Tackling the optical interconnection challenge for the Integrated Photonics Revolution

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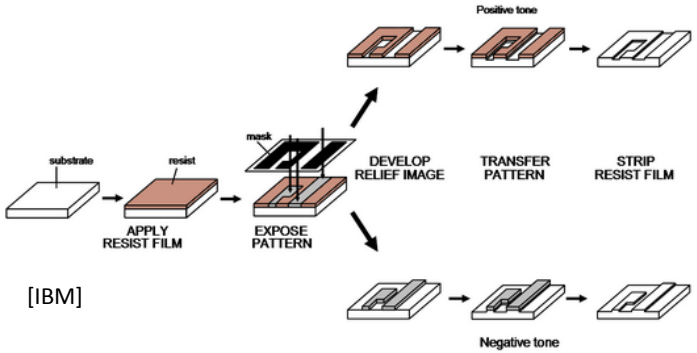
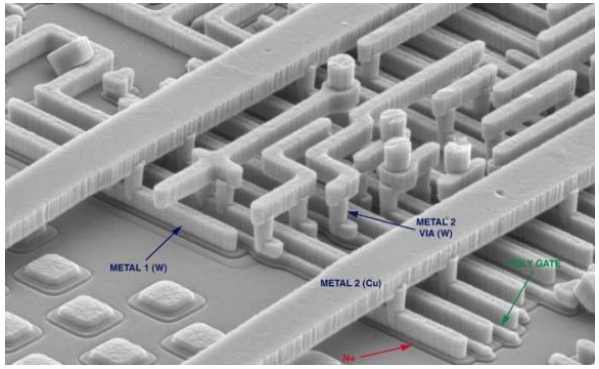
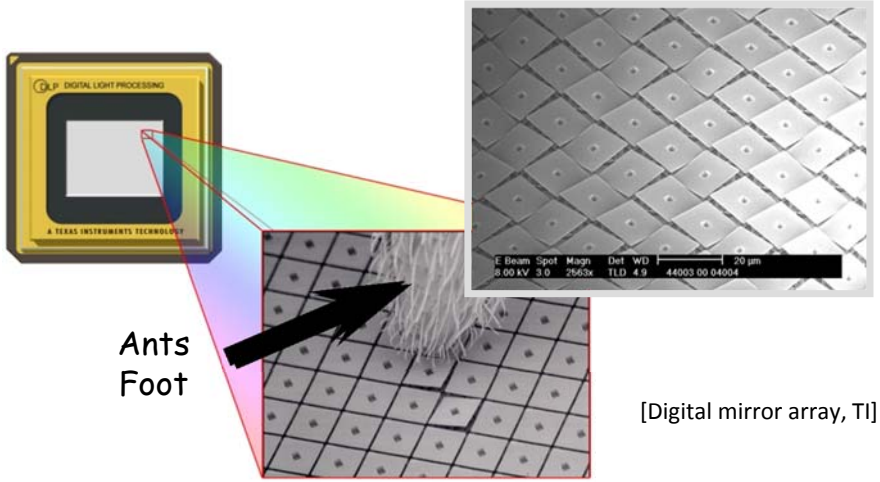
Microfabrication and MEMS …

- Si microfabrication the backbone for success of microelectronics



[IBM]



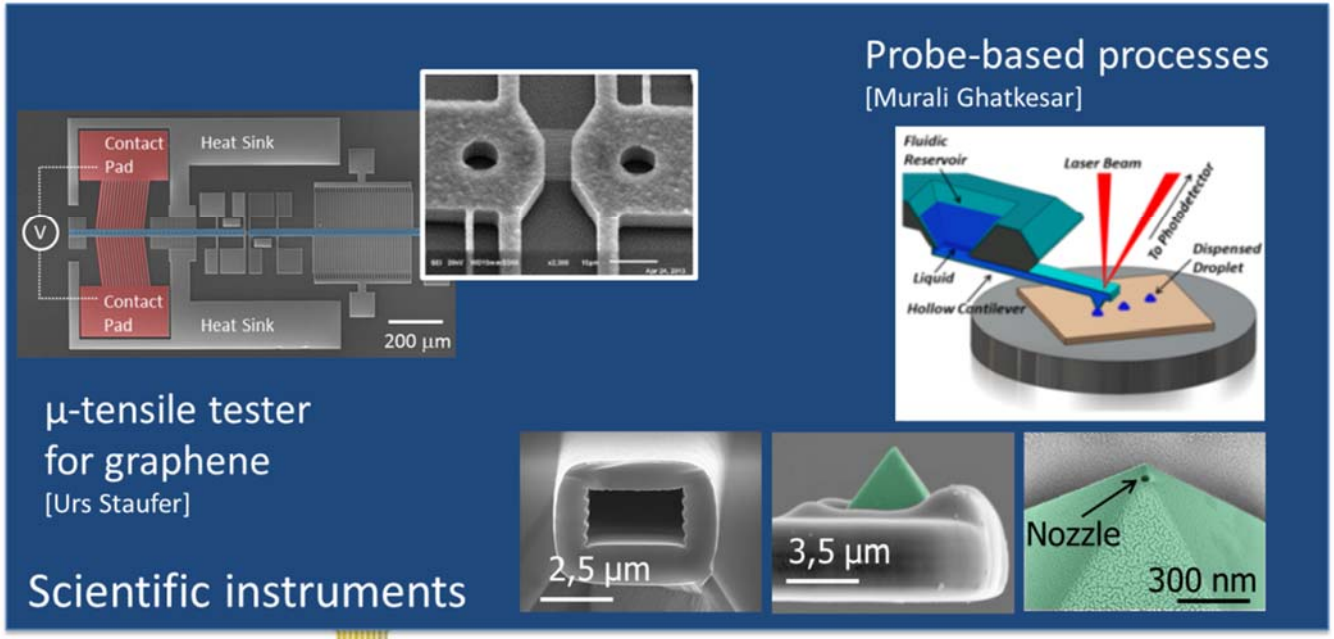


[Digital mirror array, TI]

- Same technology basis for creating micro-mechanical functions: MEMS *MicroElectroMechanical Functions*
- Accelerometers, inkjet heads, resonators, …

Microfabrication and MEMS for science and industry

- Exploit
  - Precision and sensitivity
  - Small size and integration potential
  - Volume scalability

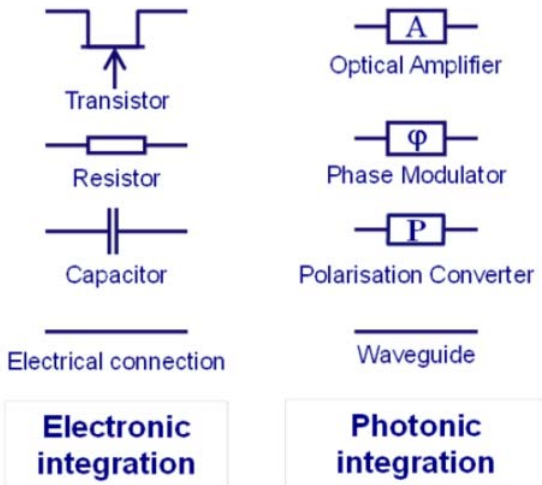


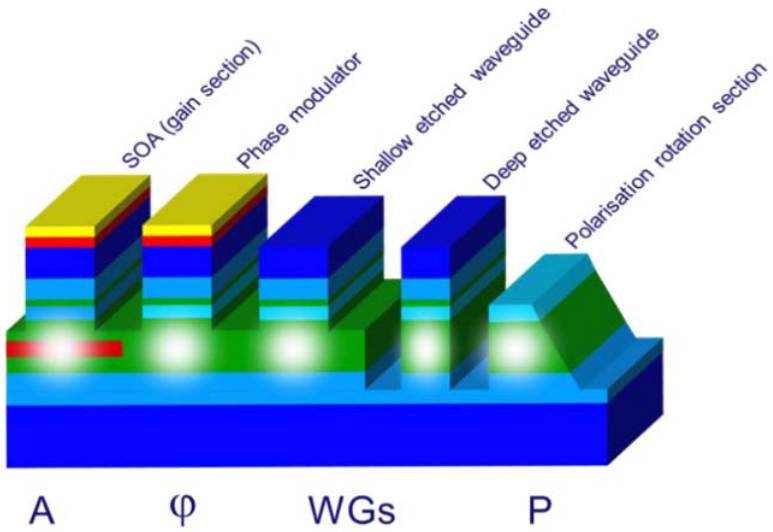
Message of the day

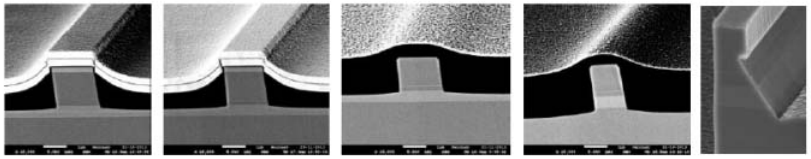
- Show that microfabrication and MEMS is a promising enabler for breakthrough in the assembly and precision alignment for photonic devices
  - **The challenge**: integrated photonics, packages and alignment
  - **The proposed solution**: concept, design and manufacture results

