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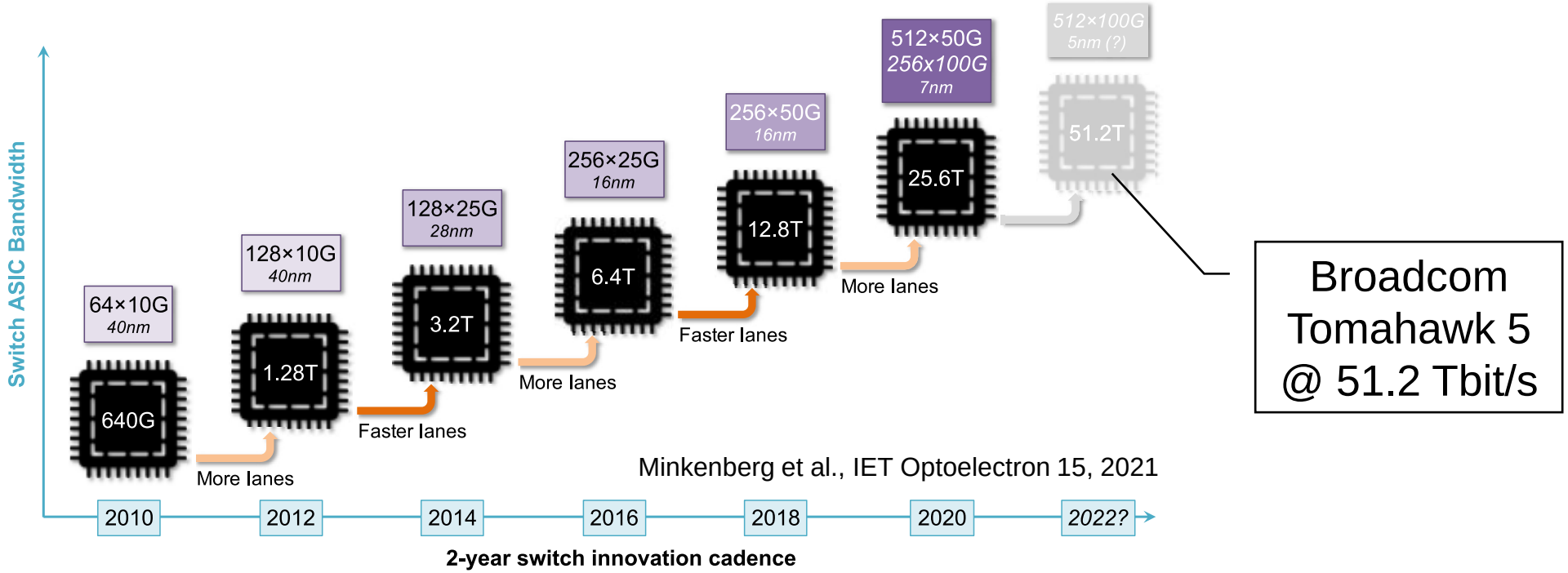
Space-Division Multiplexing for the Fiber-Optic Networking Infrastructure of Datacenters

Bundesministerium für Bildung und Forschung

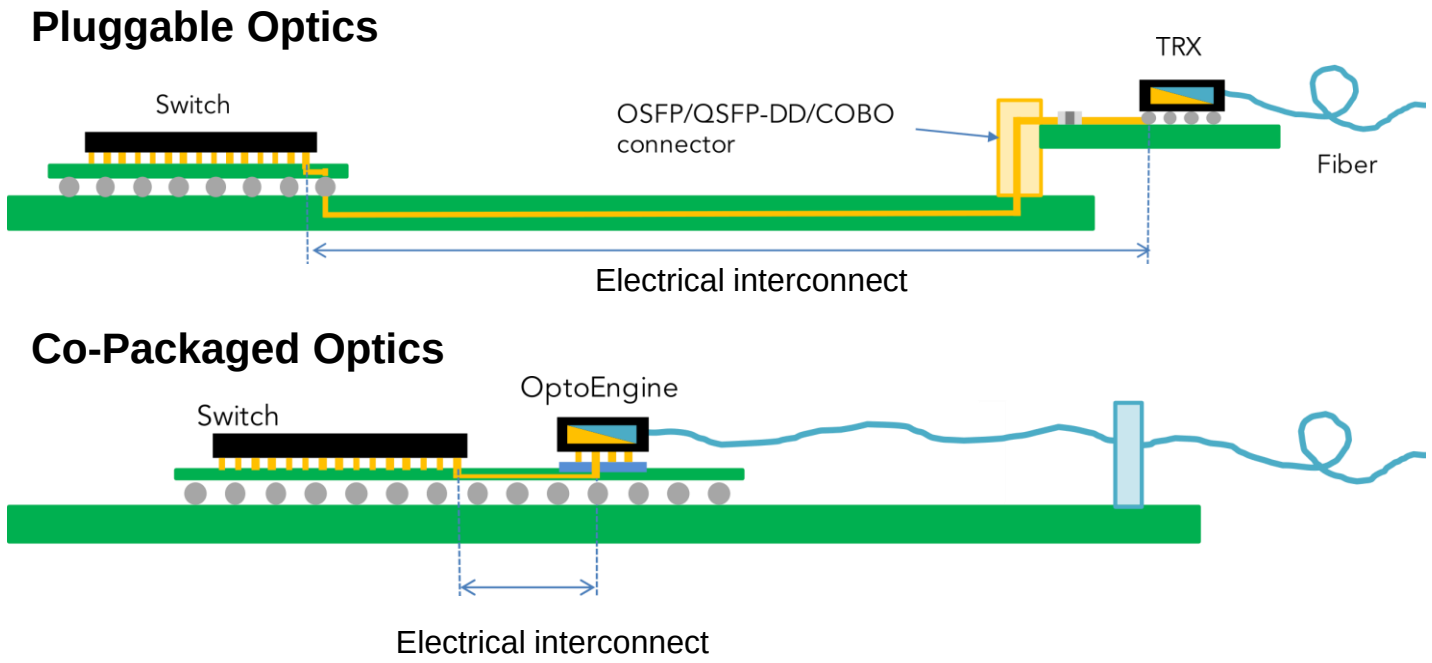
Jonas Krimmer*, Simon Stöhr†, Philipp-Immanuel Dietrich†, Stefan Schmidt§, Hermann Kapim§, Alexandra Henniger-Ludwig§, and Sebastian Randel*

