Reliability Assessment of a Fully Packaged 1x12 Silicon Photonic MEMS Multicast Switch

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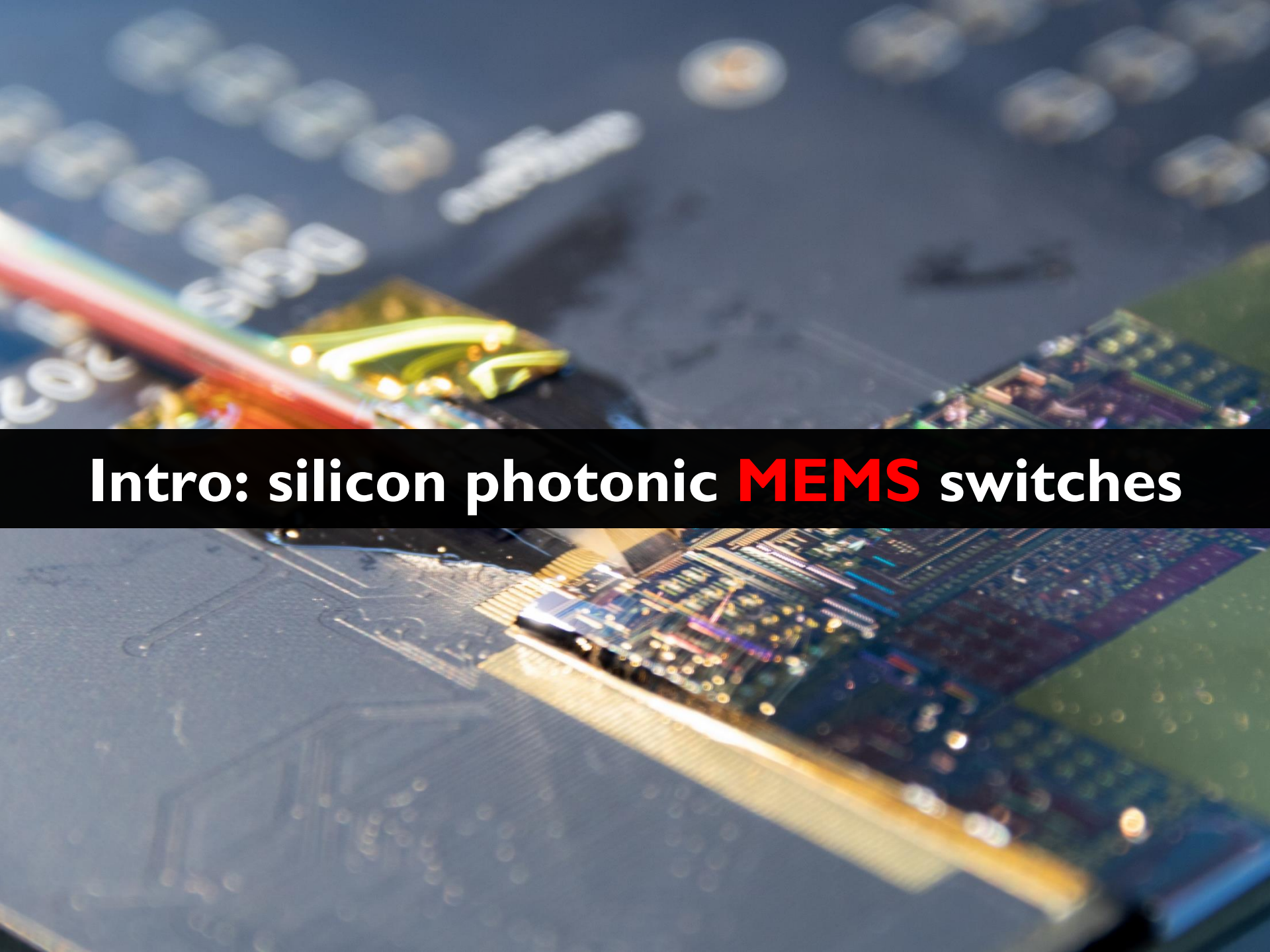
2024/01/29

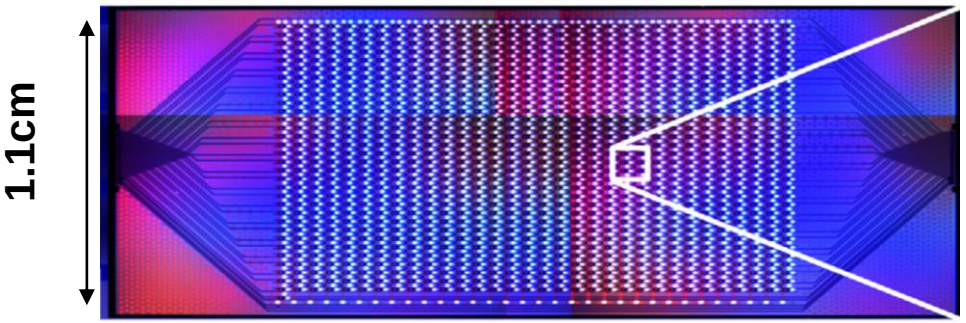
Photonics West 2024, Invited talk



Intro: silicon photonic MEMS switches

Si photonic switch

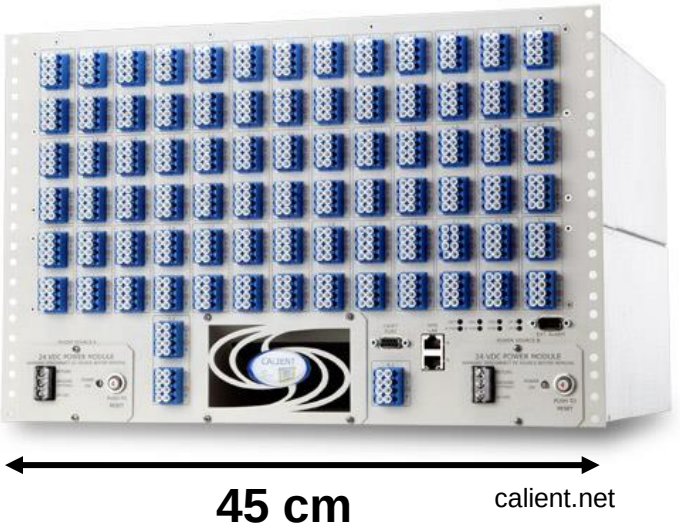
Si photonic switch (AIST)



K. Ikeda et al., Opt. Comm, (2020)

- Si waveguide + thermal heaters
- Pros
  - ~ 10 μs speed
  - Low cost (monolithic)
- Cons
  - ~32x32 ports
  - ~ 10 dB loss

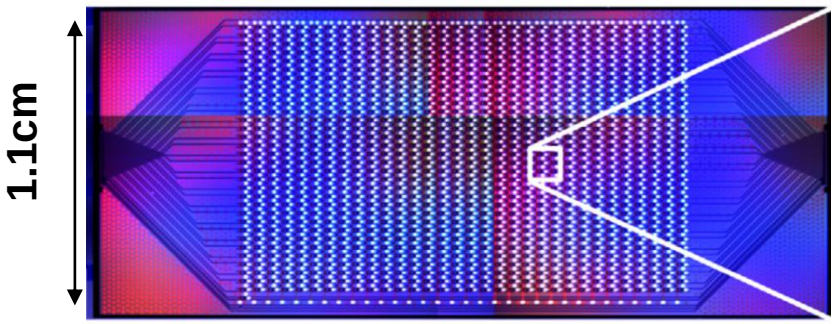
MEMS mirror switch (Calient)



- Free space + micro-mirror
- Pros
  - ~ 500x500 ports
  - ~ 1 dB loss
- Cons
  - > 10 ms speed
  - High cost (manual assembly)

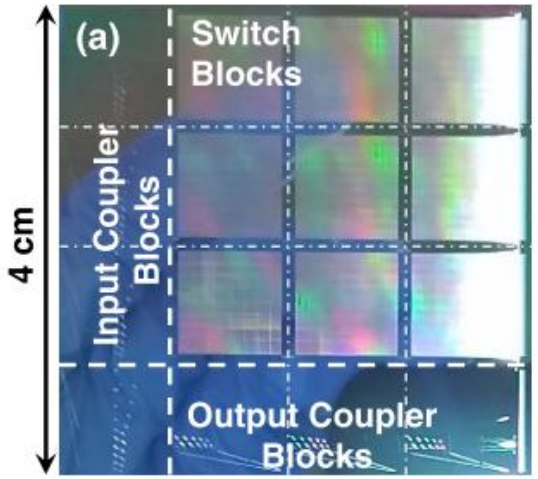
Si photonic MEMS switch

Si photonic switch (AIST)



K. Ikeda et al., Opt. Comm, (2020)

Si photonic MEMS switch (Berkeley, DGIST)

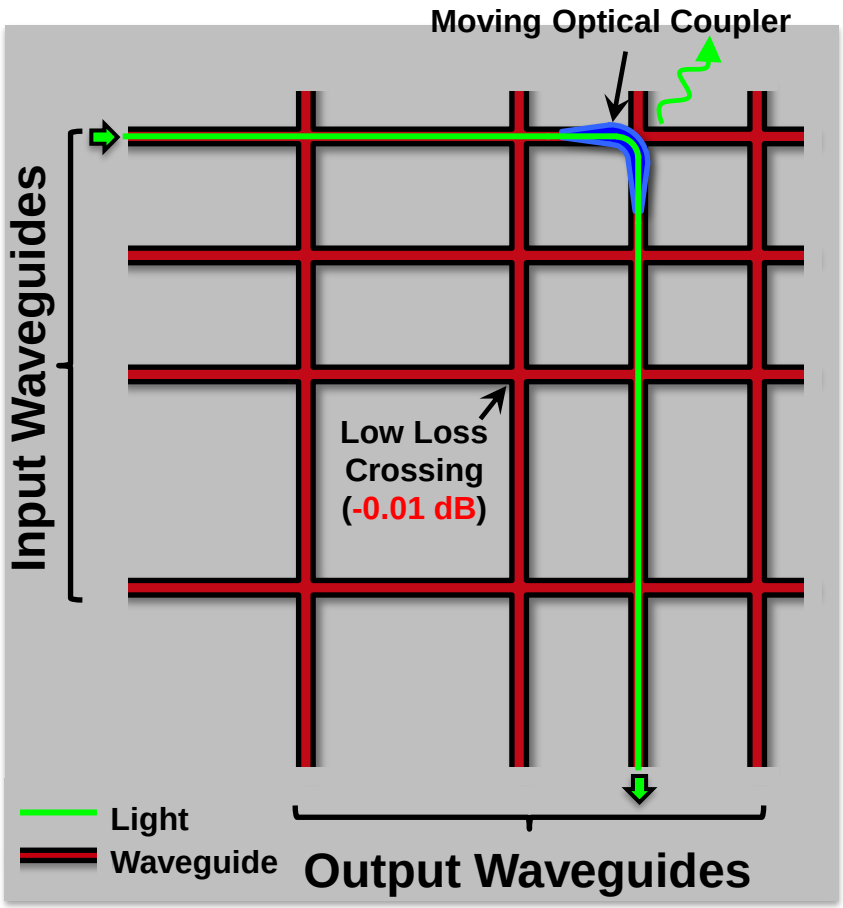


TJ. Seok et al., Optica, (2019)