Integrated Photonics

- Philosophy: photonic building blocks …

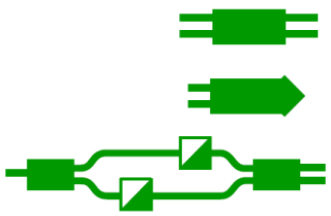




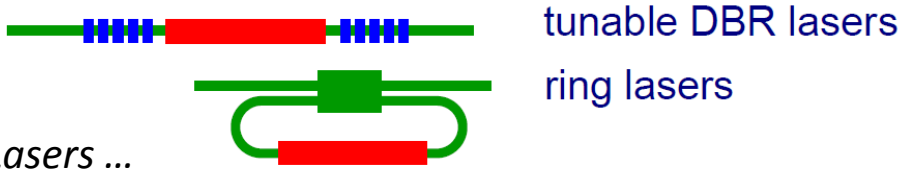


Integrated Photonics

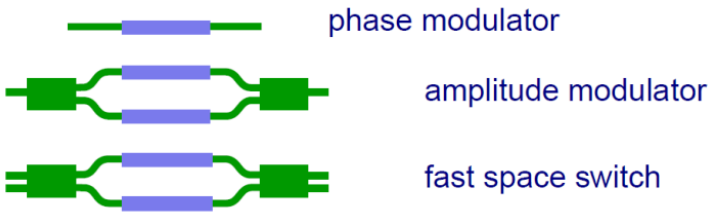
- … to design and fabricate a variety of functions



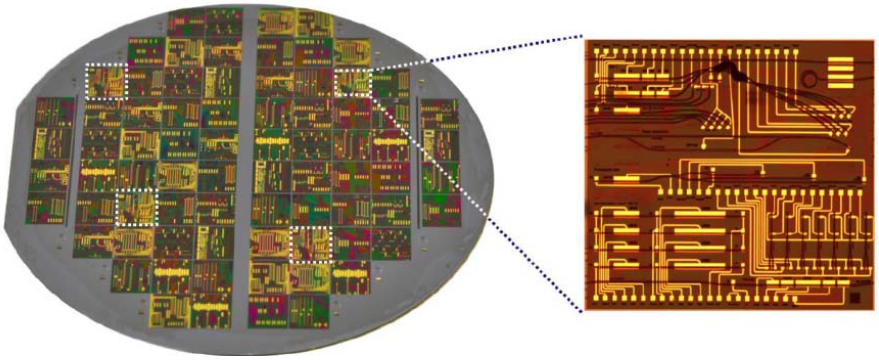
Passive devices …



Lasers …



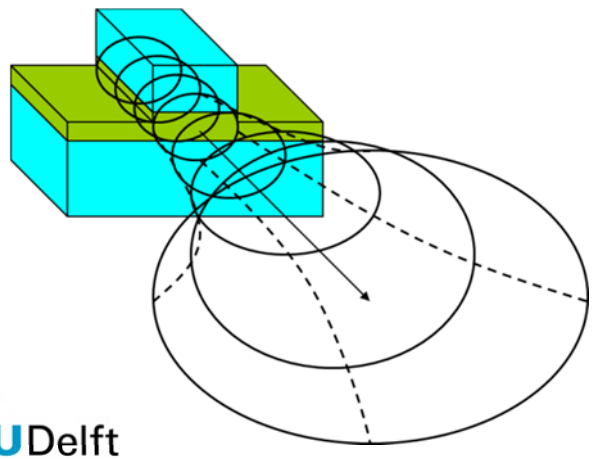
Switches and modulators …

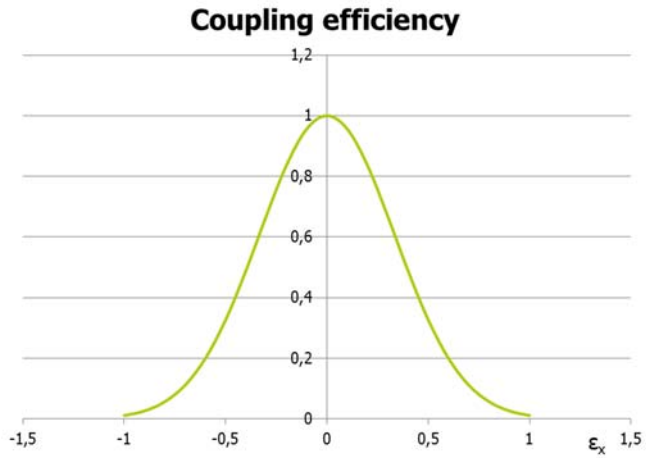


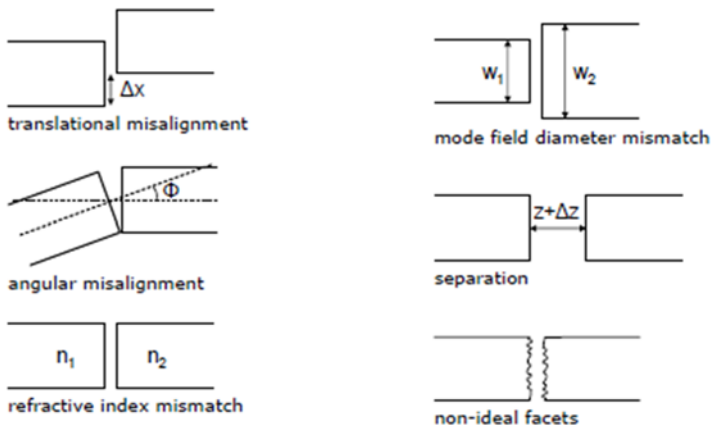
Multi-project wafer run
to share cost in R&D phase

Alignment challenge

- Optical interfacing: internal and external, e.g.
  - Optical components within package
  - Fibre (array) to chip
- Precision level depends on mode field diameter and wavelength
  In most demanding cases deep sub-µm (±100nm)







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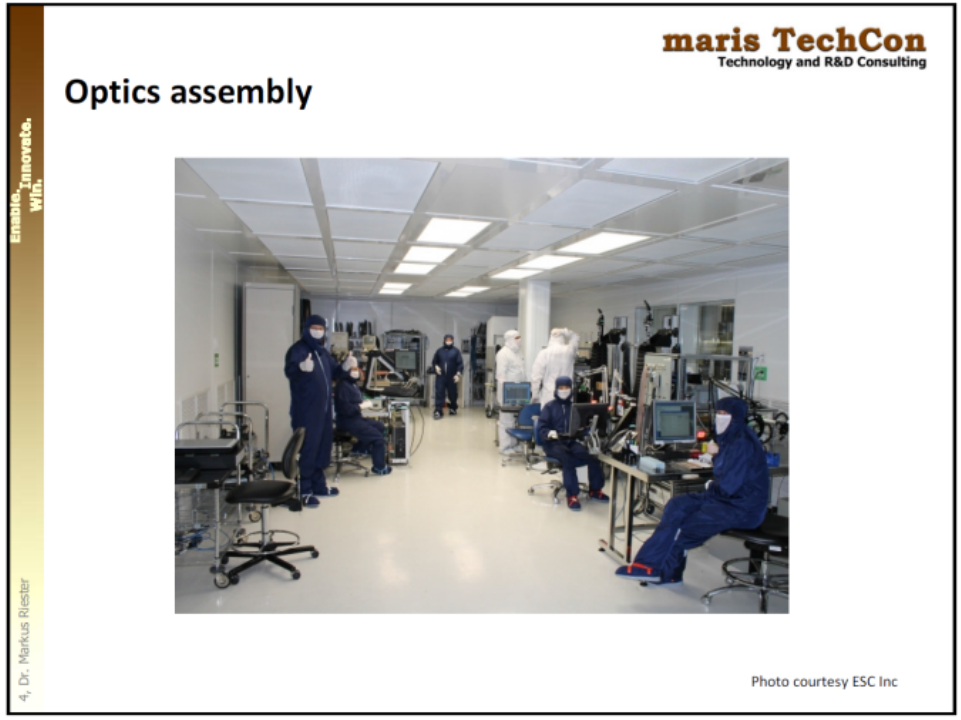
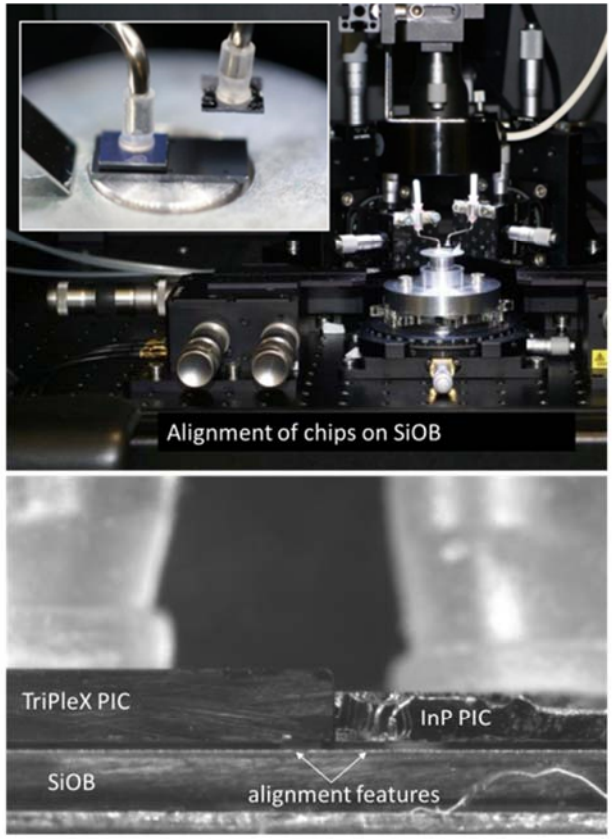
Electronic vs optical assembly/packaging