Capacity Growth of Datacenter Switches

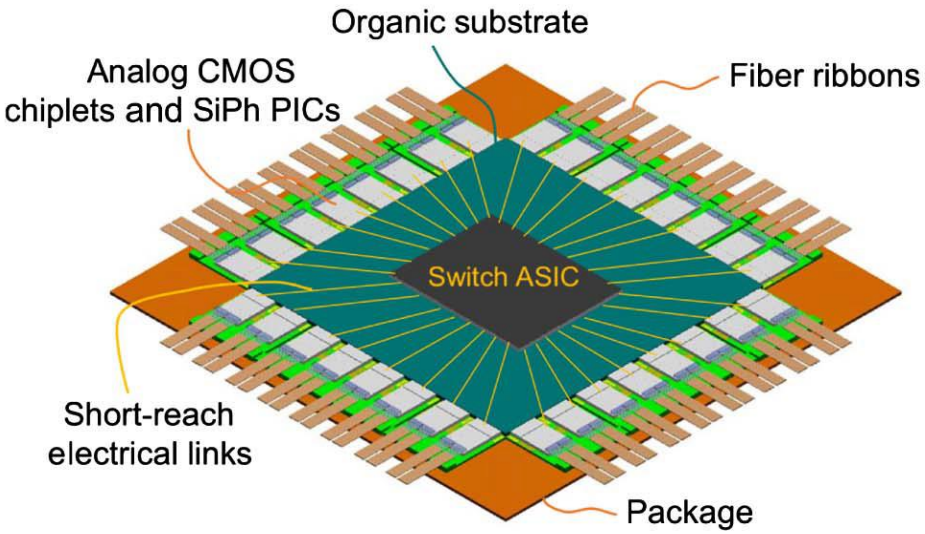


- **Traditional approach**: electrical I/Os of switch ASIC routed through printed circuit board to pluggable optical transceivers located at front panel of rack module
- Increasing signaling rates & parallelism → electrical routing becomes challenging
- **Next Gen**: reduce distance of switch chip and transceivers with co-packaged optics (CPO)

Co-Packaged Optics



Minkenberg et al., IET Optoelectron 15, 2021

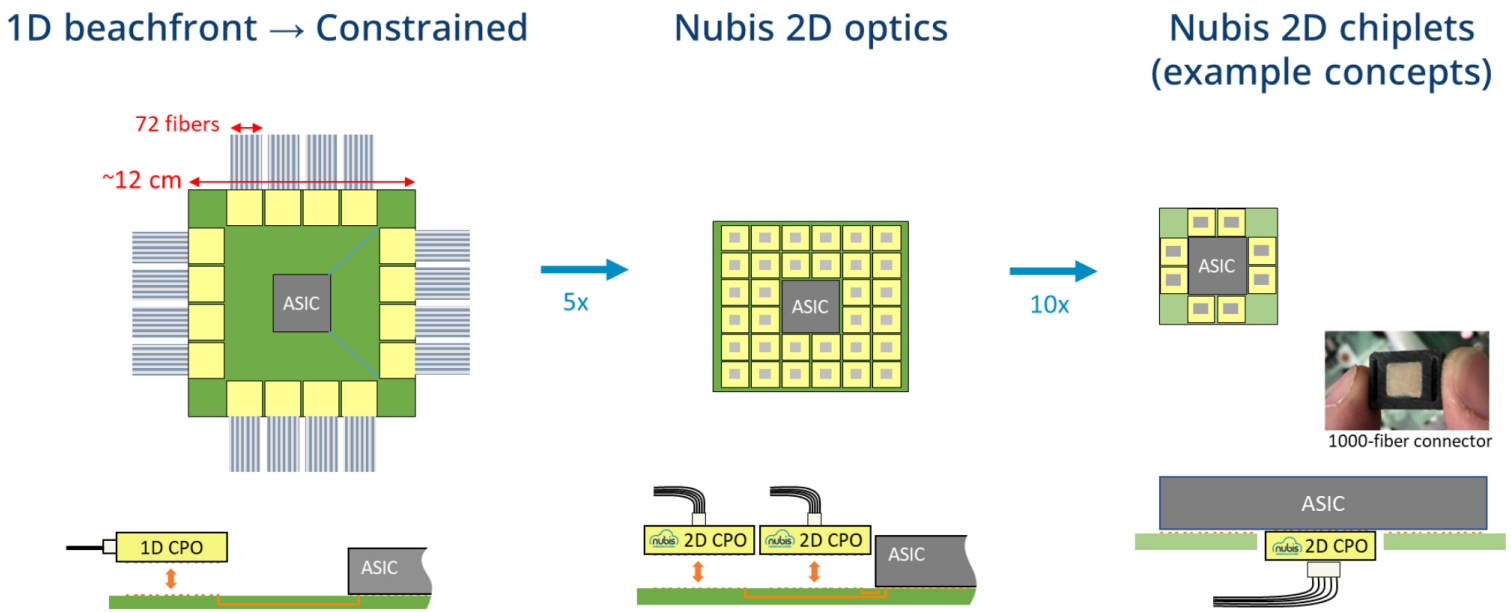


Minkenberg et al., JOCN 10, 2018

- Photonically integrated transmitters and receivers contained in the same package as switch chip
- **Consequence:** Shorter electrical interconnects with larger capacity

Overcoming Space Constraints?