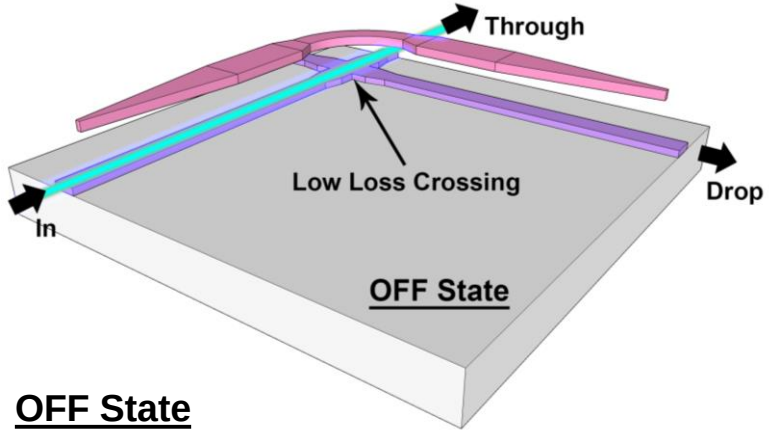
- Si waveguide + thermal heaters
  - 32x32 ports (10 dB loss)
  - 10 μs speed
- Si waveguide + high speed MEMS
  - 240x240 ports (10 dB loss)
  - < 1 μs speed

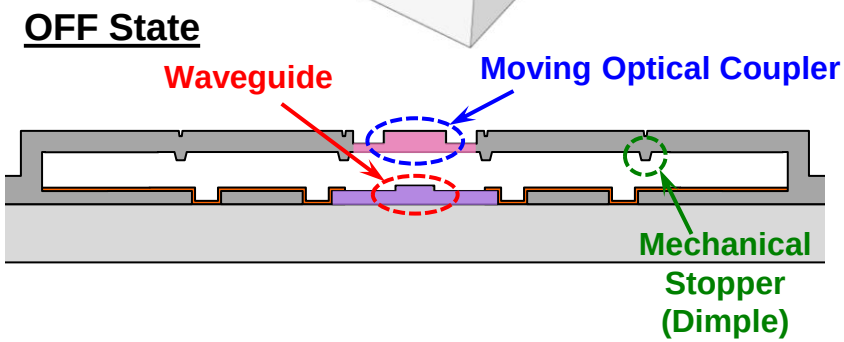
Si photonic MEMS switch

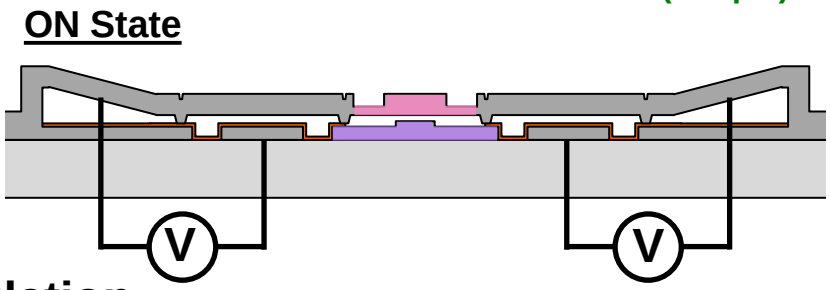
Layout



Unit cell



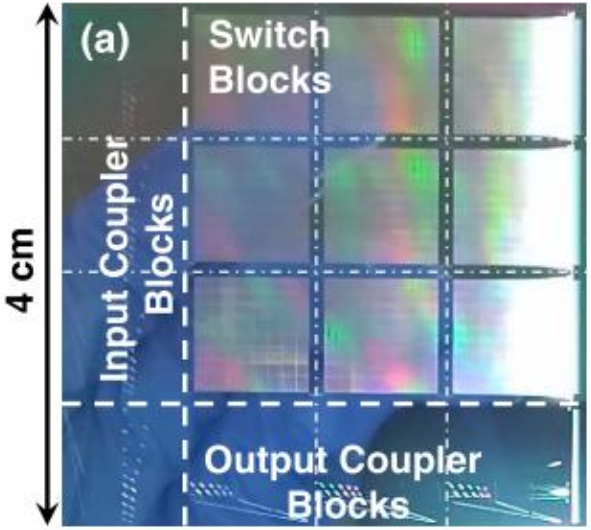




- **Single stage switching → no loss accumulation**
- **Electrostatic operation → ultra-low power (10 fW), 10^{12} reduction**

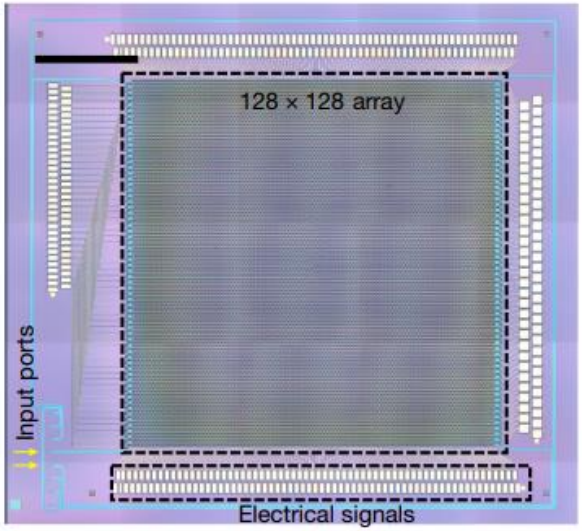
Applications of SiPh MEMS switch

240 x 240 switch
(Berkeley)



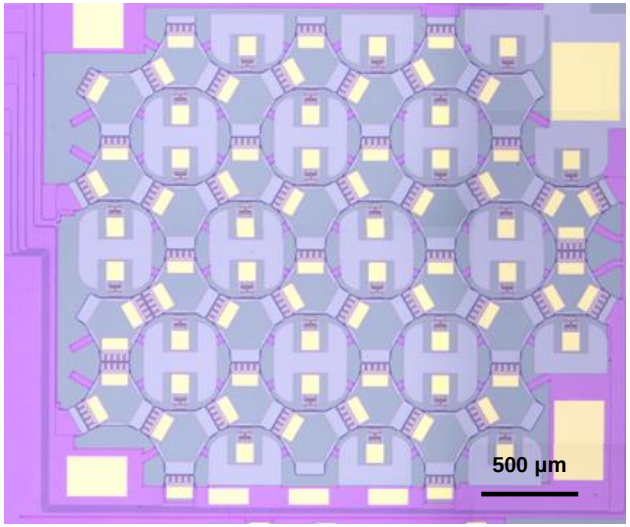
TJ. Seok et al., Optica, (2019)

128 x 128 beam scanner
(Berkeley)



Zhang, et al., Nature (2022)

Femto-watt
Programmable photonic array
(DGIST)



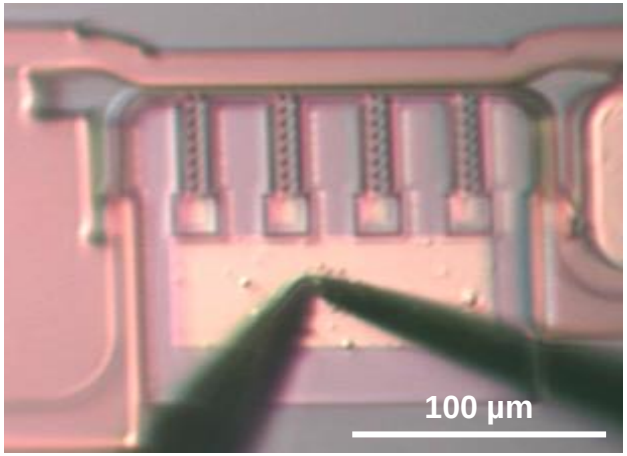
Kim, et al., Nature Photonics (2023)

- **Large scalability and ultra-low power consumption**

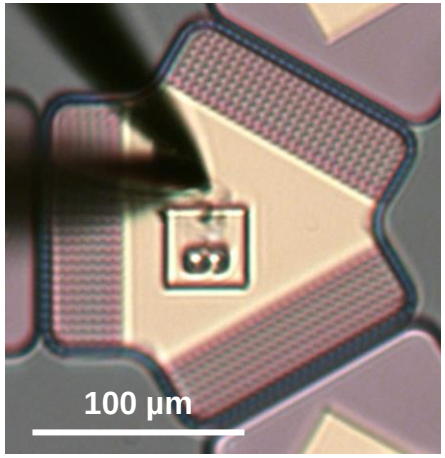
→ **opened up new applications for integrated switch**