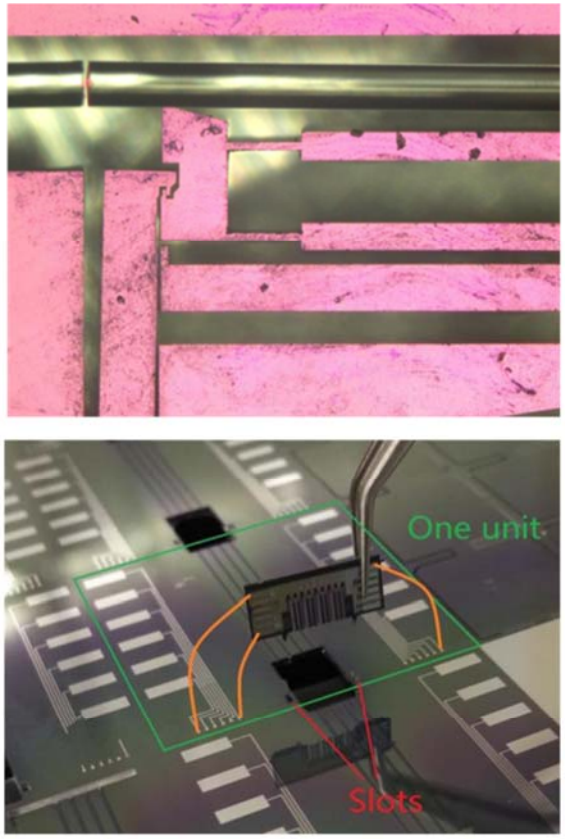


The need: high precision, low(er) cost, higher throughput, higher levels of automation

Microfabrication as enabler for photonic alignment



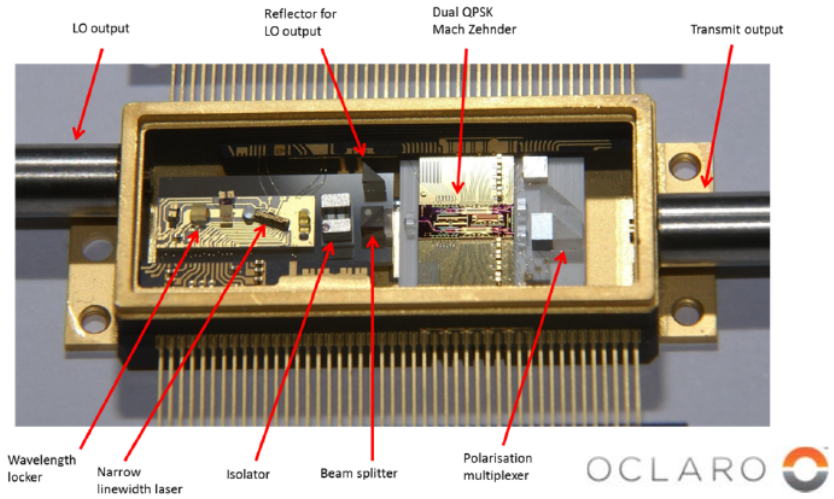
- **Passive alignment**: geometric mating features



- **Active alignment**: use of **MEMS**

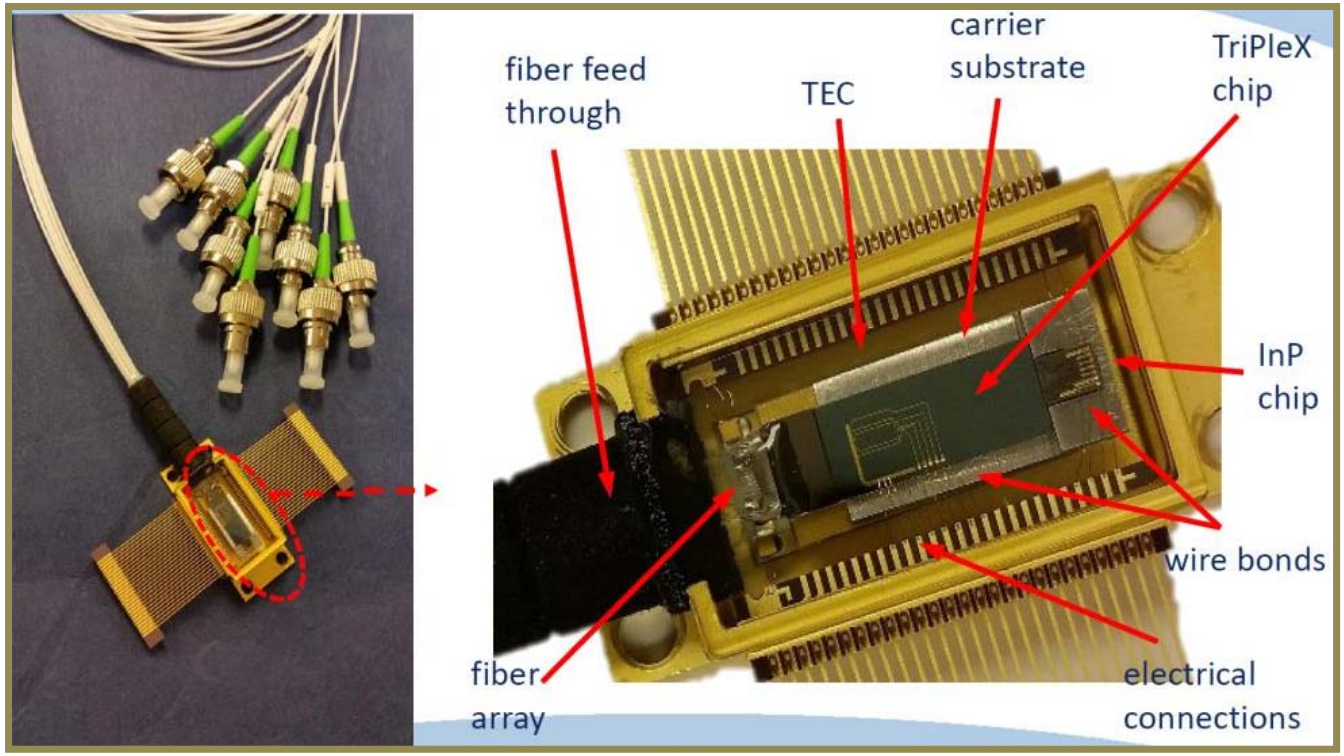
Photonics for data communication

- Photonic packages to enable massive data communication
- Complex packages: Photonic Integrated Circuit (PIC), micro-optics, …
- Integration is a key challenge
  Technology exists for assembly, however:
  - Labour intensive
  - Expensive



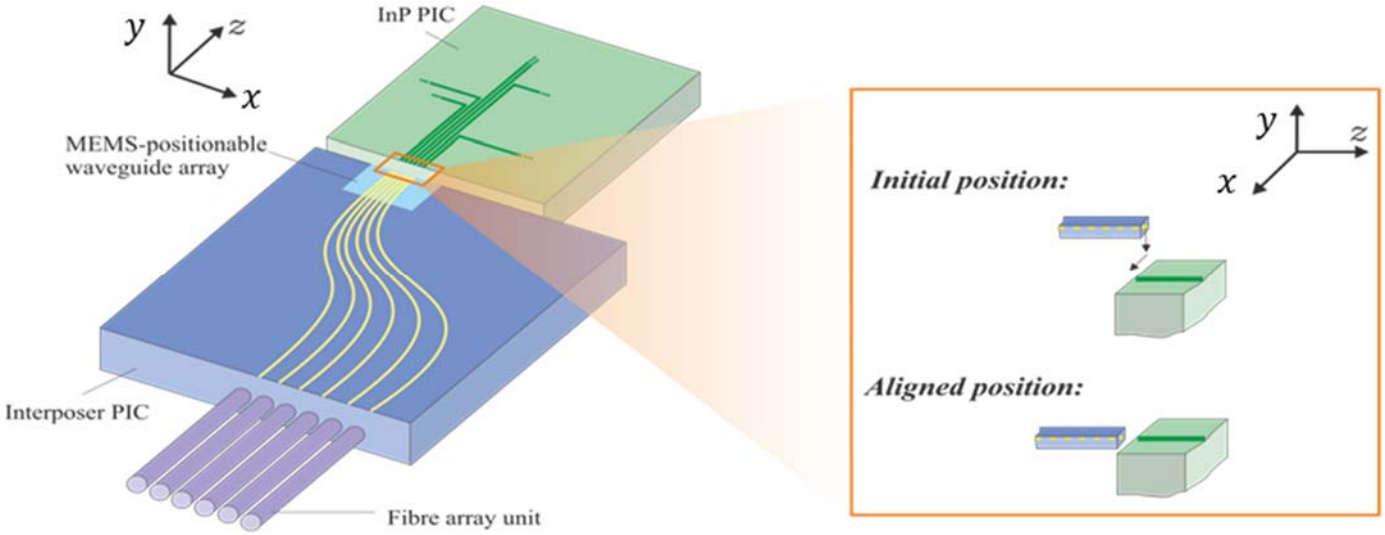
New generation: multi-chip package

- InP PIC with TriPleX interposer, coupled to optical fibre array

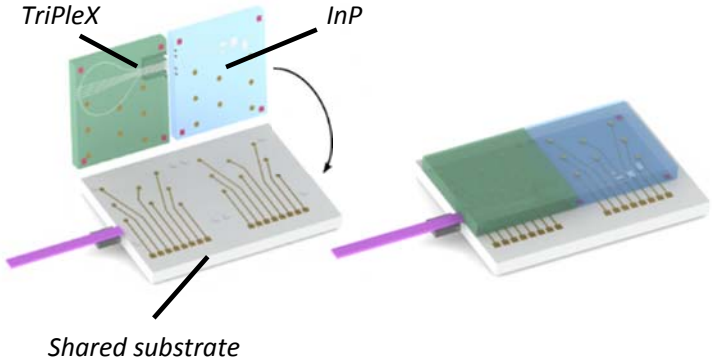


Chip-to-chip alignment

- Multiple optical ports
- High precision, waveguide-to-waveguide (100nm)