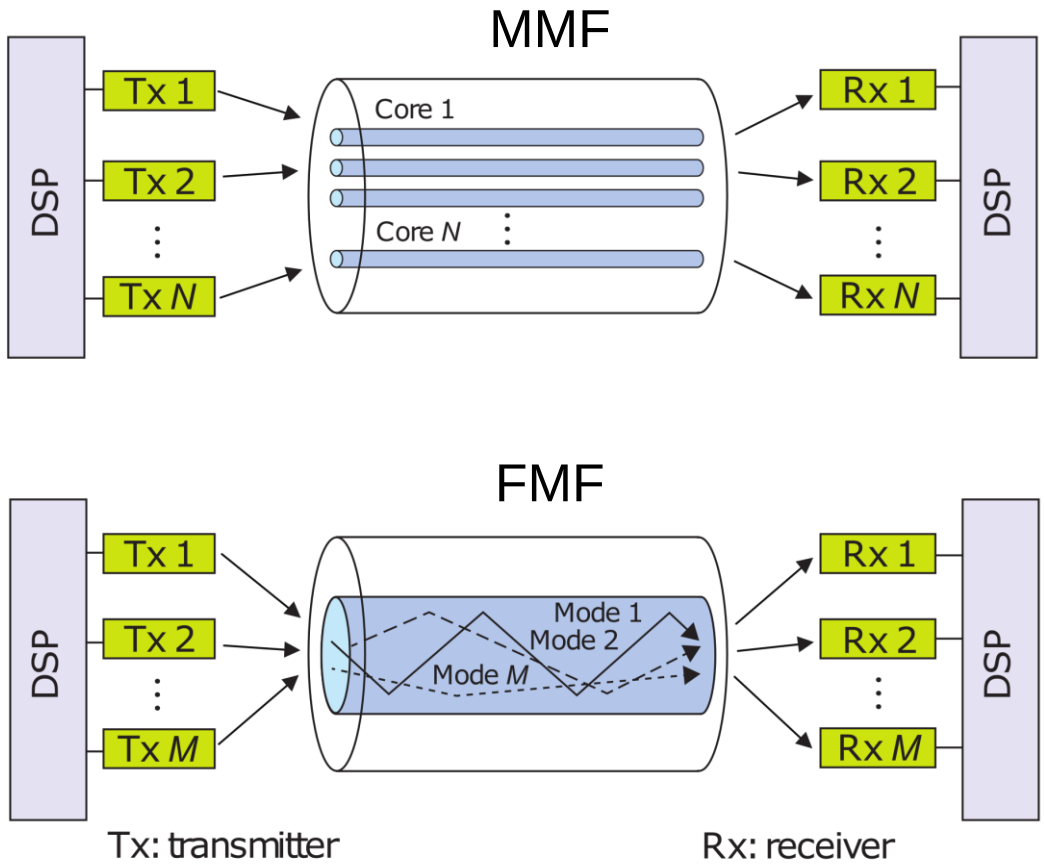
- Nubis Communications XT1600: 16×112 Gbit/s full-duplex optical engine (footprint: 5 × 7.5 mm²)
- Bandwidth density without WDM > 500 Gbit/s/mm
- Surface coupling to 2D array interfaces 36 fibers to single photonic chip (four laser feeds)



https://www.gazettabyte.com/home/2023/3/3/nubis-bandwidth-packed-tiny-optical-engine.html, visited on 08.05.2023

SDM-Fibers for Co-Packaged Optics

- Scaling of optical transceiver capacity becomes increasingly challenging
- Pitch of single-mode fiber (SMF) arrays limited → scaling fiber number affected by space constraints
- Multi-core fibers (MCFs) and few-mode fibers (FMFs) feature higher transmission capacity with footprint comparable to SMFs
- **Question:** How can we make pluggable transceivers SDM-compatible?



Mizuno et al., NTT Technical Review 6, 2017

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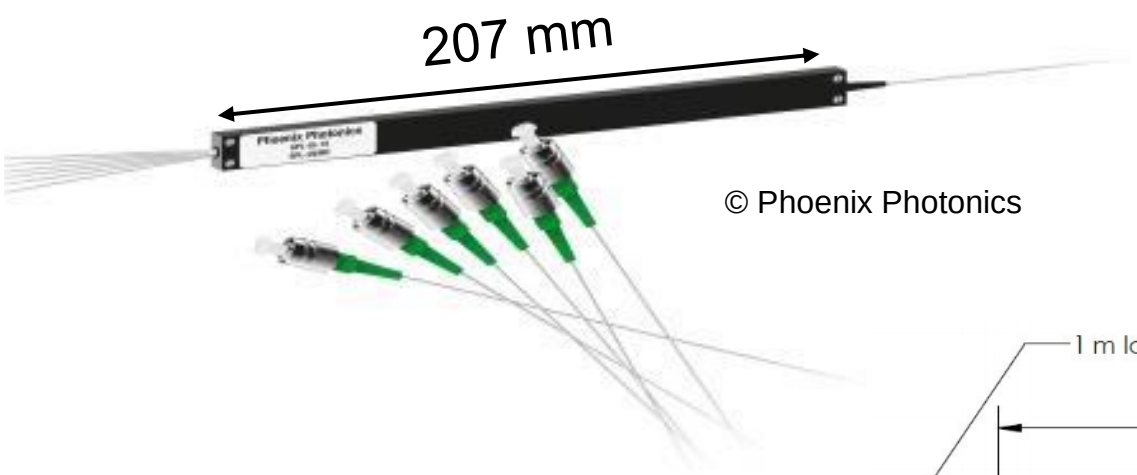
Multiplexers for SDM-Fibers



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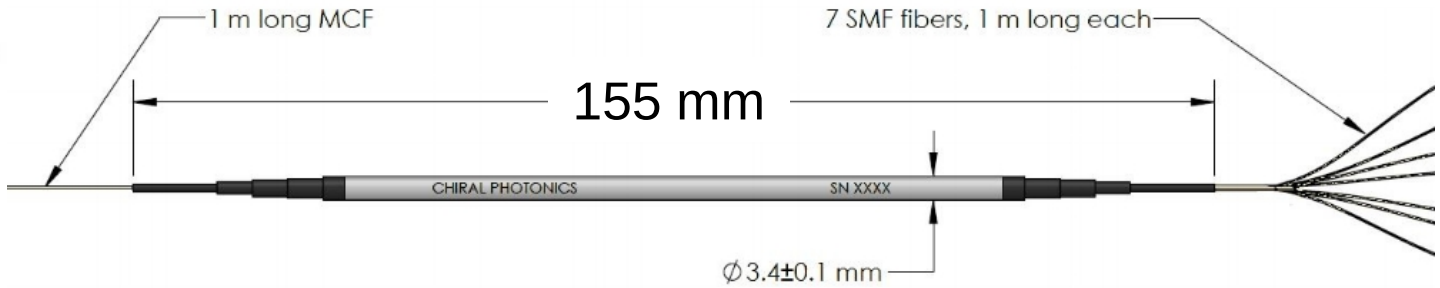


