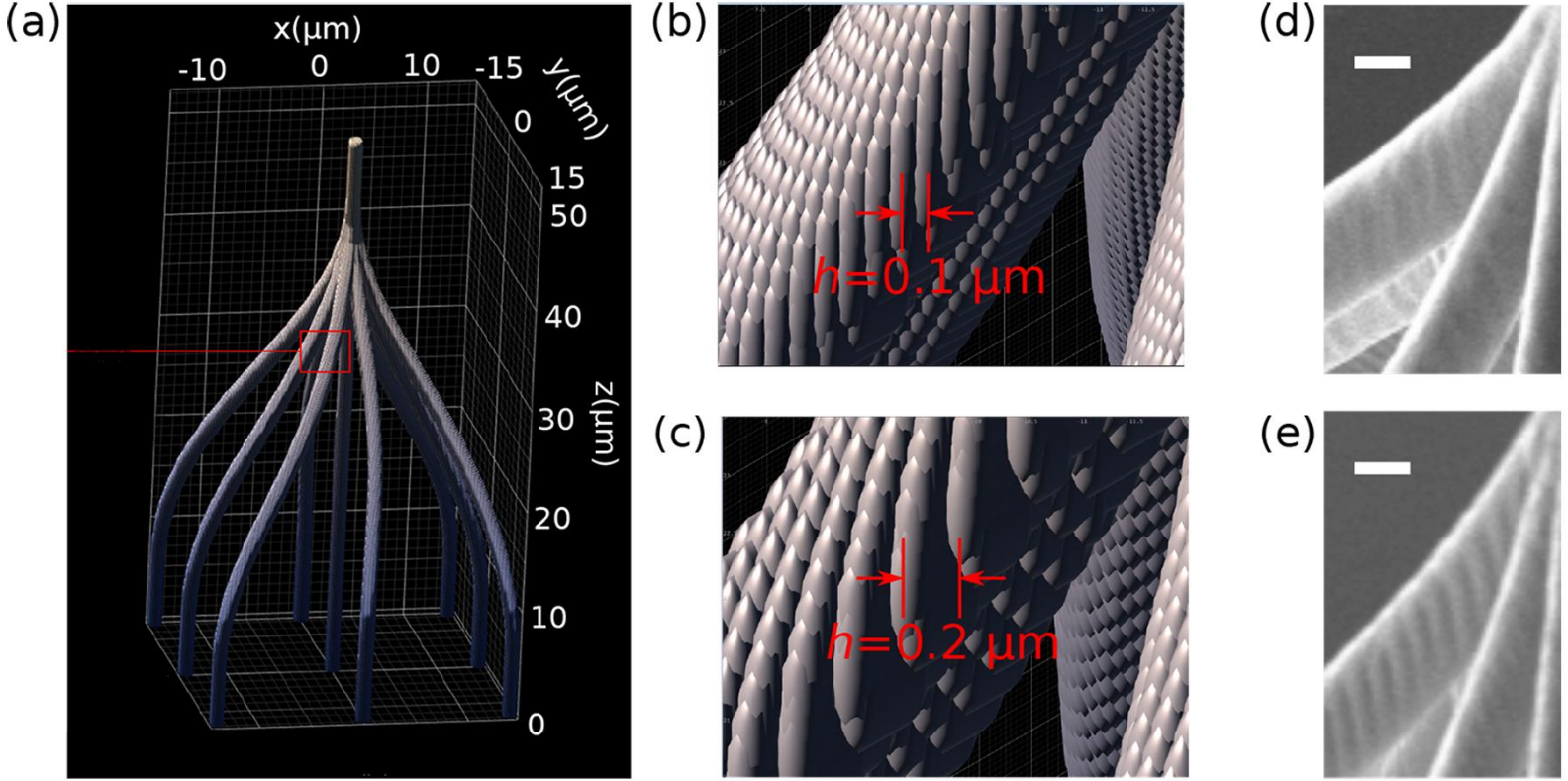


Multimode splitters for photonic interconnects



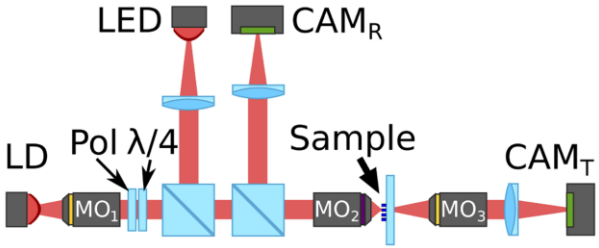
Optical Materials Express **10**, 2952 (2020)