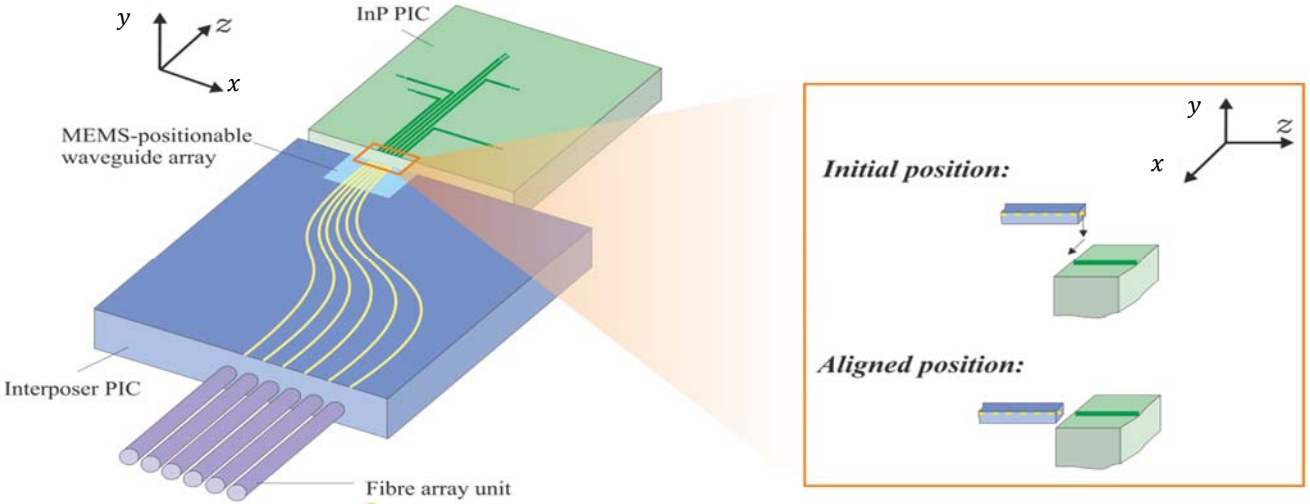


On-chip MEMS

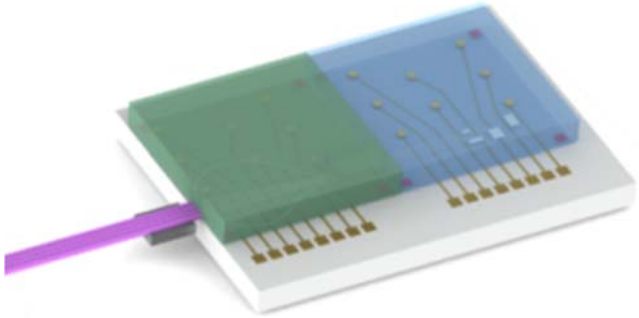


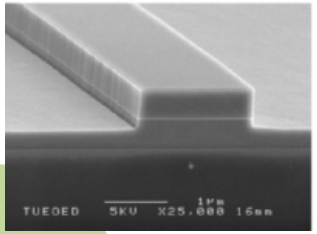
- Pre-assembly: chips placed and bonded with moderate precision
- On-chip MEMS for fine-alignment and locking to final precision, <100nm, waveguide to waveguide

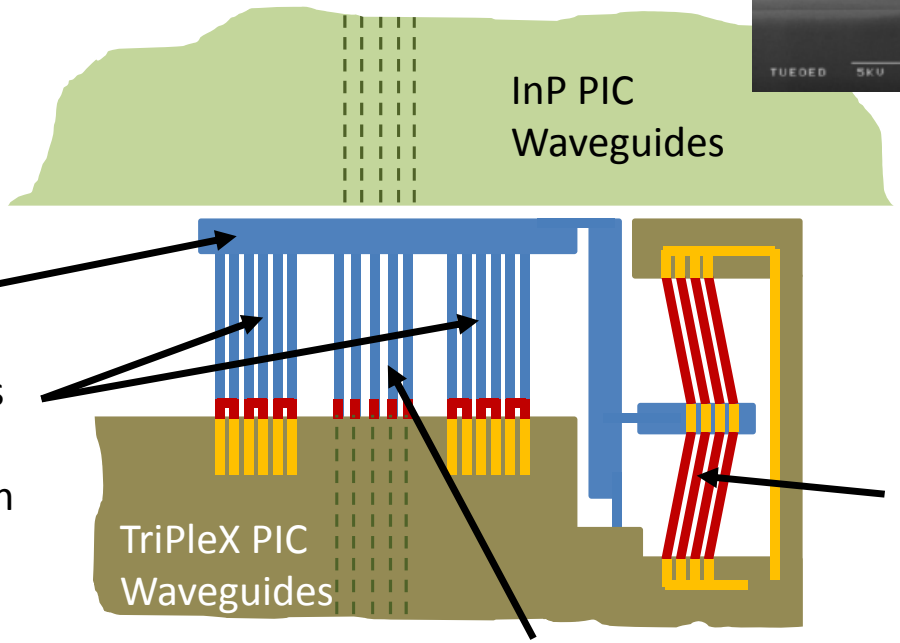
- On-chip functions:
  - Flexible waveguides
  - Actuators for 3 critical motion directions: T_x, T_y, R_z
  - Locking in final position



Design concept







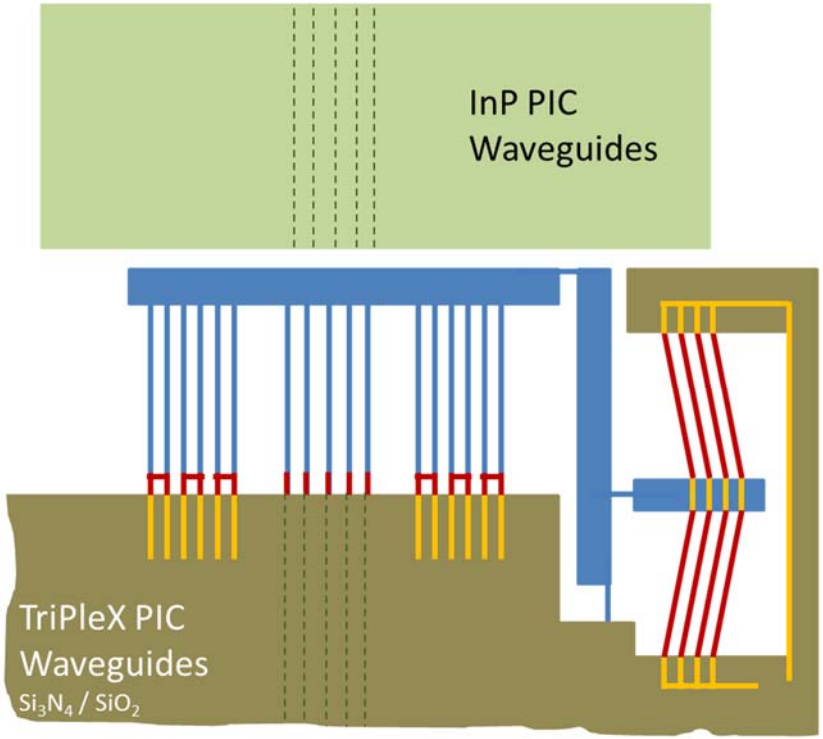
Cross-bar
Two **bimorph** actuator sets
Short loop actuators
Out-Of-Plane (OOP) motion
(Ty, Rz)

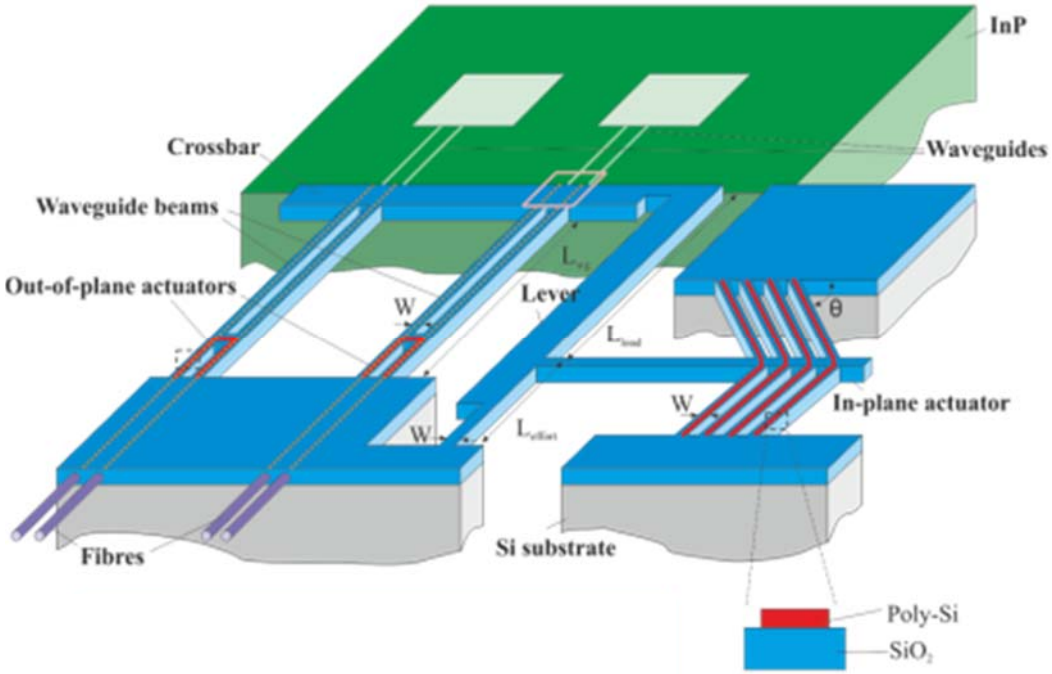
Chevron actuator
In-Plane (IP) motion
(Tx)
Lever mechanism