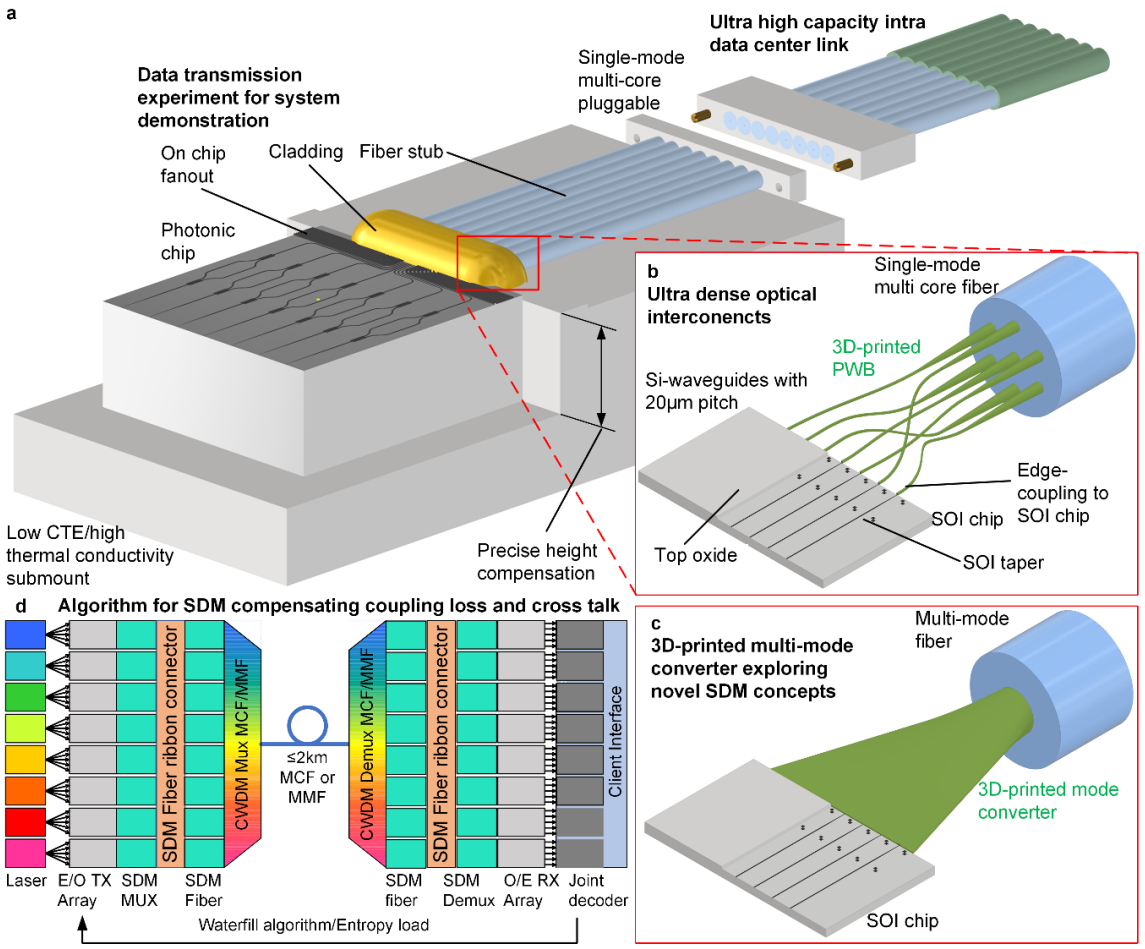
https://chiralphotonics.com/products/multicore-fiber-fanout/, visited on 07.05.2023

- Multi-core & few-mode fiber multiplexers commercially available
- These variantes are too large for the integration into pluggable transceivers → **microstructure** multiplexers required

Project KONFORM

- “Skalierung der **Ko**mmunikationsinfrastruktur in ver**n**etzten Rechenzentren mittels **f**aser**o**ptischem **R**aum**m**ultiplex”
- Design and fabrication of freeform 3D-printed microstructure multiplexers for SDM transceivers
- Realize interfaces between single-mode channels of photonic chip and
  - … multi-core fiber (MCF) vanguard AUTOMATION
  - … few-mode fiber (FMF) IPQ
- Present necessary steps and analyses for using MCF arrays in connector ferrules

Rosenberger



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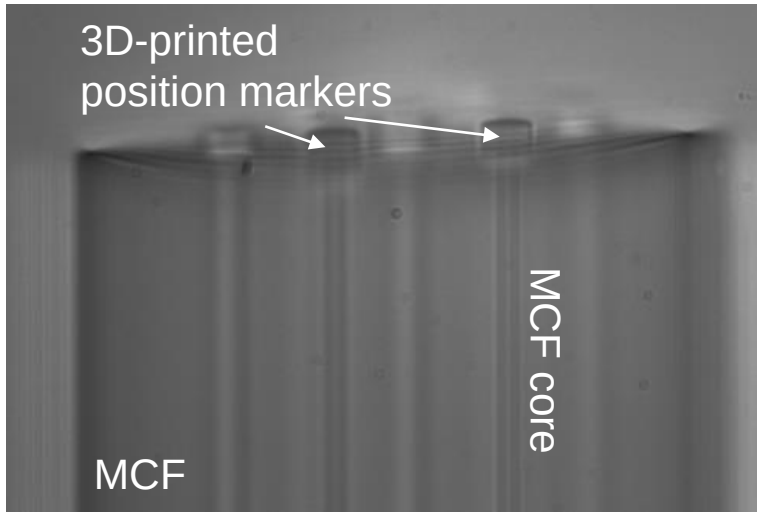
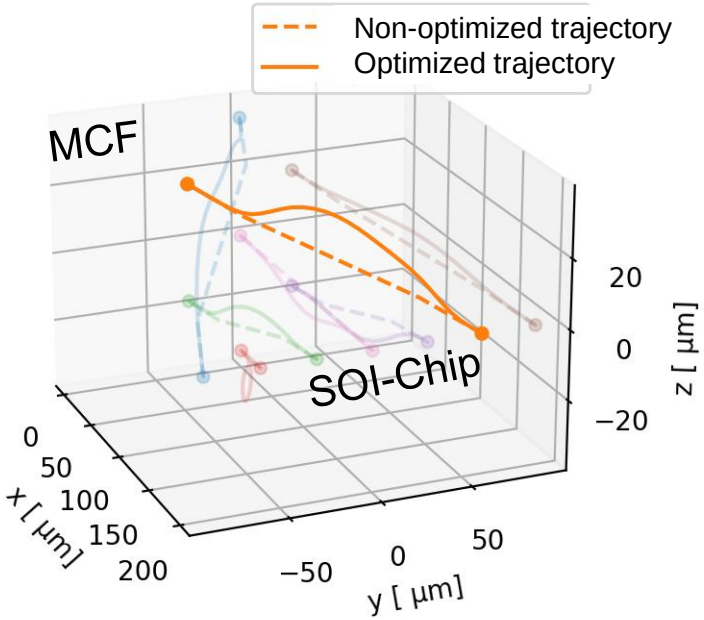
Microscale Multi-Core Multiplexers (I)