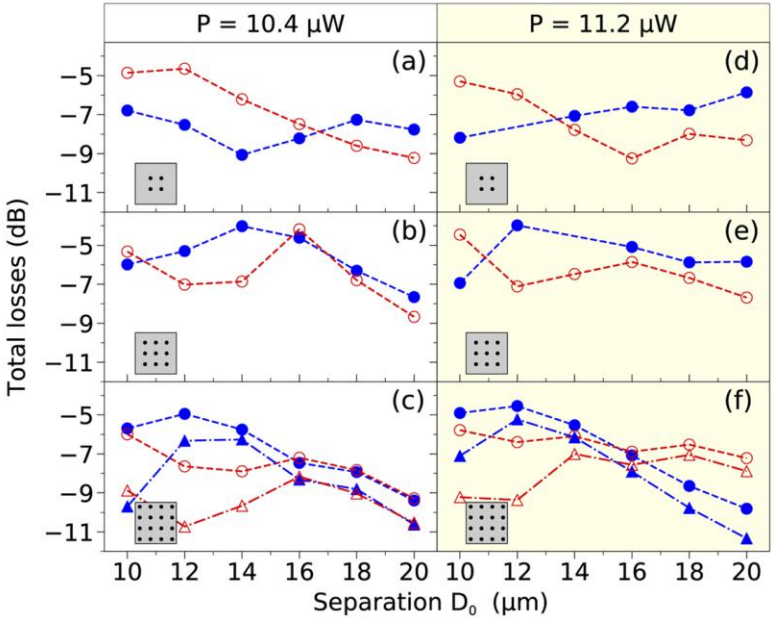
Multimode splitters for photonic interconnects