Actuation videos

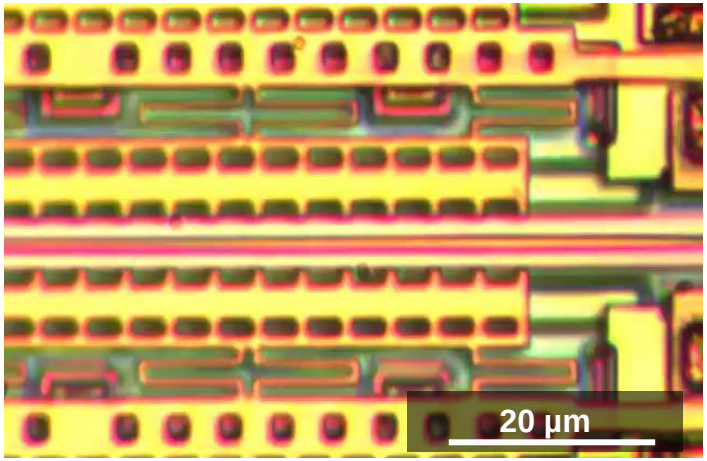
Multicast switch



Programmable photonic array



Polarization-independent switch



- **Less than 1 μm of displacements are needed**

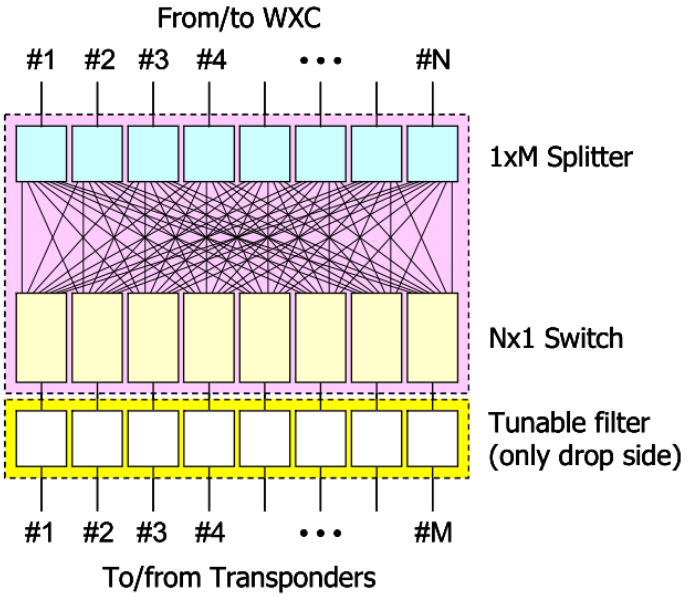
→Large advantages in reliabilities

→Fast operation speed

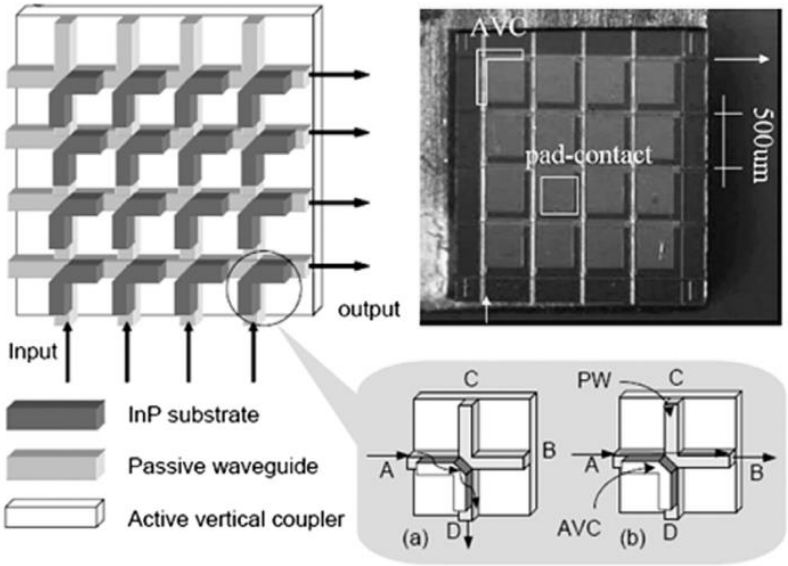
→Compact device footprint

Multicast 1x12 Si Photonic MEMS switch

Multicast optical switches



Watanabe, et al [NTT], OFC 2012

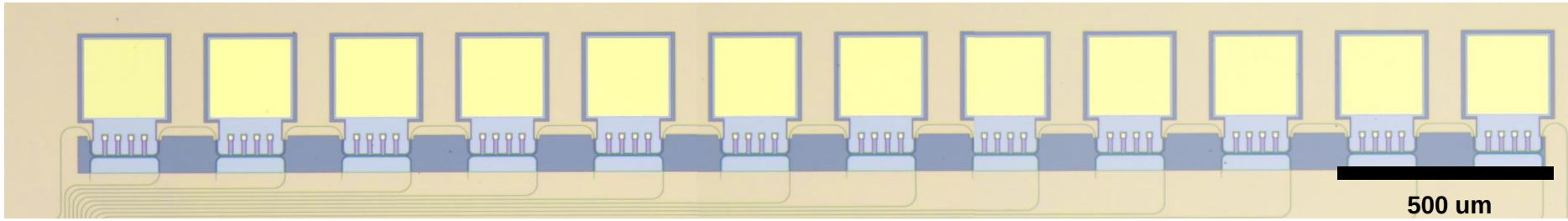


Geldenhuys, et al [Univ. of new South Wales], Opt. Switch. Netw 2011

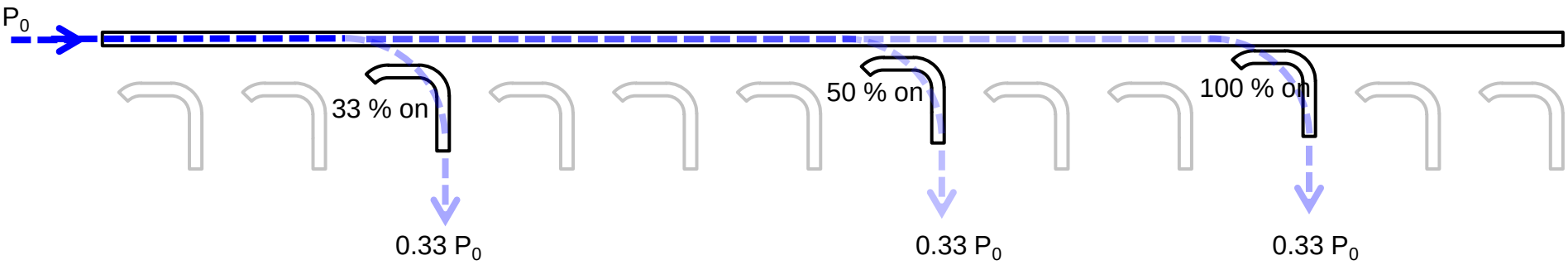
- **Multicast optical switches allow high bandwidth transmission from one source to multiple destinations**
  - **e.g. video conference, video-on-demand (VoD), IP-based television (IPTV)**
- **Previous implementation of multicast switches**
  - **Broadcast-and-select: optical power wasted**
  - **Active coupler: high electrical power consumption**

Multicast SiPh MEMS Switch (DGIST)

Chip image



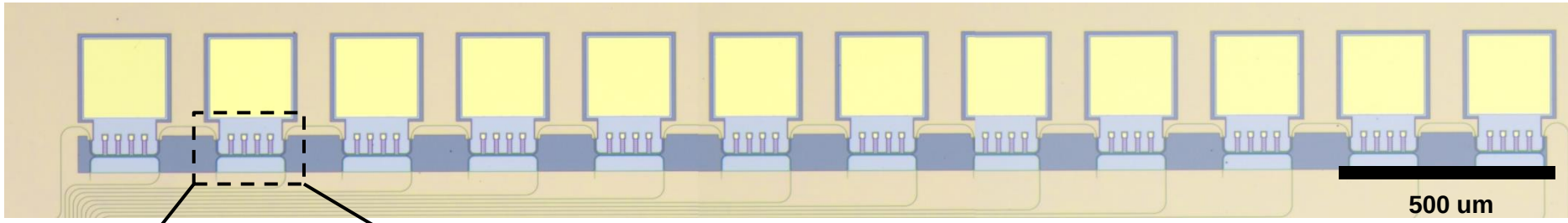
Schematic

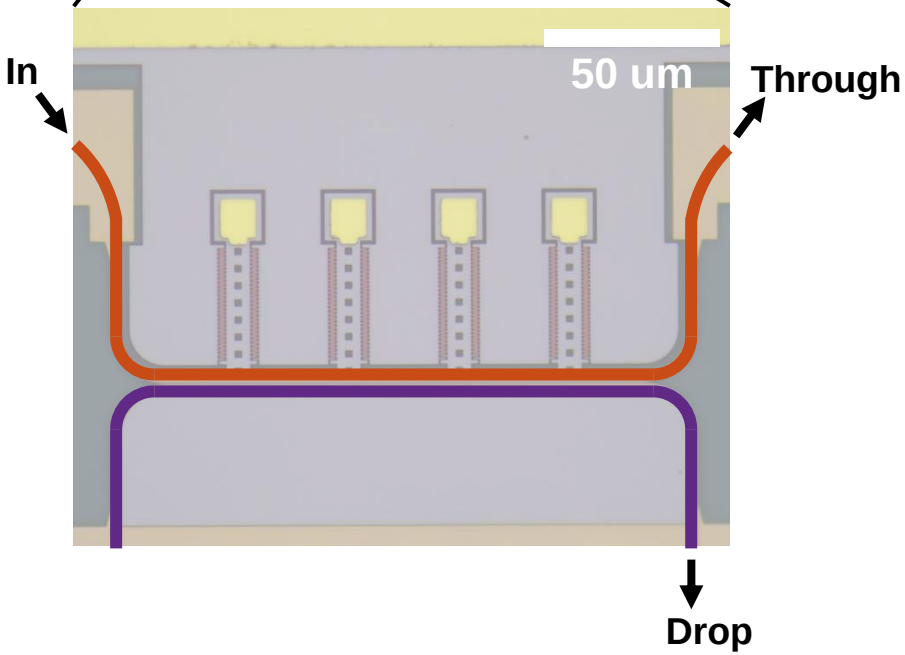


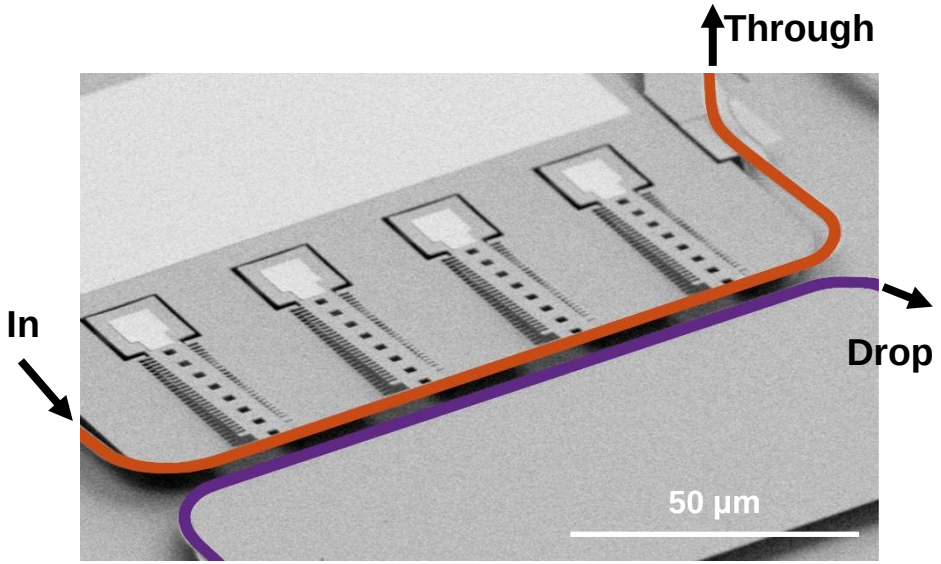
- **Splitting light power to multiple ports by partially turning on MEMS coupler**
- **No optical power loss to un-selected ports**