Successful realization of automated core-detector for MCFs



Automated routing between on-chip waveguides & MCF cores

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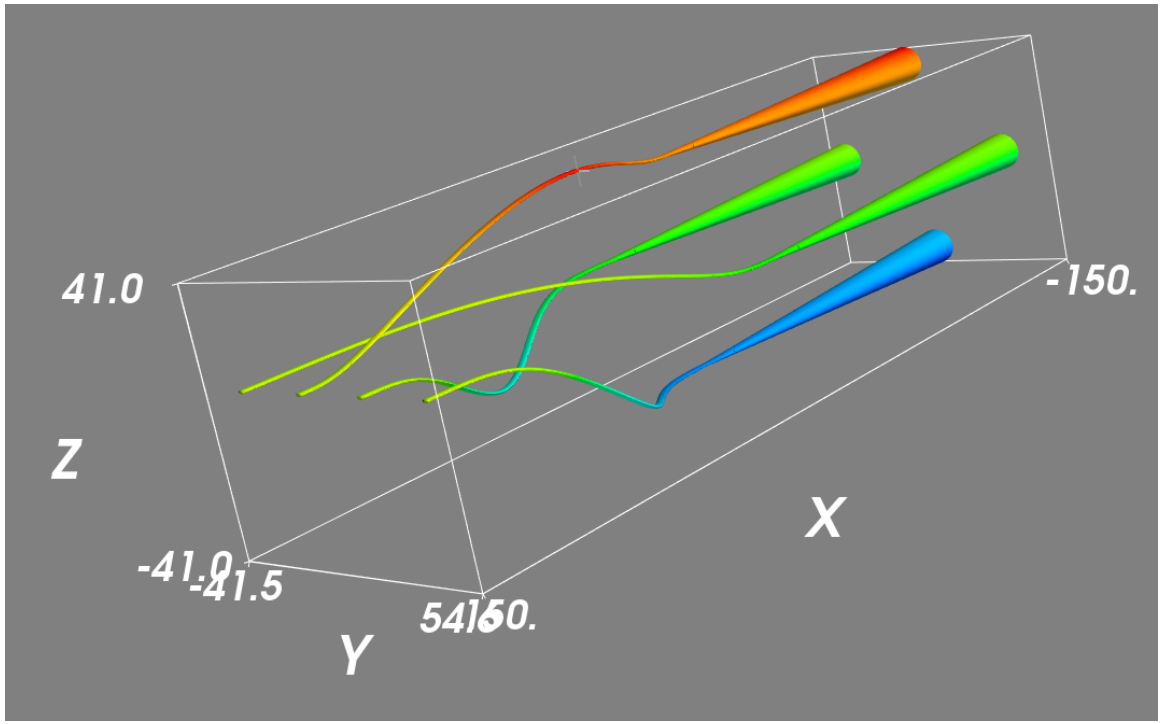
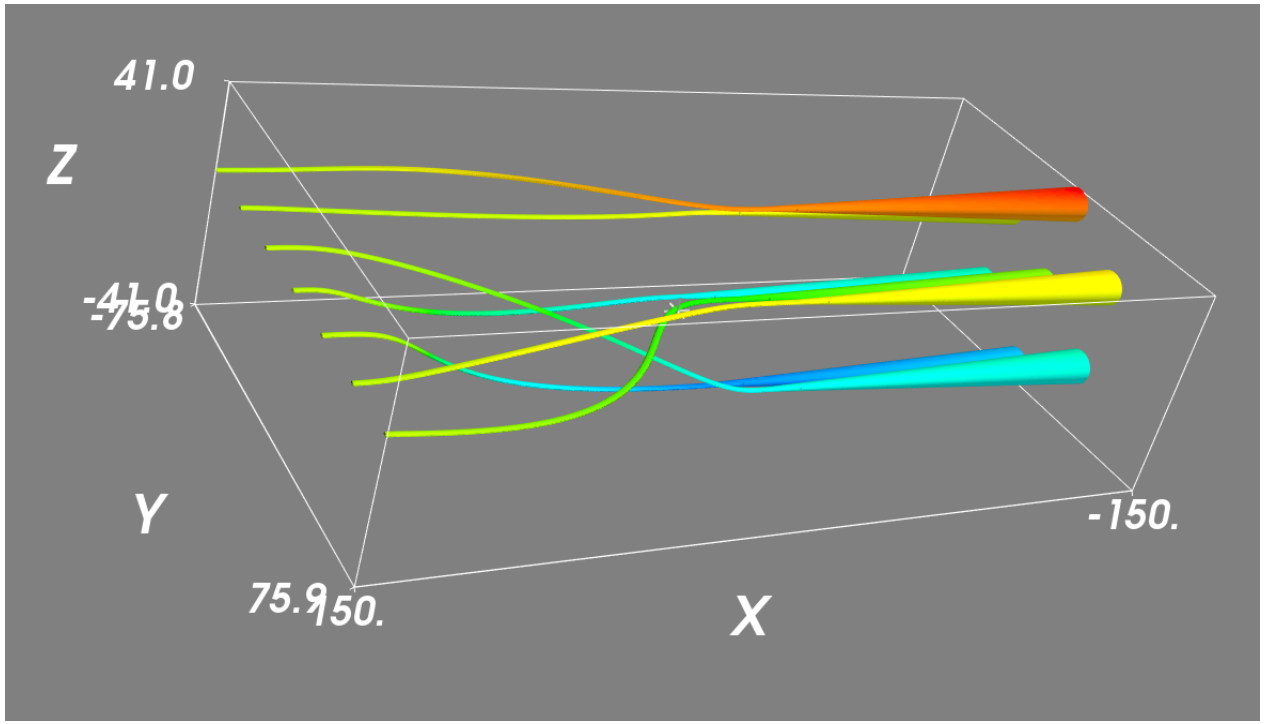
Microscale Multi-Core Multiplexers (II)