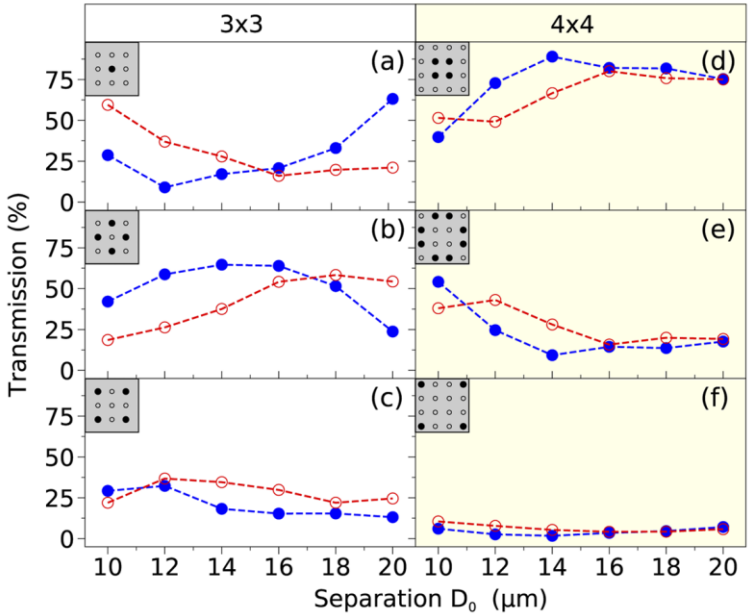


Multimode splitters for photonic interconnects

Gang Wang

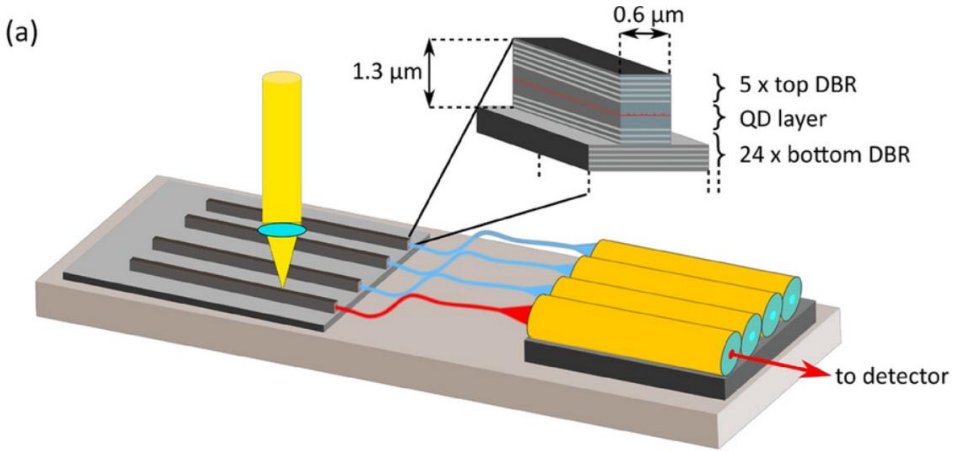


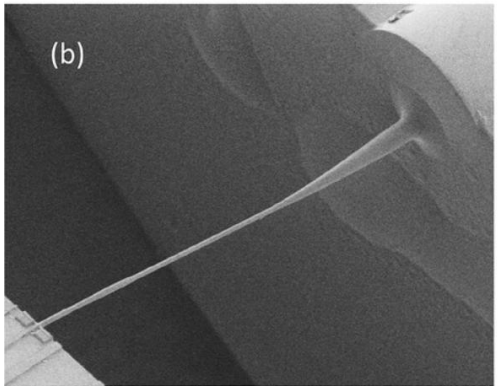


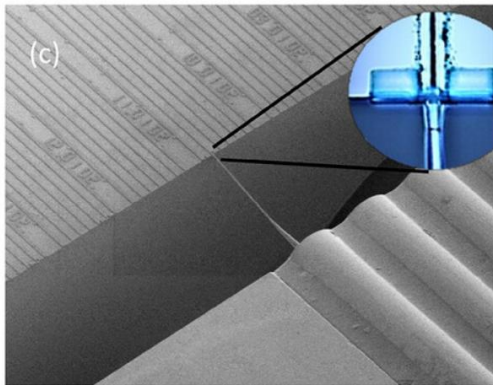


h = 0.1 μm
h = 0.2 μm

Quantum dots to fiber via PWB

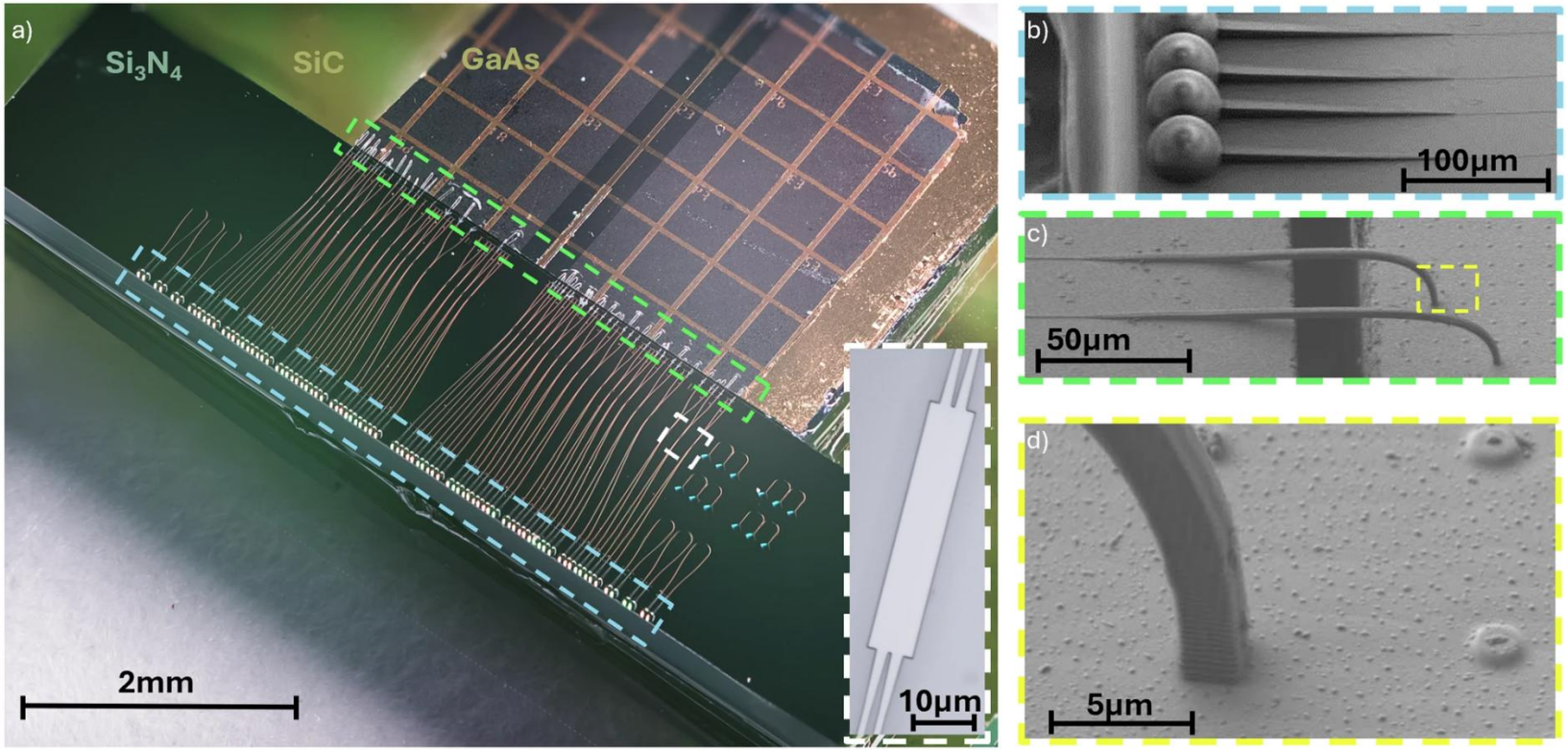






Advanced Quantum Technologies 7, 2300227 (2024)

Quantum dots to silicon-nitride circuits via PWB



npj Nanophoton. **2**, 11 (2025)