Multicast SiPh MEMS Switch

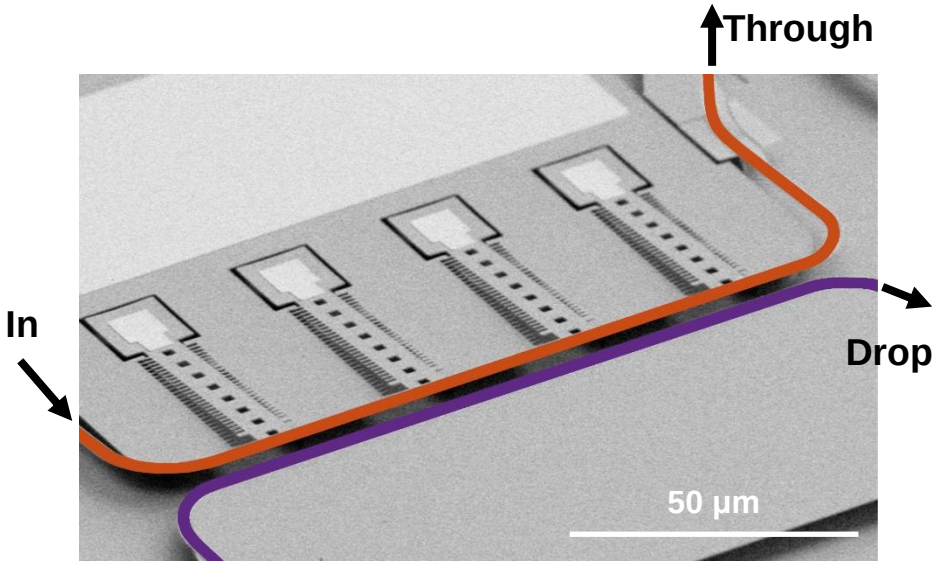
Chip image

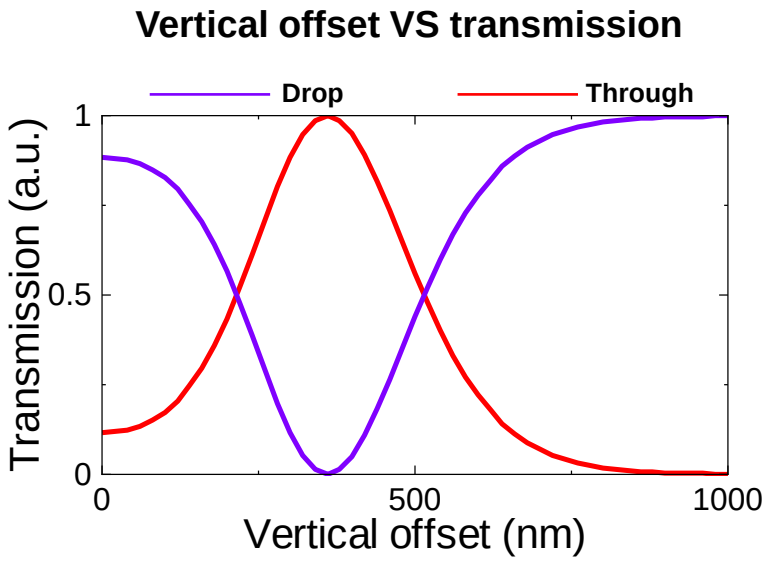


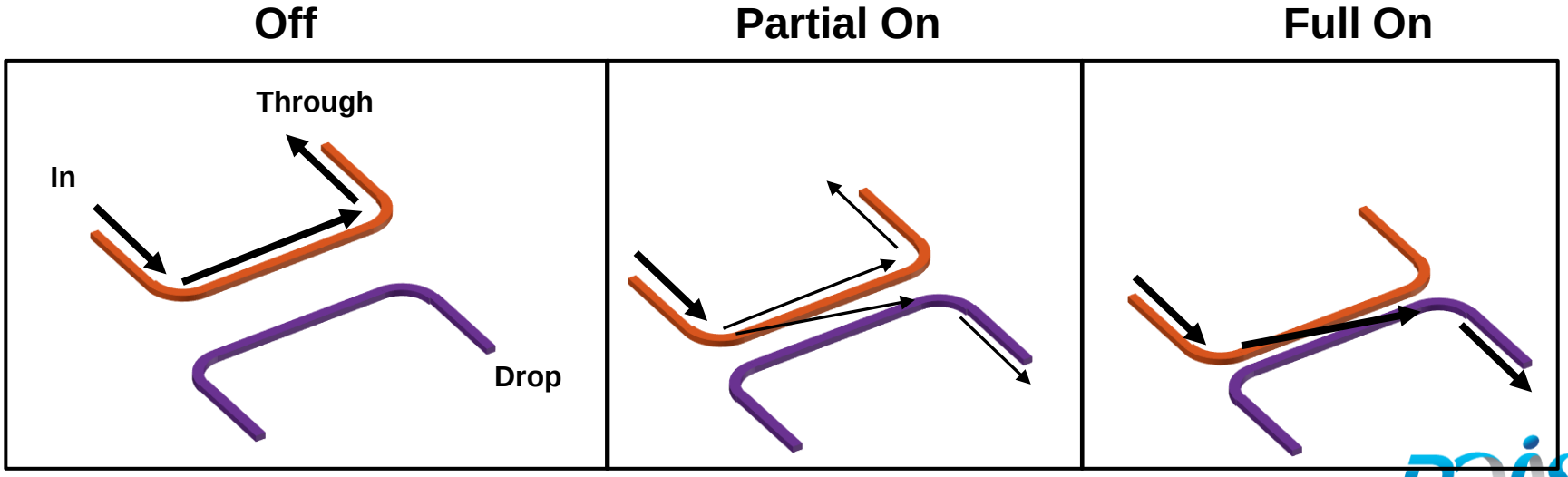




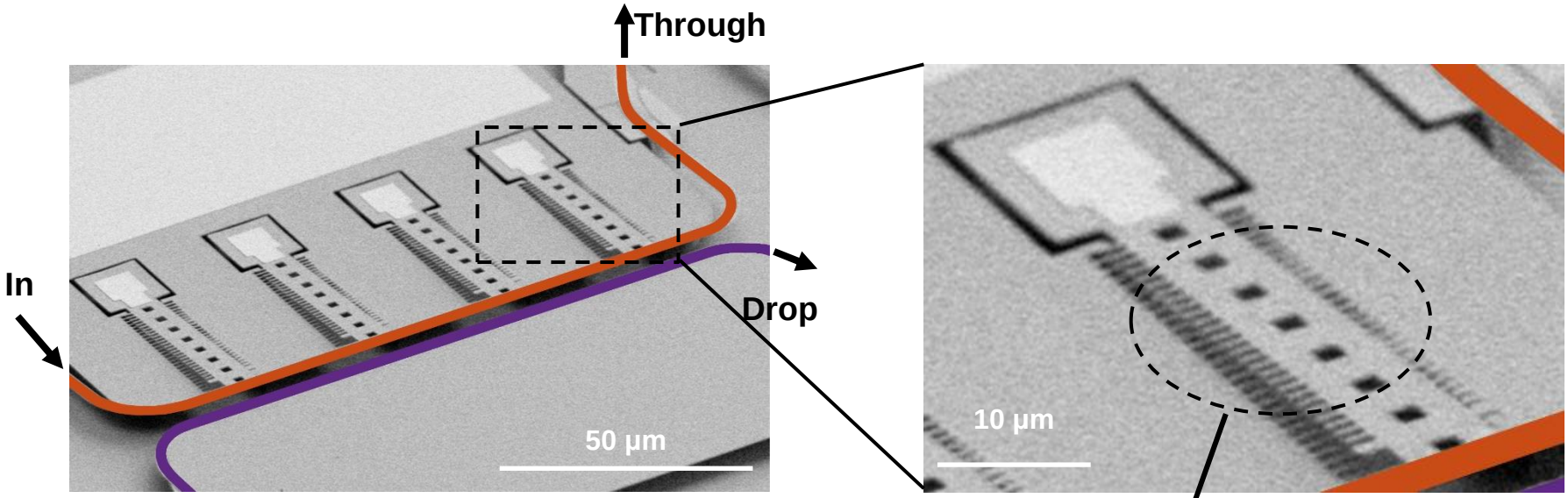
How unit cell works (optical)



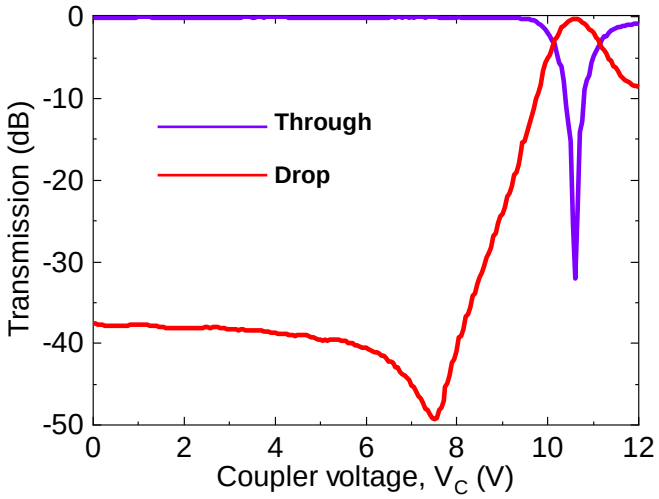




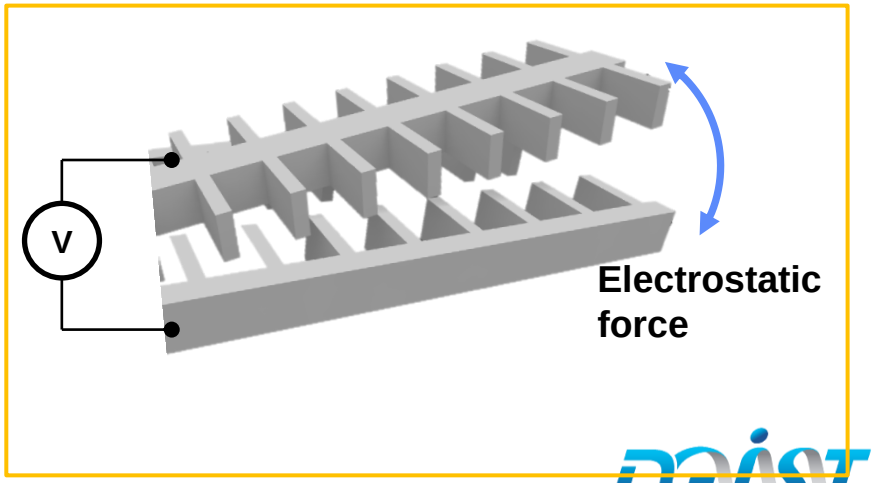
How unit cell works (electro-mechanical)



Voltage VS transmission



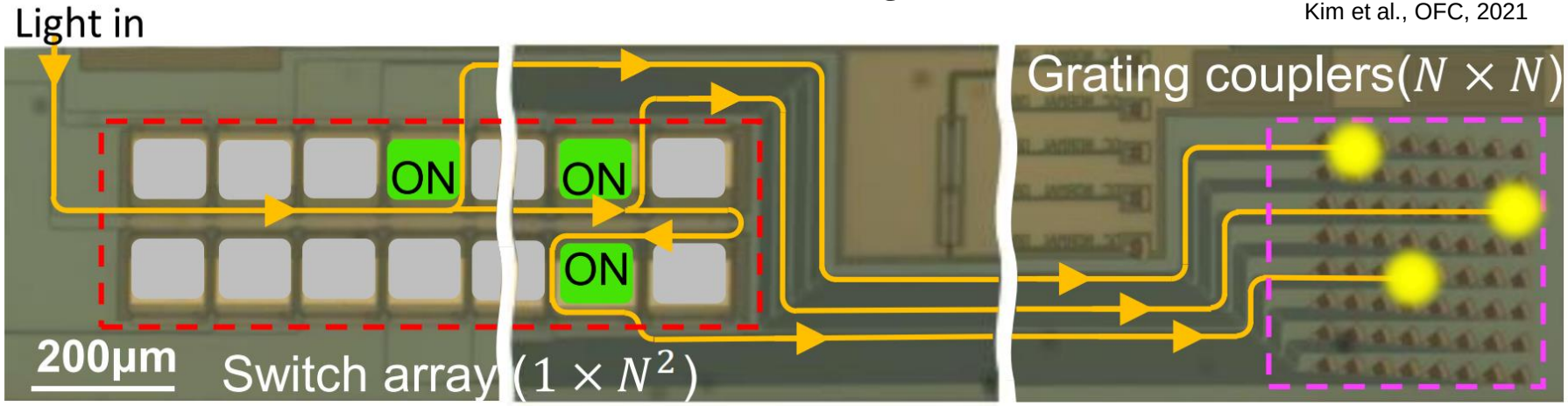
Vertical comb-drive actuator



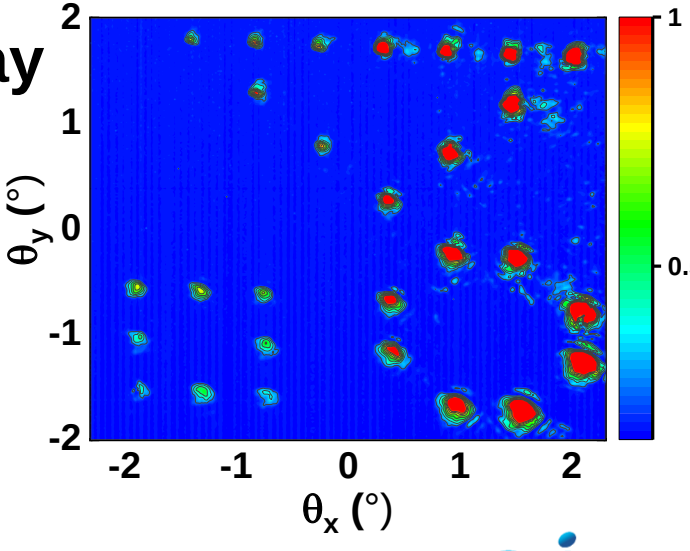
Multicast MEMS switch in LiDAR (DGIST)