Flexible waveguide beams

- SiO_2 + Si
- Suspended SiO_2
- Heater / poly-Si
- Conductor

Design concept



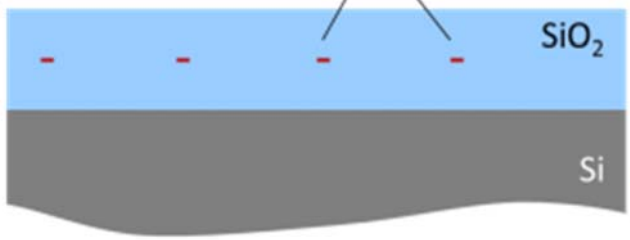


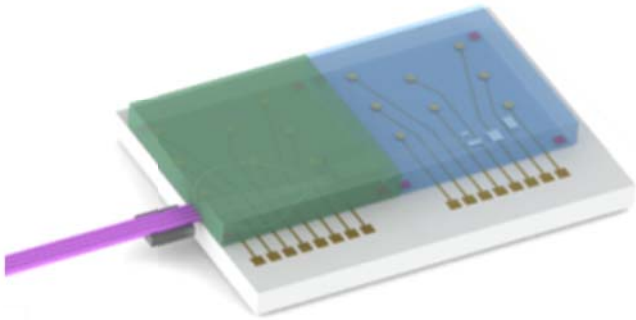
SiO_2 photonic MEMS – the challenges

Post-fabrication deformation
Residual stress in multi-material stacks

Fabrication
Compressive stress in thick SiO_2

Waveguide cores Si_3N_4





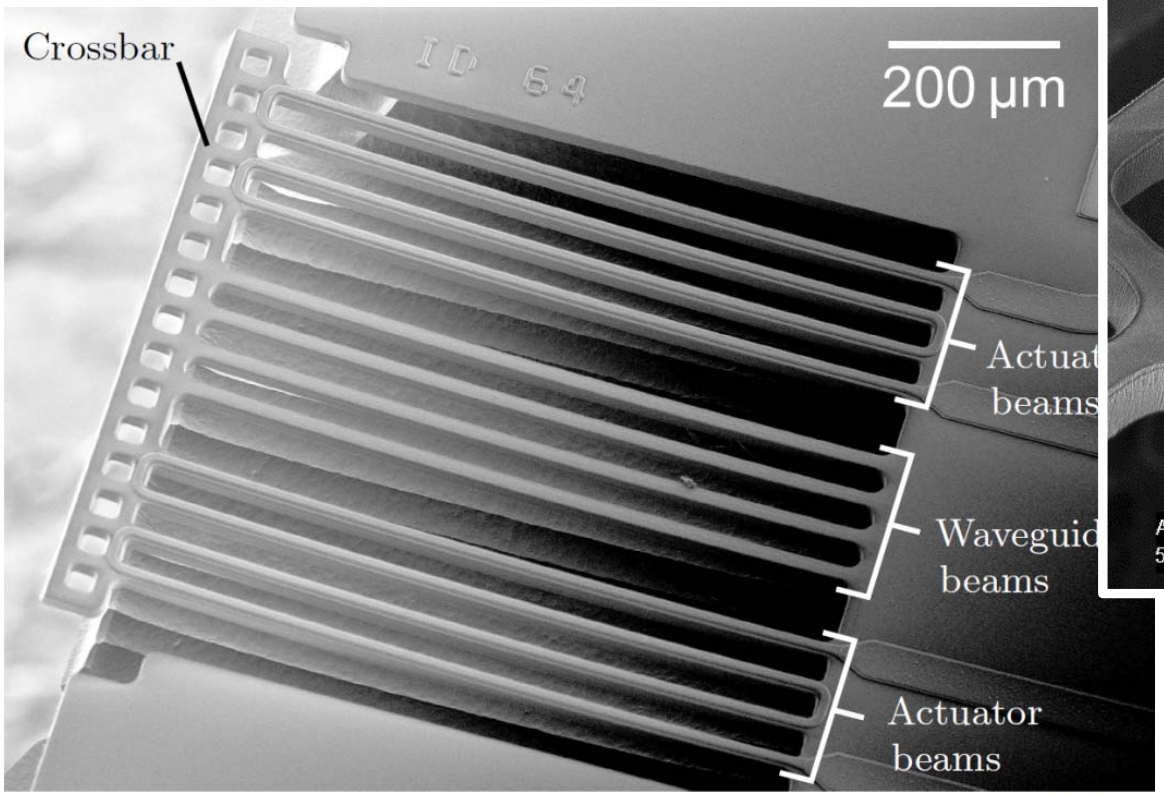
TriPleX™ platform

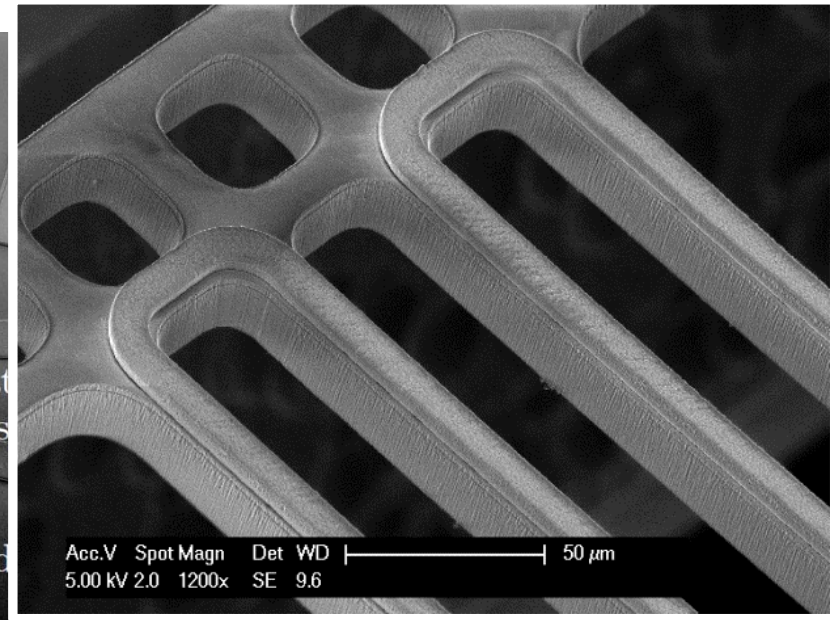
Actuation range
All relevant motion direction
CTE of SiO_2 (thermal actuators)

Locking precision
Maintain position

Design integration
All functions cooperating, space consumption

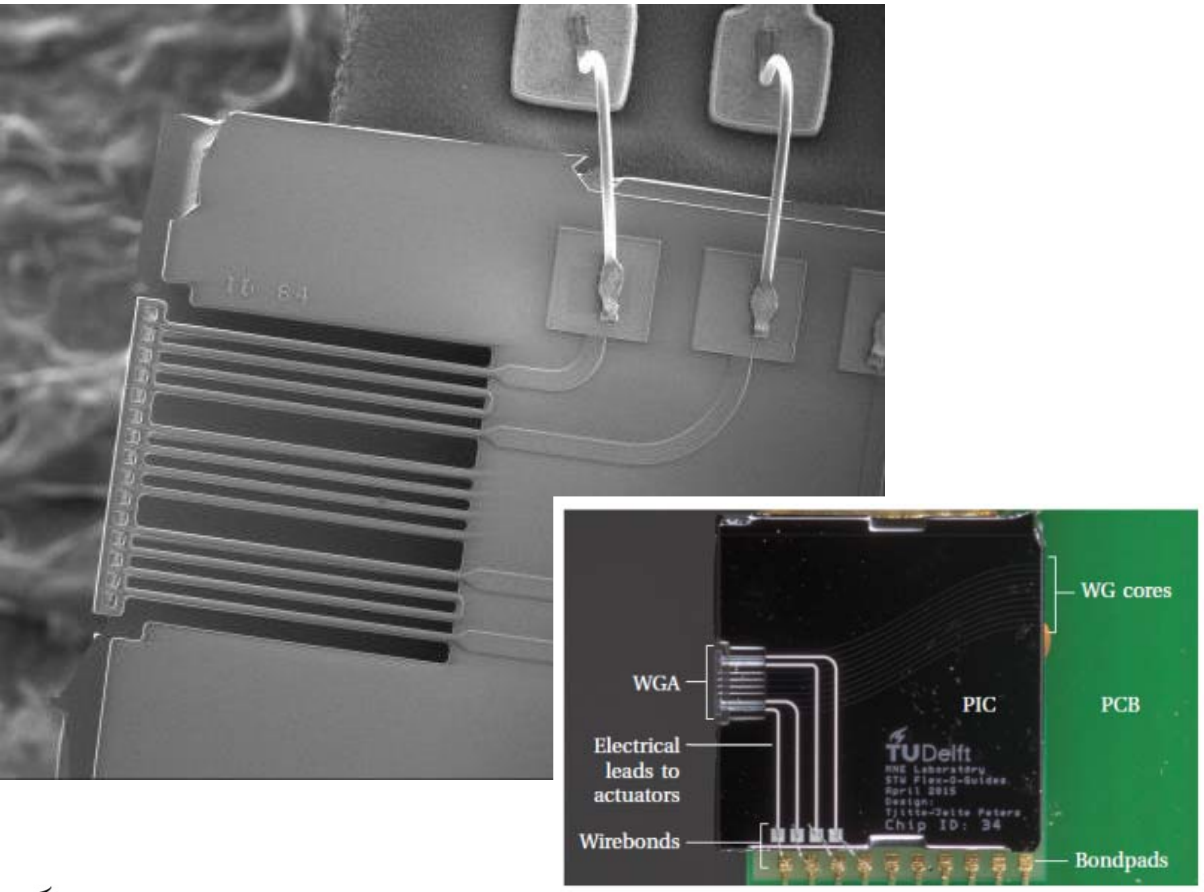
Example structure: waveguide beams and bimorphs