vanguard AUTOMATION
bright connections

4CF-Chip-Interface



7CF-Chip-Interface

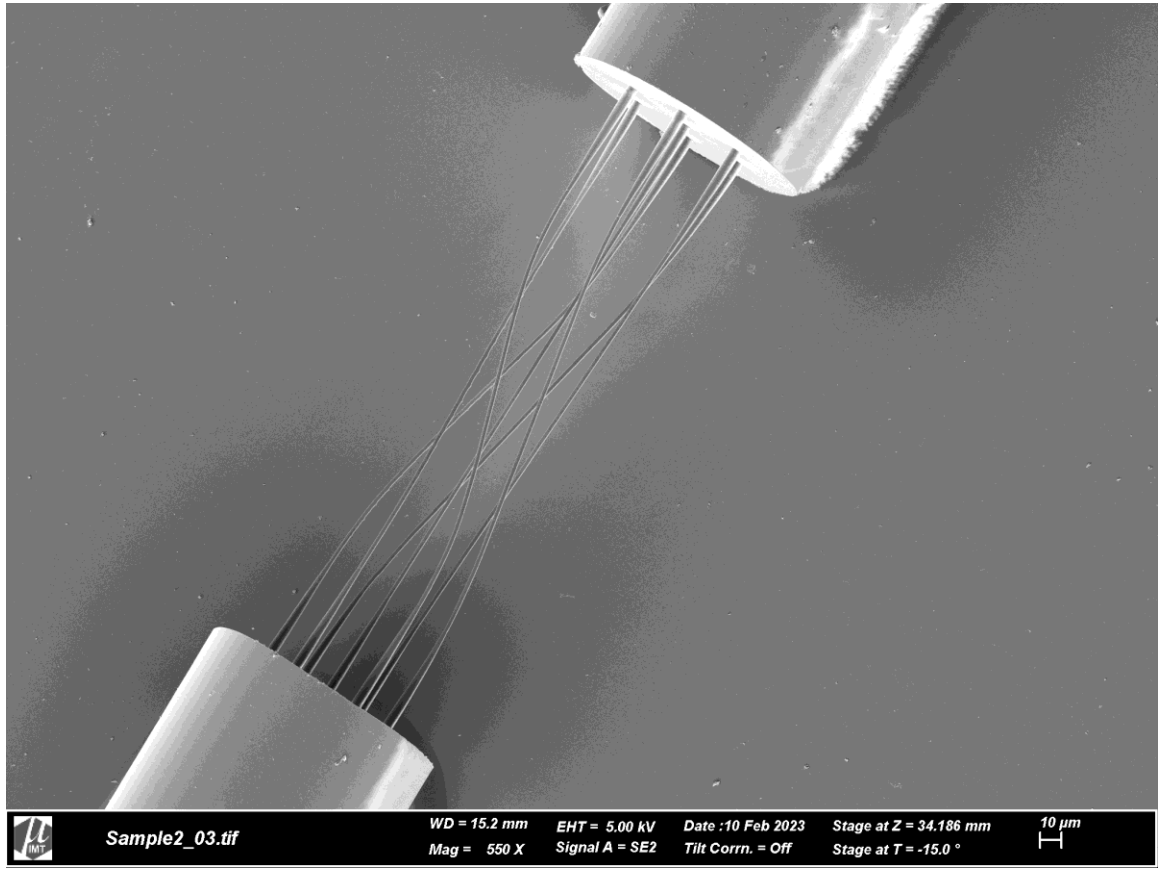


Fully-automated routing-algorithm enables **passive alignment** of fiber cores to silicon photonics chip!

Microscale Multi-Core Multiplexers (III)

vanguard AUTOMATION
bright connections

- Silicon photonics test chip delayed
- First tests of algorithms: MCF to MCF interface build
- Average loss of core-to-core interconnects on first try: 2.4 dB
- Further optimization required



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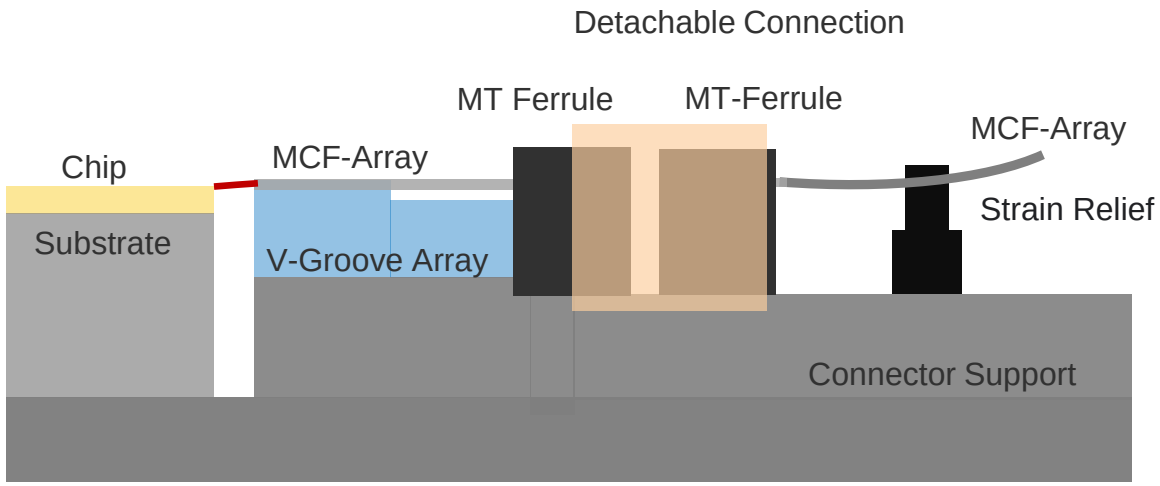
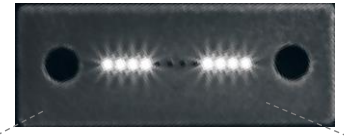
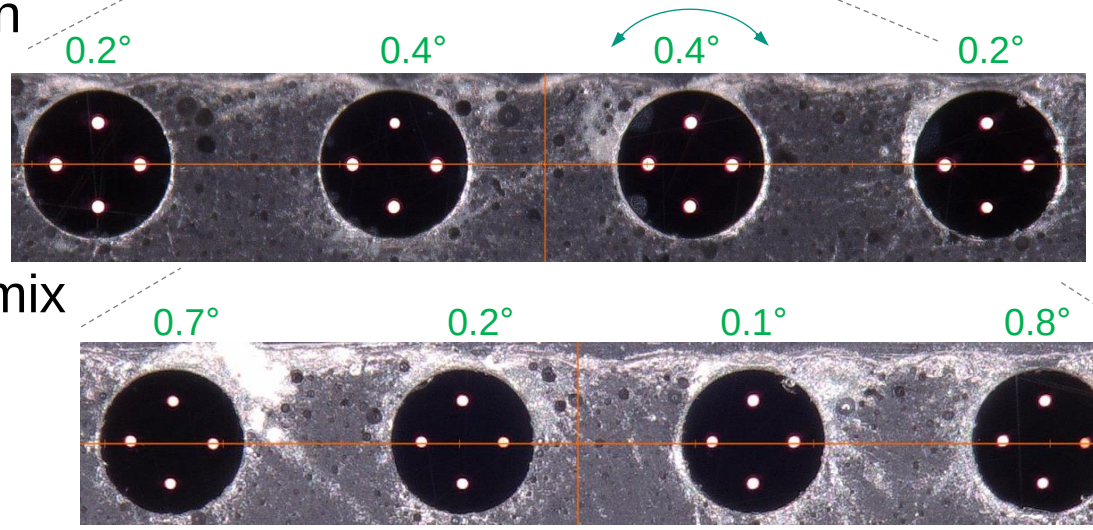
Multicore-Multifiber-Connector