Device image

Kim et al., OFC, 2021



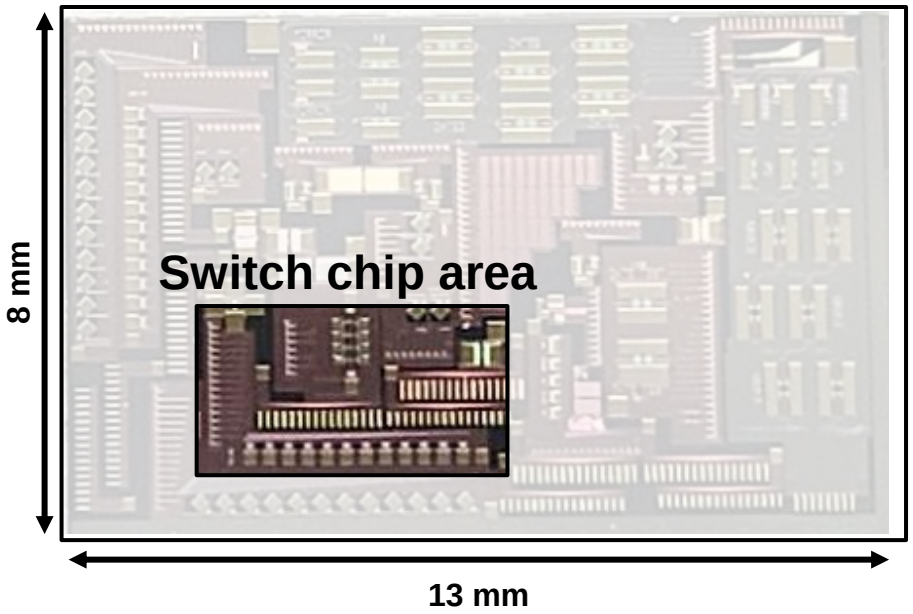
- **Multicast switch + grating coupler array**
- **Can program beam pattern to emit**
- **Applications: space optical communications, LiDAR**



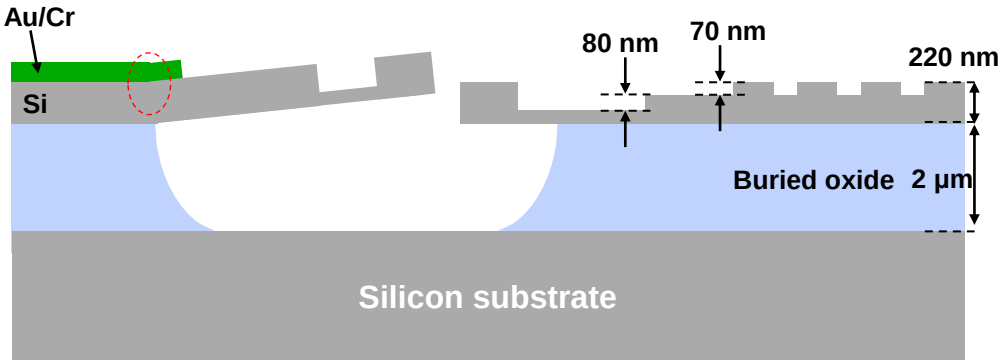
Electrical packaging

Switch chip overview

Switch chip image

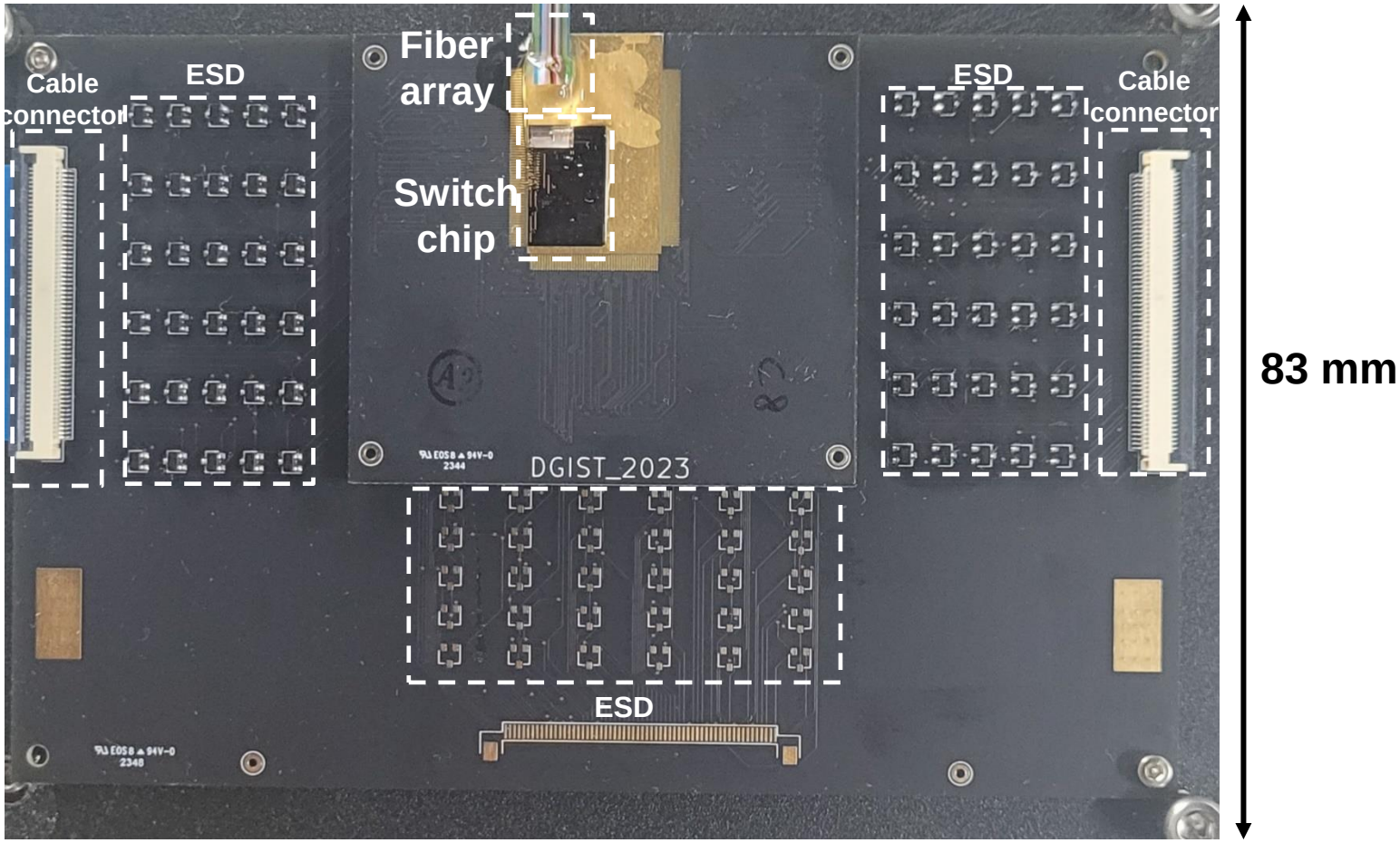


Chip cross-section



- Co-fabricated with other Si photonics devices (CMOS compatible)
- 200 mm silicon-on-insulator wafer with KrF stepper
  - Si: 220 nm, Buried oxide: 2 μm
- Four-mask process
  - 3 steps: Si etching, 1 step: metal definition
- HF vapor etching as a final step to release actuators

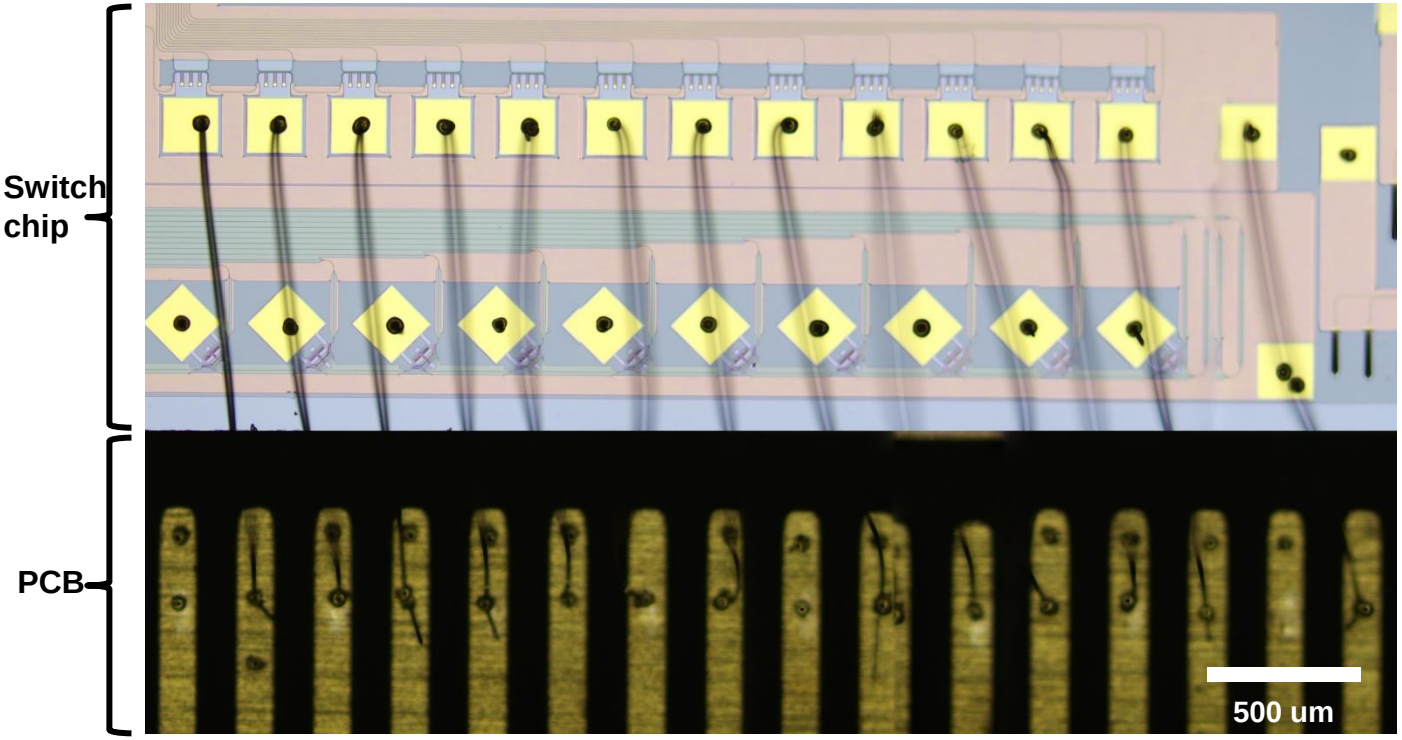
Packaged chip overview



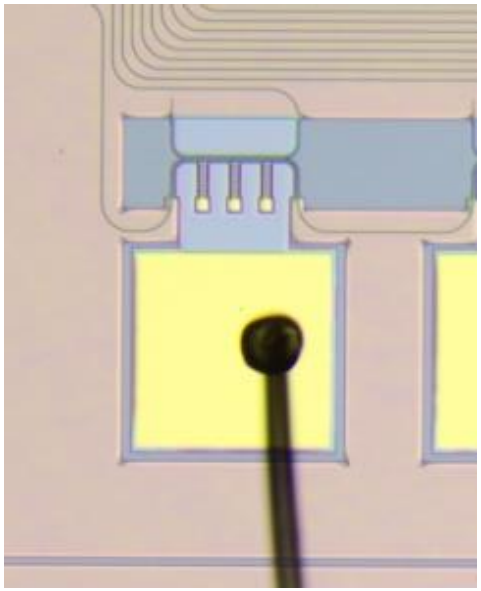
- **Custom-designed printed circuit board**