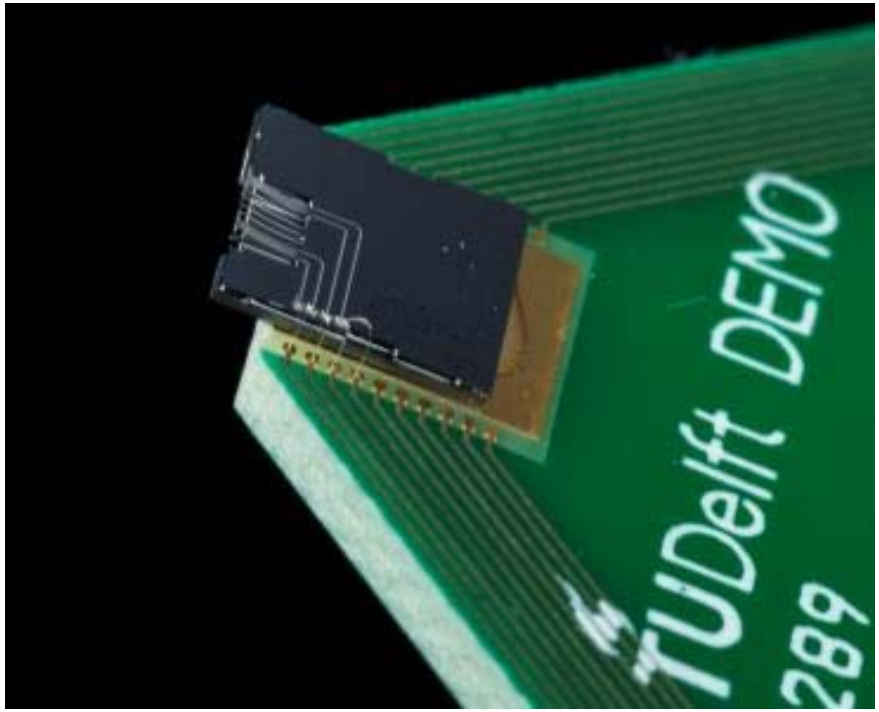


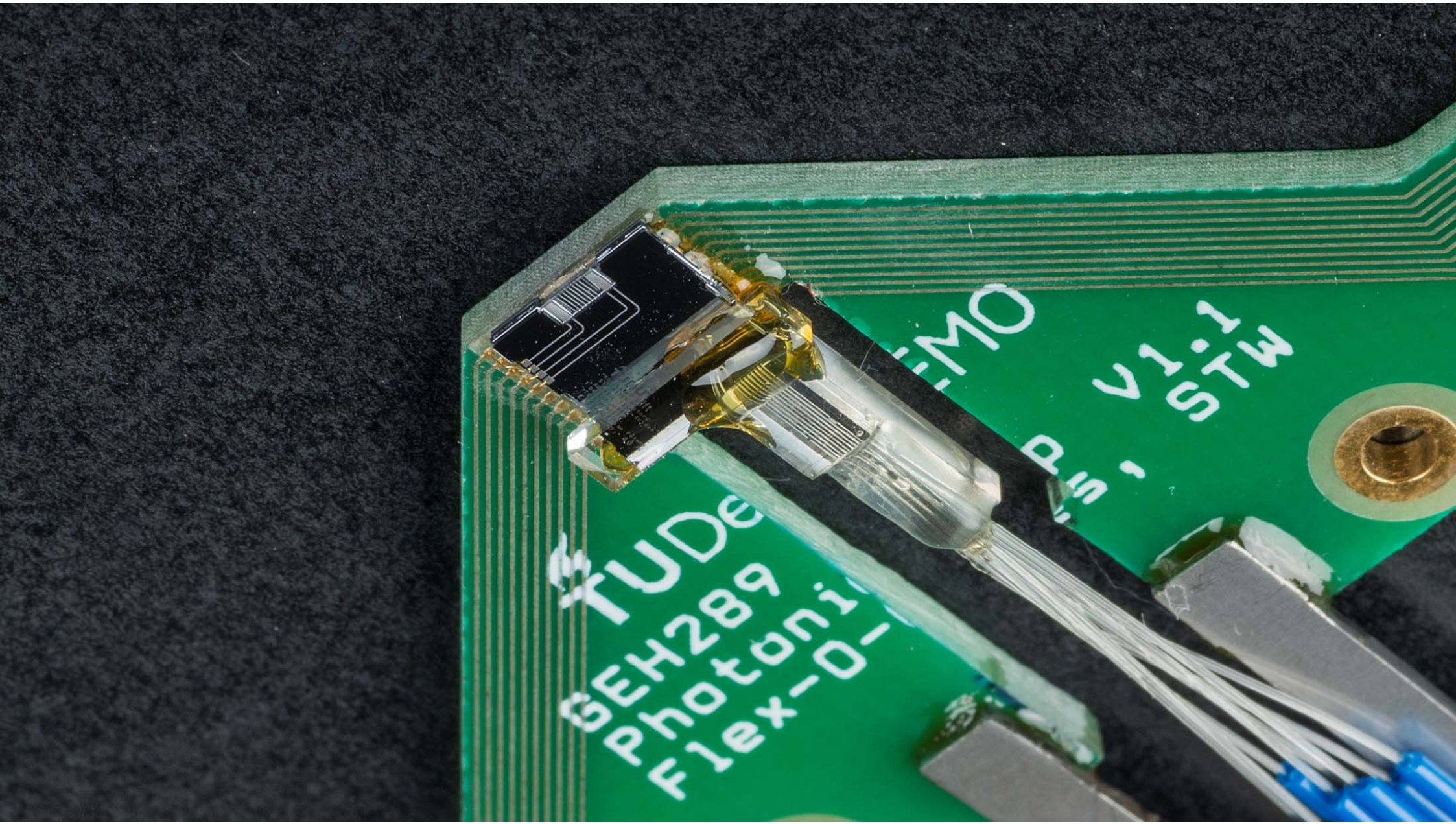


Post-fabrication of TriPleX wafers

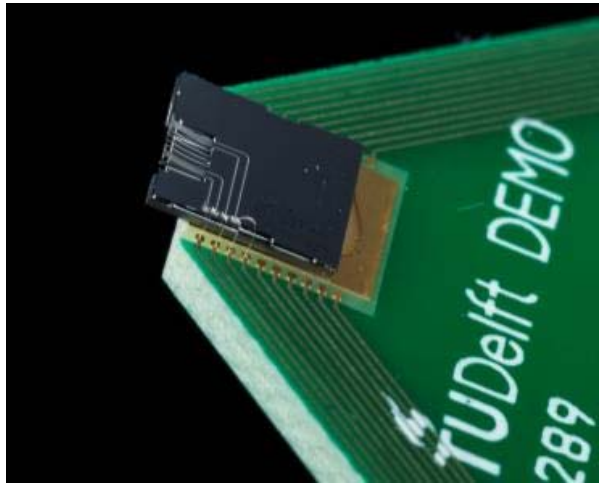
MEMS chip packaged for laboratory testing