Base: MTP®/MPO Connector

MT Interface Side



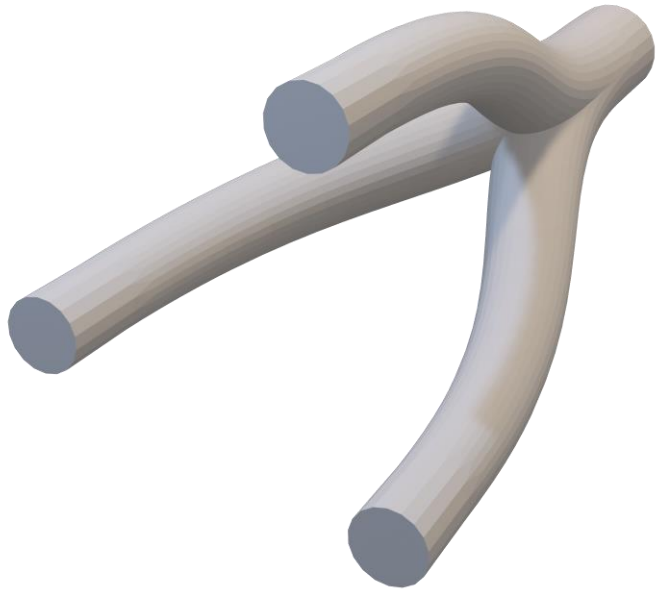


- Detachable fiber chip coupling for easy production
- External standard MT inferface
- Easy chip handling without pigtail
- Core alignment <1°by fiber rotation for universal mix and match
- Strain relief for fiber ribbon

Microscale Mode-Multiplexers (I)

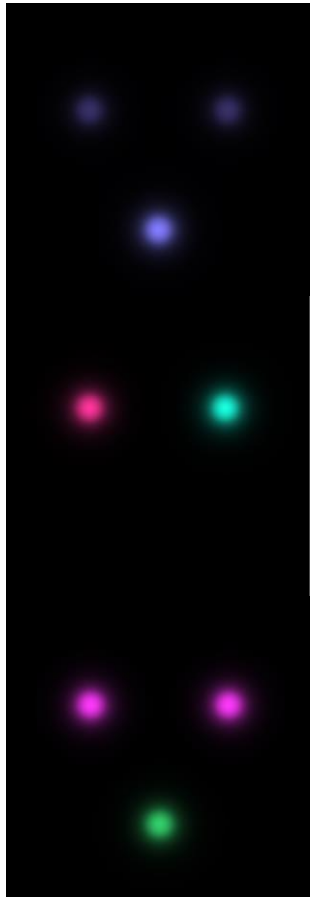
- **Initial design idea**: microscale mode-multiplexers directly connecting FMF to photonic chip
- Natural design approach with two-photon lithography: adiabatic 3D structure similar to photonic lantern
- Adiabatic structure → multiplexer must be much longer than wide → FMF-to-chip interface very long
- Write-field using two-photon lithography limited → **revised design:** multi-core to few-mode multiplexer

First design draft:
Distance between cores: 50 µm
Length of multiplexer: 120 µm



Microscale Mode-Multiplexers (II)