with ESD for protection from electrostatic discharge

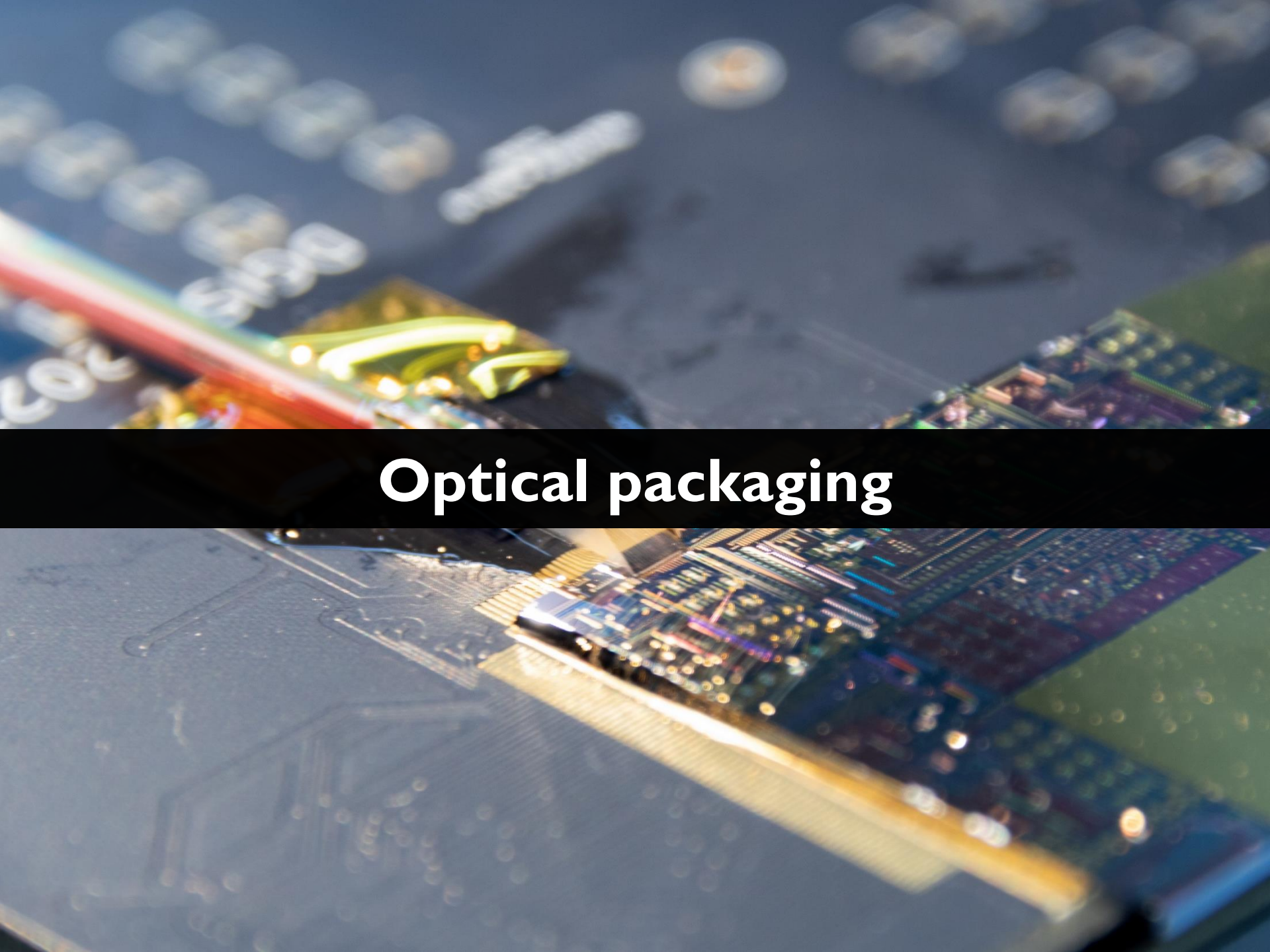
Au ball wire bonding



Unit cell

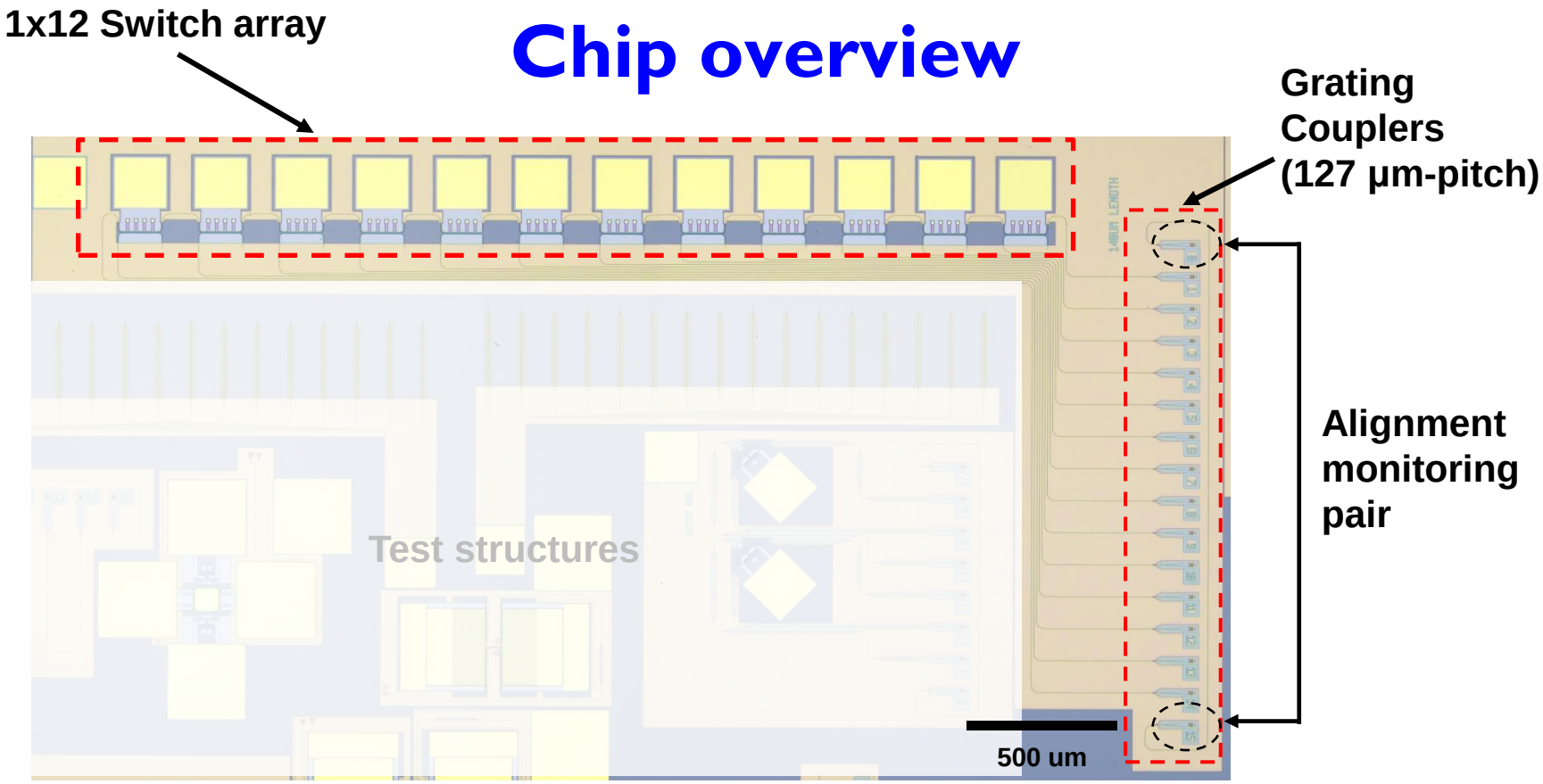


- **Metal pad size: 200 x 200 μm²**
- **Wire type: 25 μm diameter, Au, ball bonding**
- **Wire was securely grounded while wire bonding**



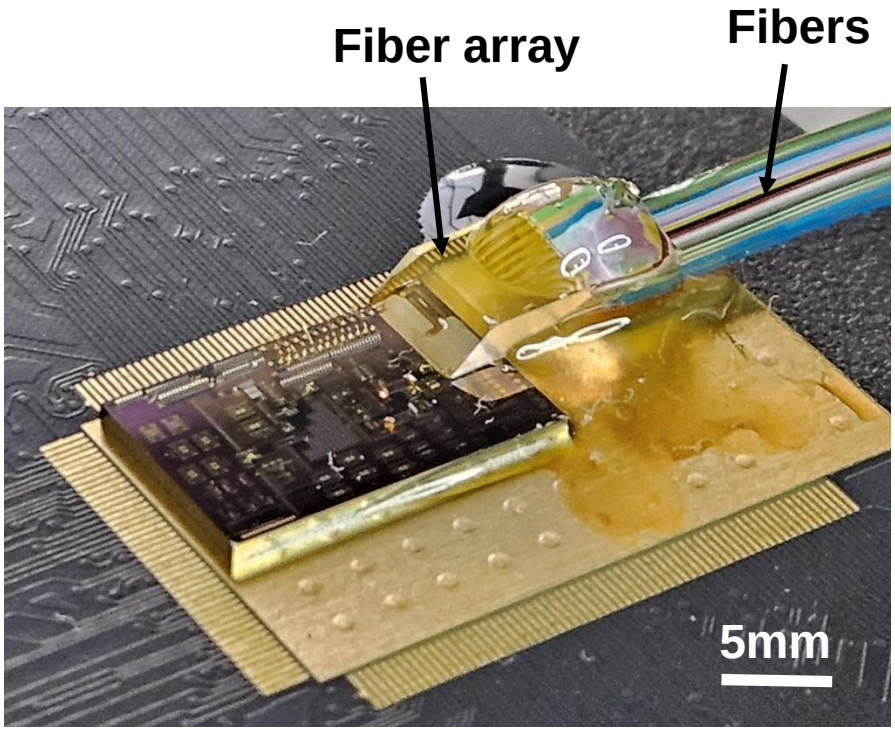
Optical packaging

Chip overview

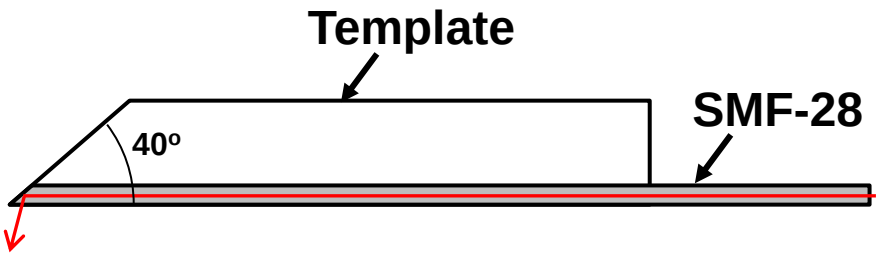


- 127 μm-pitch grating coupler array
- Coupling angle: 8°
- Loop back grating coupler set for alignment monitoring