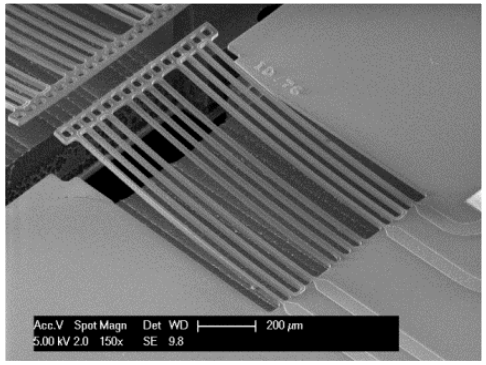


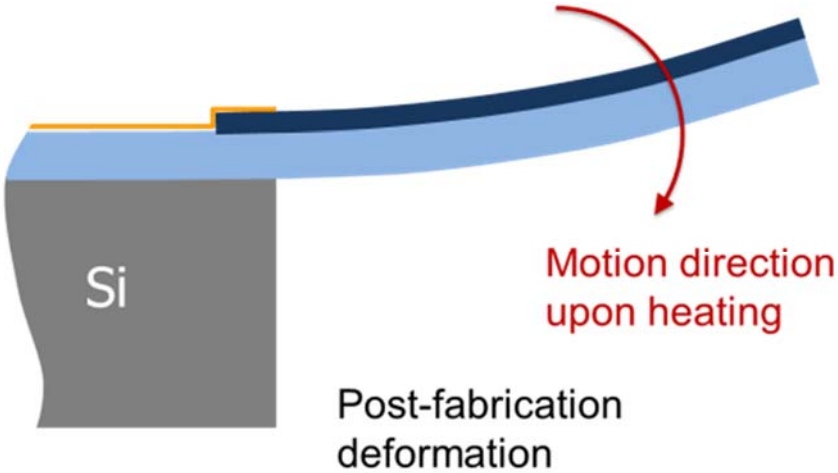



EMO
V1.1
STW
TUDe
GEH289
Photoni
Flex-O-

Post-release curvature and bimorph actuation





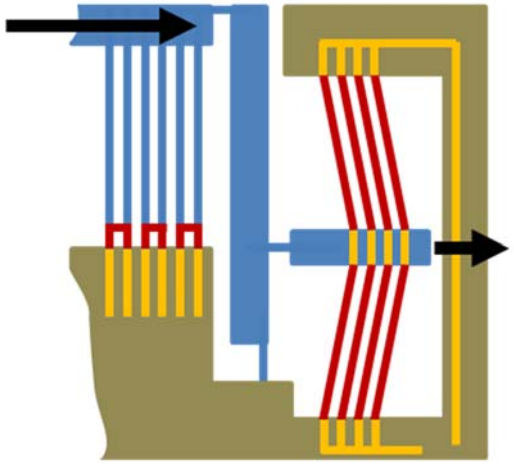


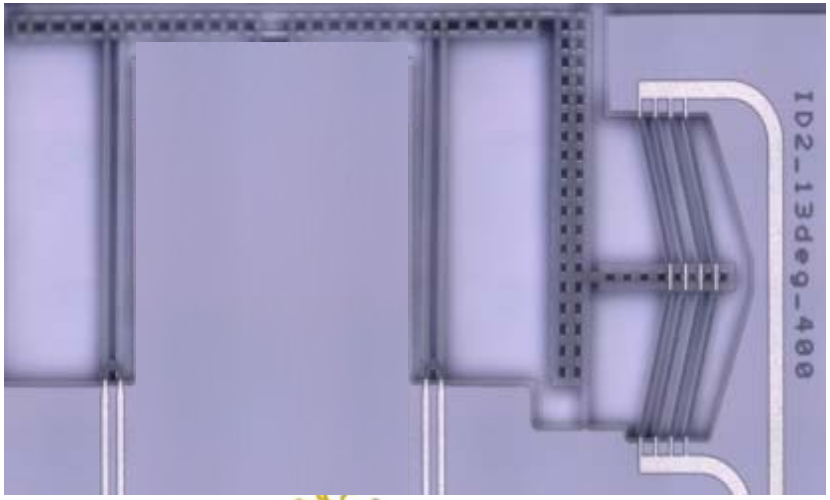
- Temperature ranges during fabrication
- CTE's of materials

In-plane motion

- Chevron actuator: SiO_2 beams with poly-Si on top
- Low CTE of SiO_2 limits motion range ➔

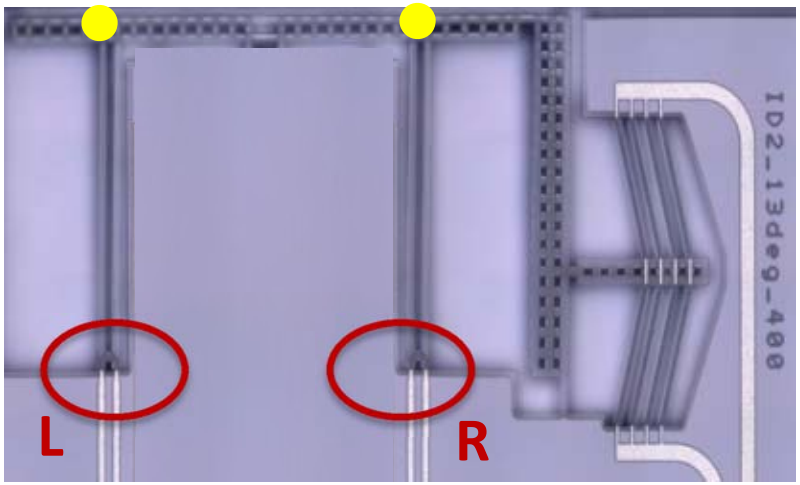
motion amplification by lever mechanism

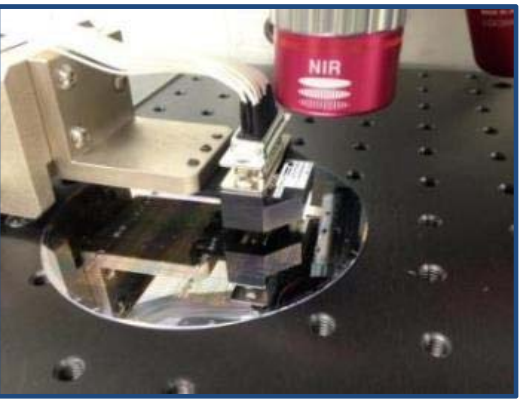


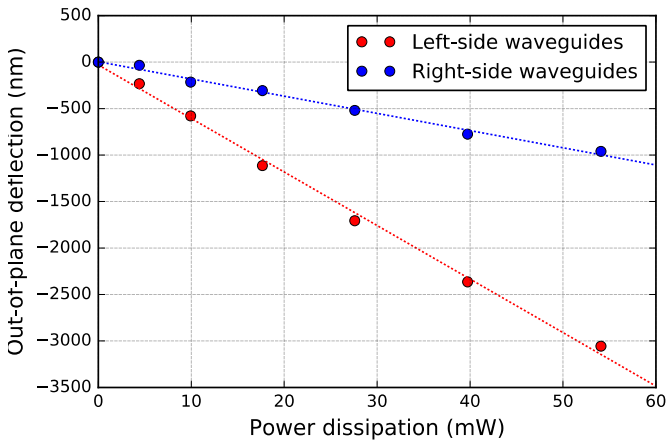


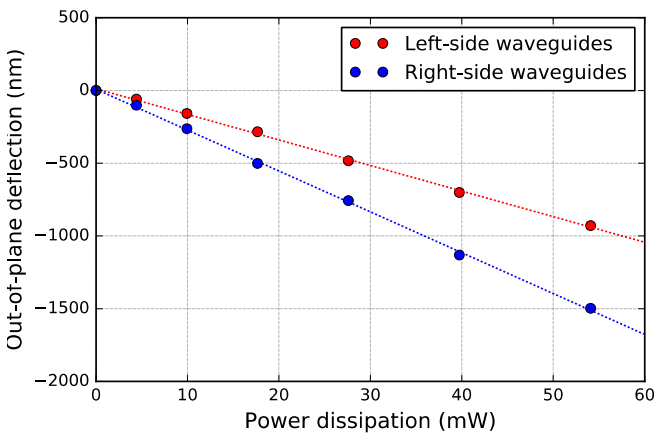
Out-of-plane / bimorph actuators

- Short-loop bimorph actuators
- Left/Right performance not equal due to mechanical cross-sensitivity, connection with in-plane actuation structure