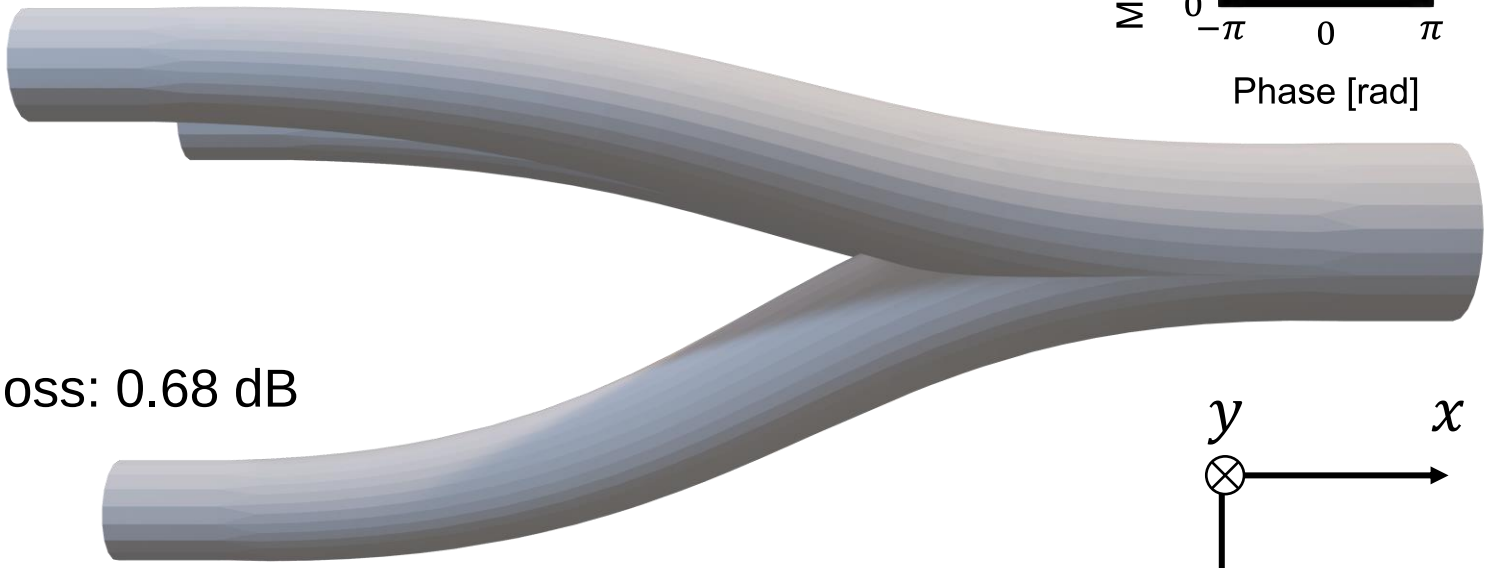
MCF-Modes



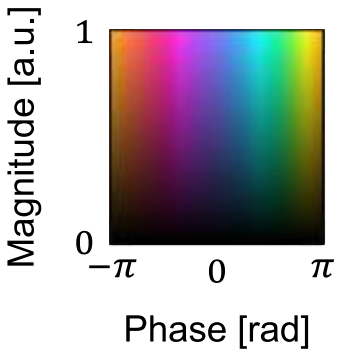
TX loss: 1.05 dB

TX loss: 0.68 dB

TX loss: 2.28 dB

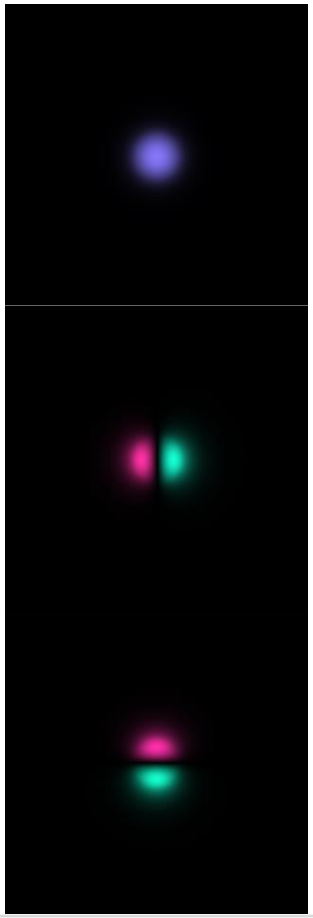


Colorbar



Design requires further optimization!

FMF-Modes



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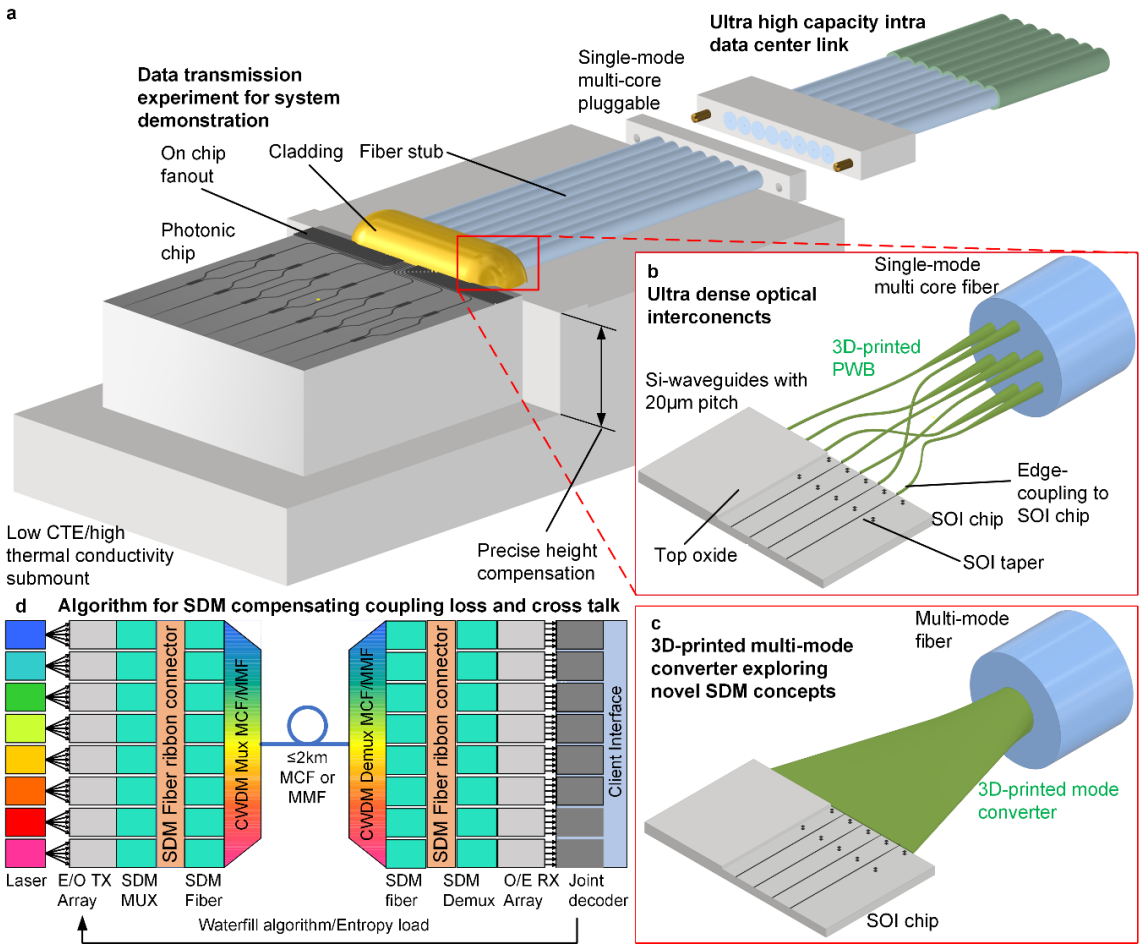
Conclusions

- Co-Packaged Optics has the potential to connect future ultra-high bandwidth datacenter switch chips
- Microscale mode- and core-multiplexers → SDM for pluggable transceivers
- KONFORM: partners completed first steps towards…
  - … multi-core to photonic chip interface
  - … multi-mode to multi-core interface
  - … pluggable connectors for multi-core fiber arrays



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