Packaged chip overview



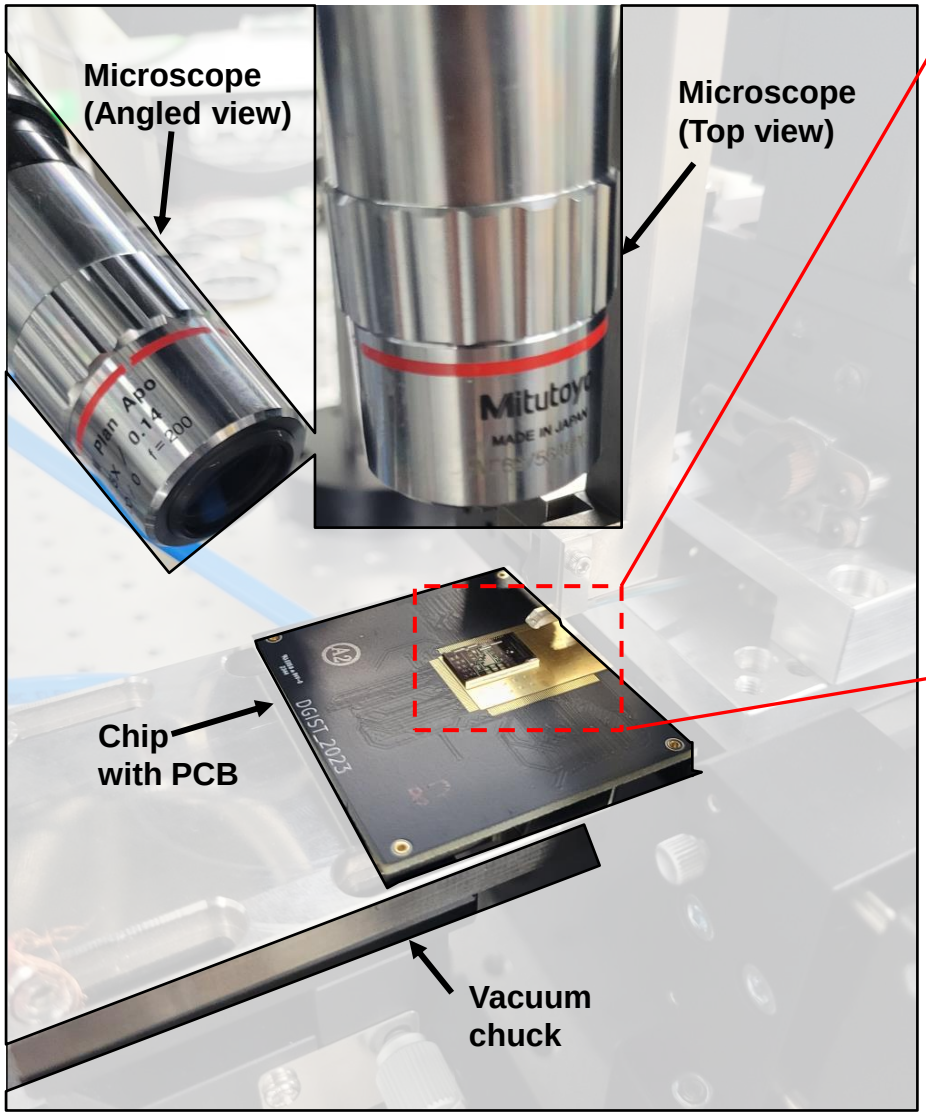
Fiber array cross-section



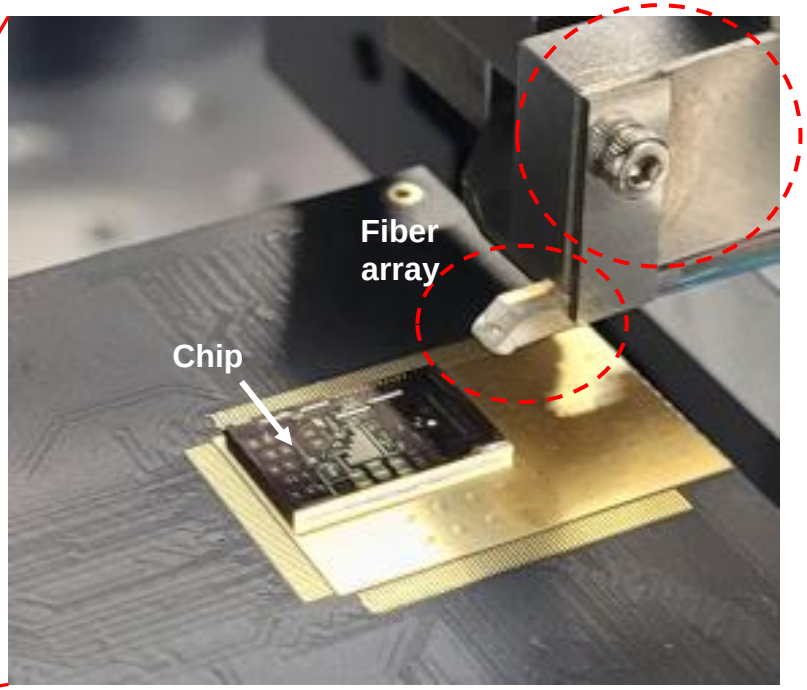
- UV epoxy was applied between the chip and fiber array
- SMF-28 fiber (MDF = 8.4 μ m)
- 127 μm-pitch, 32-channel (16 channels used)
- 40° polished (total internal reflection for near vertical coupling)

Fiber array align & bonding setup

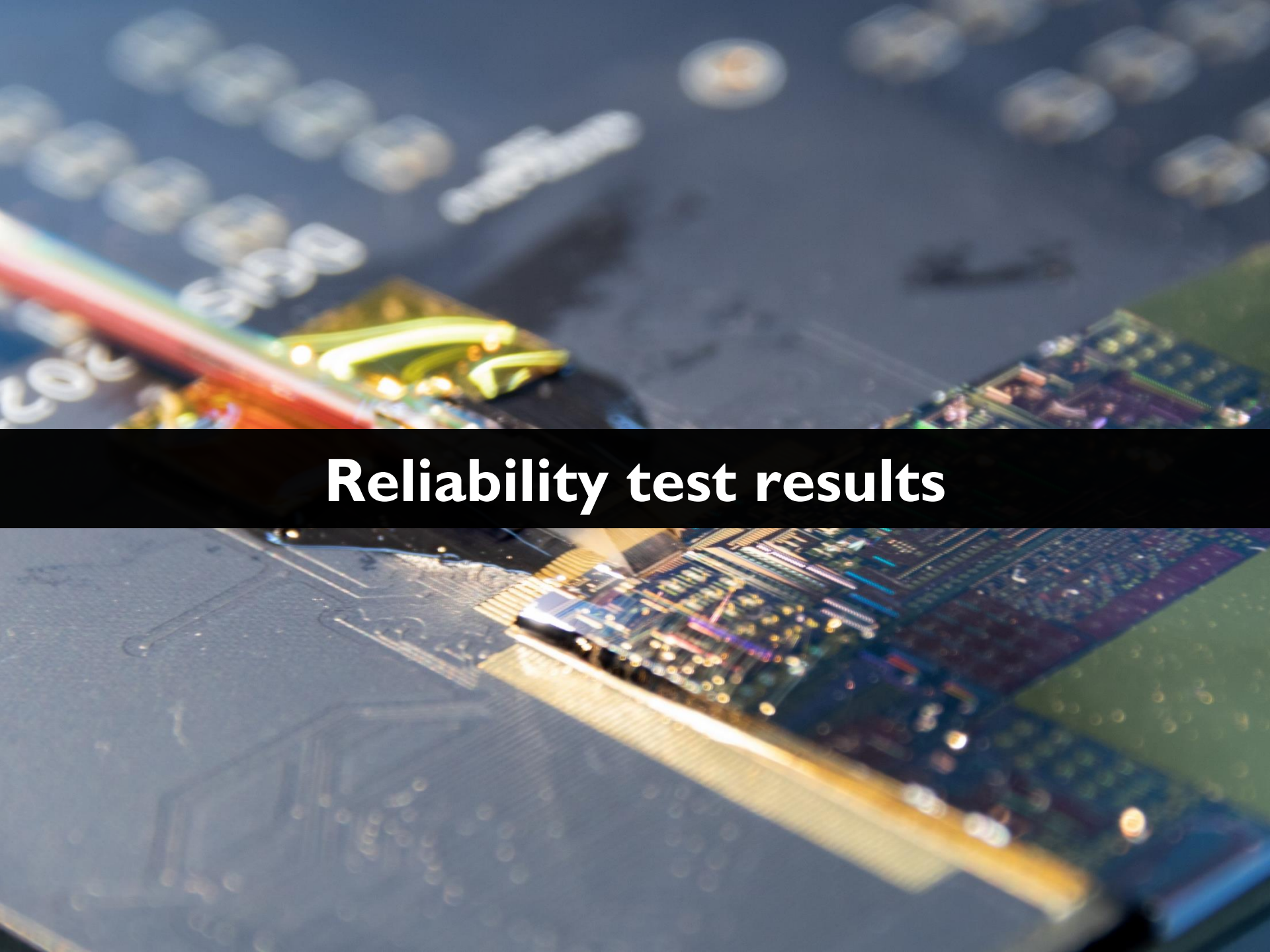
Setup image



To 6-axis micro-stage

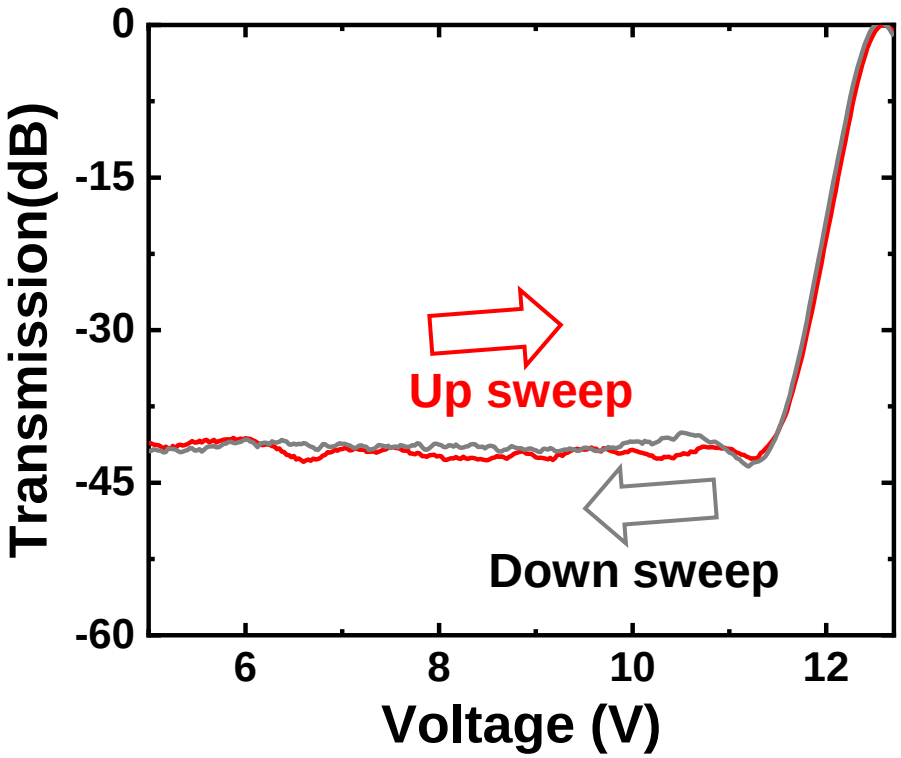


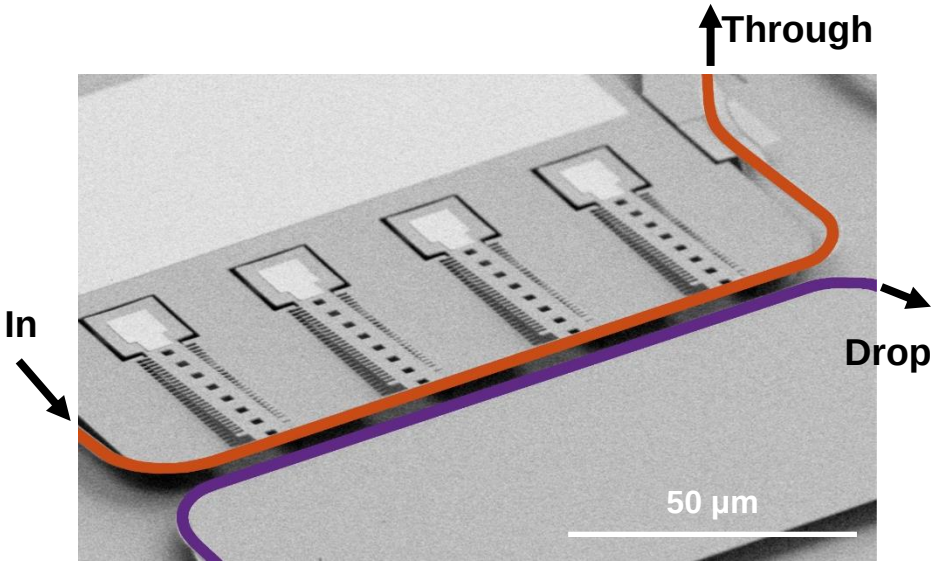
- Two microscopes for top and angled view
- 6-axis micro-stage for fiber array alignment $(x, y, z, \theta_x, \theta_y, \theta_z)$
- Fiber-chip insertion loss: 6 dB