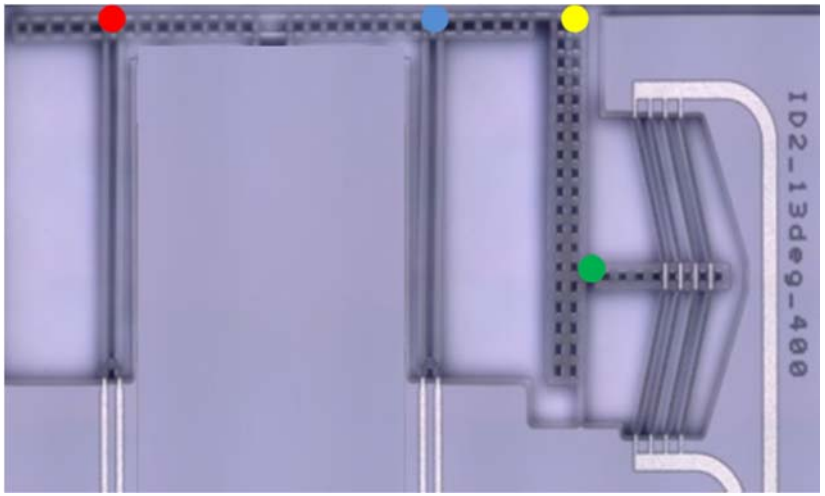


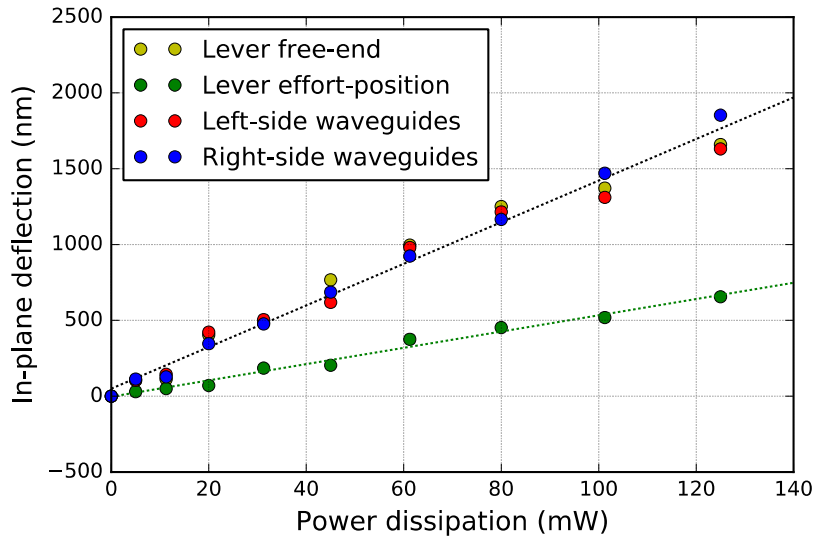




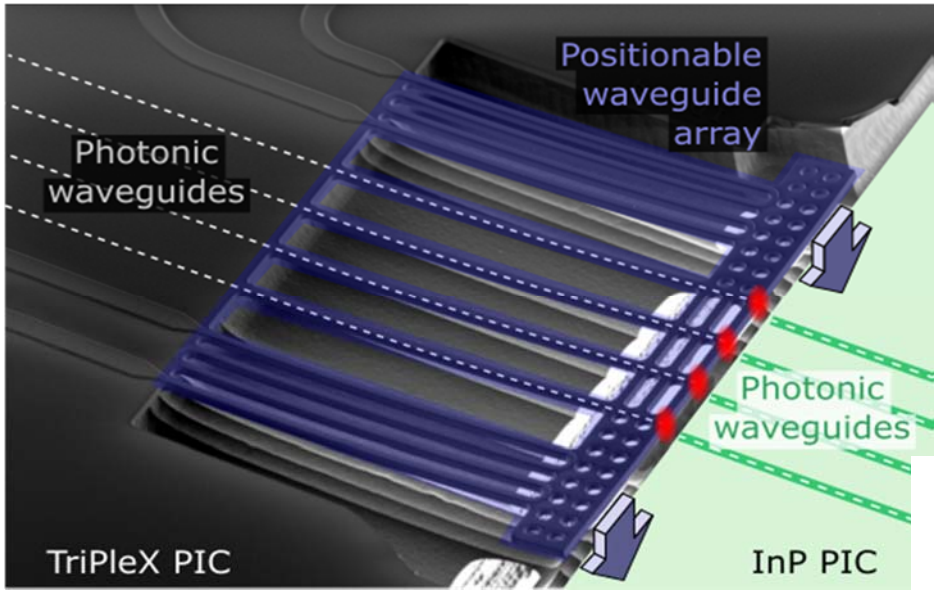
In-plane / chevron actuation

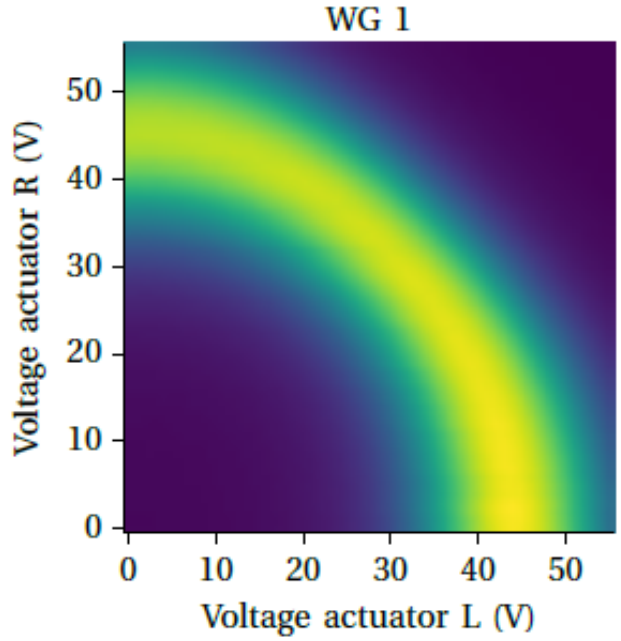
- Designed motion amplification: ~3.3, measured ~3.4
- In-plane motion ~1.8µm @ ~125mW, approaching required level

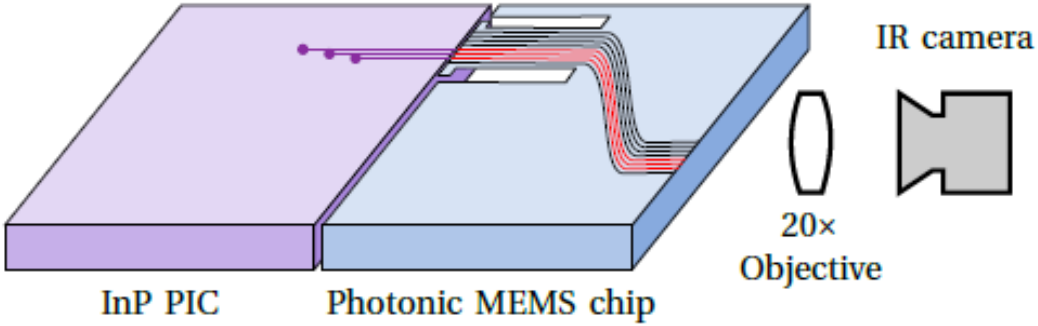




Optical coupling

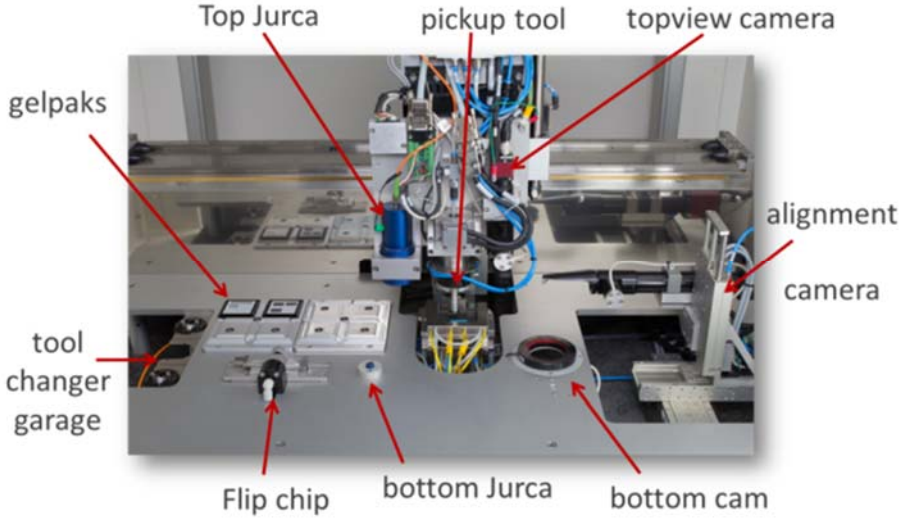


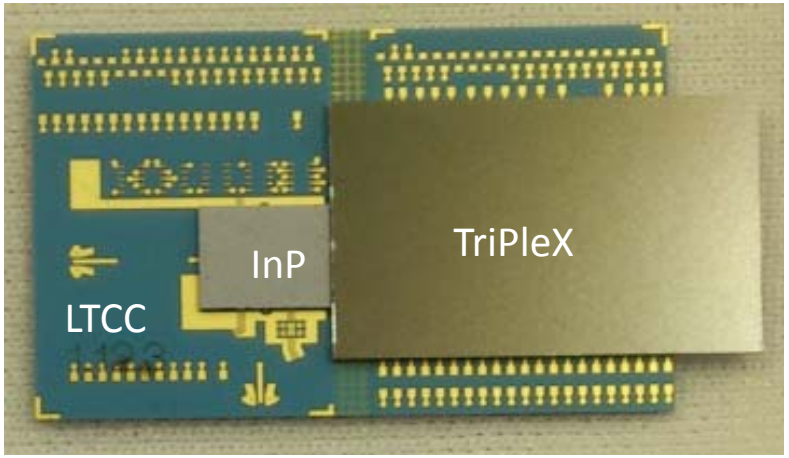




Pre-assembly

- Chip placement, bonding, and electrical interconnection (DC, RF)
- “Moderate precision”: few µm
  Is in reach of advanced industrial die bonders





Conclusions

- Microfabrication and MEMS offer potential for new assembly concepts for the photonic domain

- Various scenarios:
  - Passive alignment: microfabrication offers precision
  - Active alignment: actuator functions for fine alignment in two-step assembly process

- Potential for breakthrough solution: volume-compatible assembly of advanced photonic packages

Acknowledgement

TU Delft co-workers

Tjitte-Jelte Peters, Kai Wu, Alexandre Beck

Funding

- STW GTIP grant 11355 , Flex-O-Guides
- EU FP7 grant 619267, PHASTFlex, www.phastflex.eu

Collaborators from partners, user committee members

Further reading

- Wu, K., Tichem, M. *In-plane positioning of flexible silicon-dioxide photonic waveguides*, International Conference on Manipulation, Automation and Robotics at Small Scales (MARSS 2017), July 17-21, 2017, Montréal, Canada
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Thank you