Reliability test results

Hysteresis test

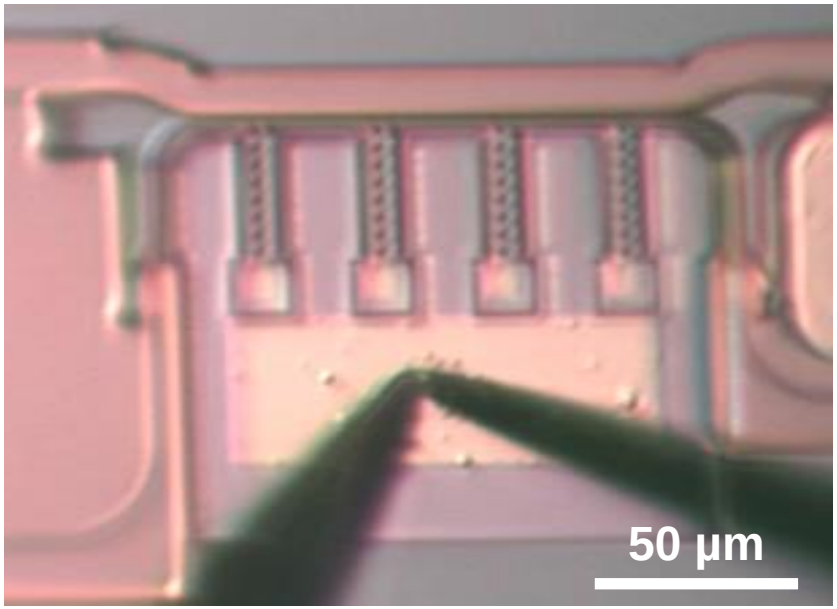




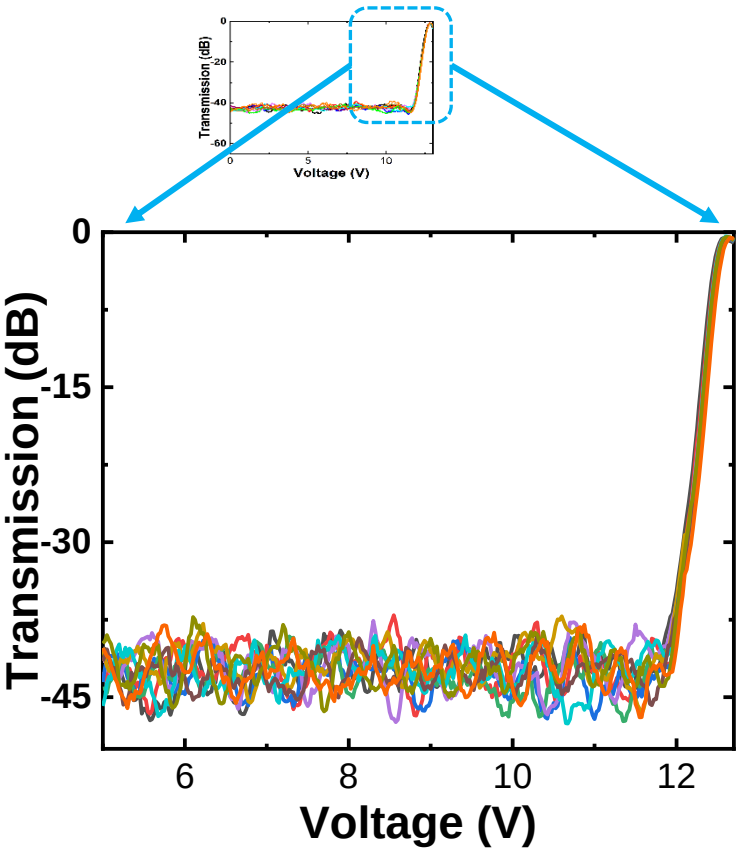
- **Identical switch response for up sweep and down sweep.**
- **No noticeable hysteresis has been found.**

On-off cycling test

Actuation video
(actual device under test was packaged)

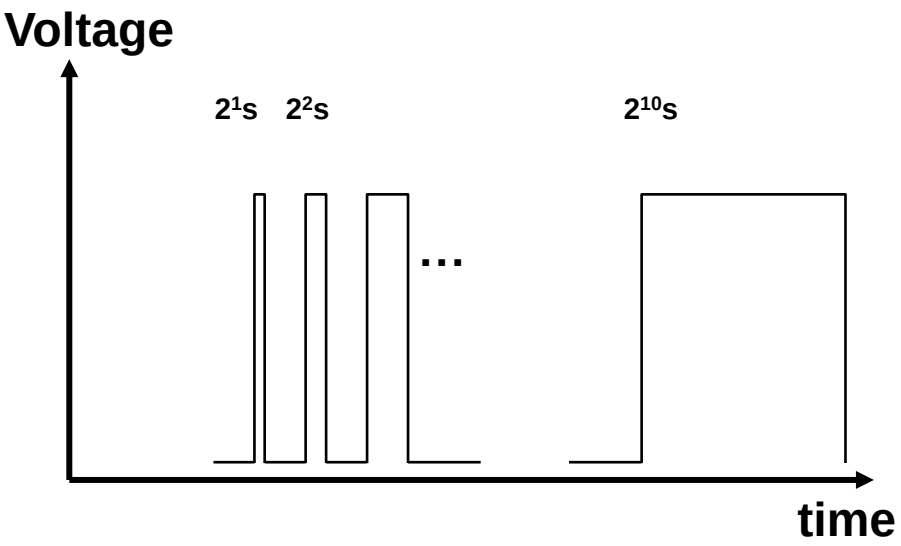


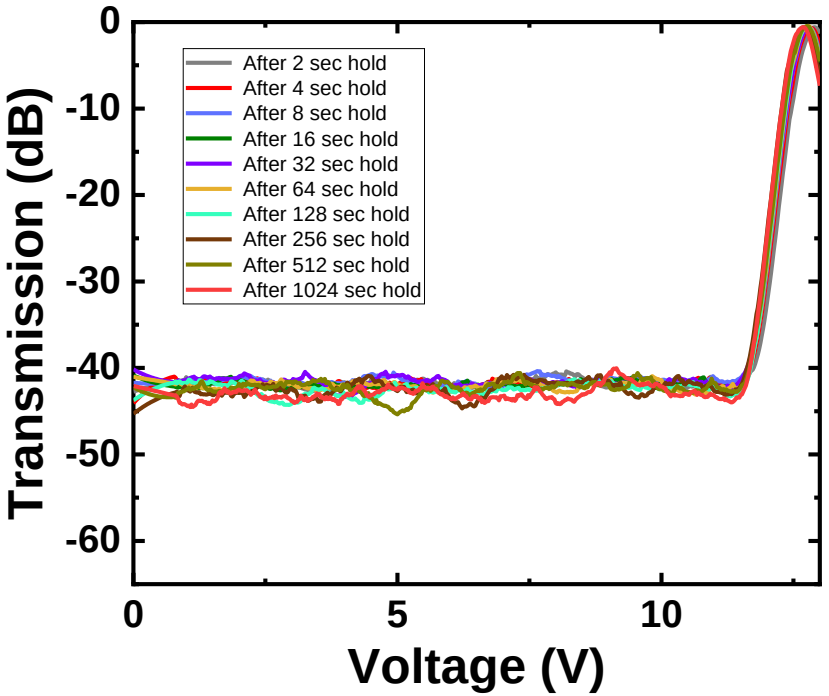
Transmission over 10^9 cycles
(measured every 10^8 cycles)



- **Total 10^9 cycles on-off**
  - **50 kHz square wave, ~ 6 hours**
- **Tested under ambient conditions (no humidity/temperature control)**
- **Transmission curve was obtained every 10^8 cycles**

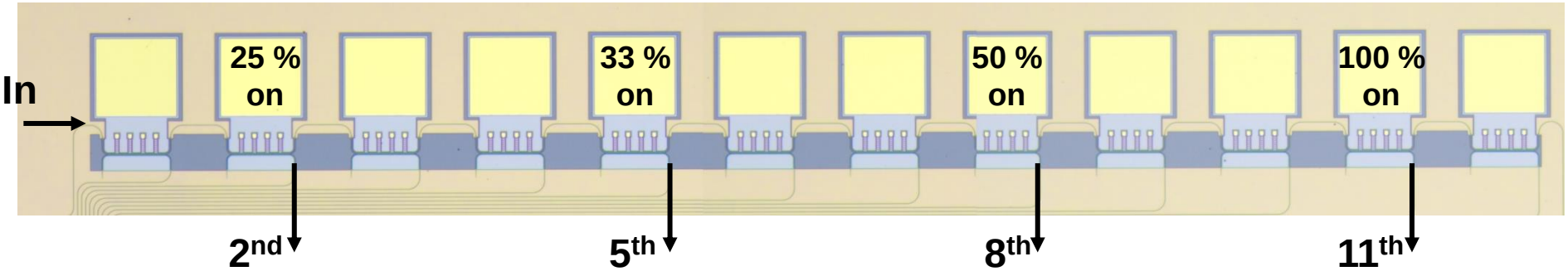
On hold time test



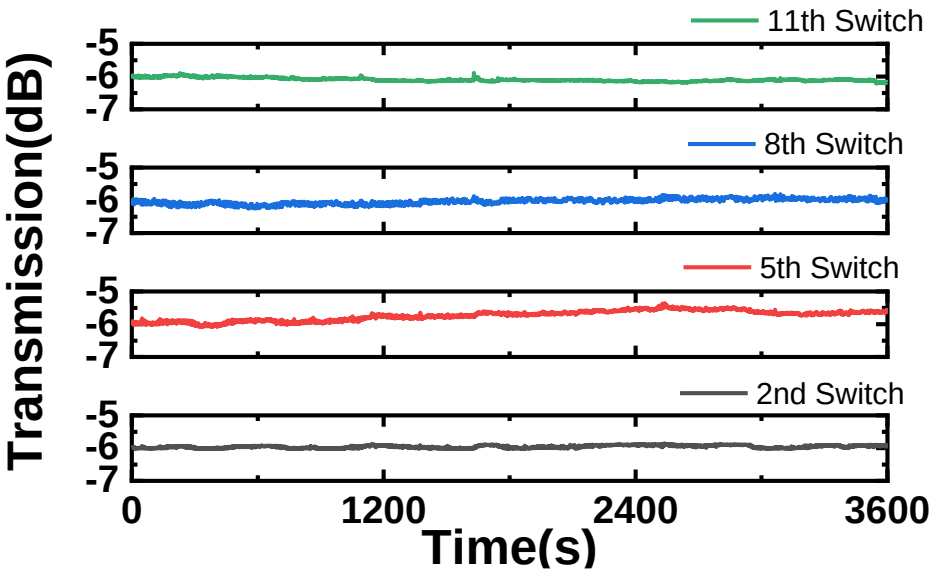


- **Switch response measured after On hold times of 2^1, 2^2, 2^3 …, 2^{10} s**
- **No noticeable change in switch response**

Multicast Stability Test

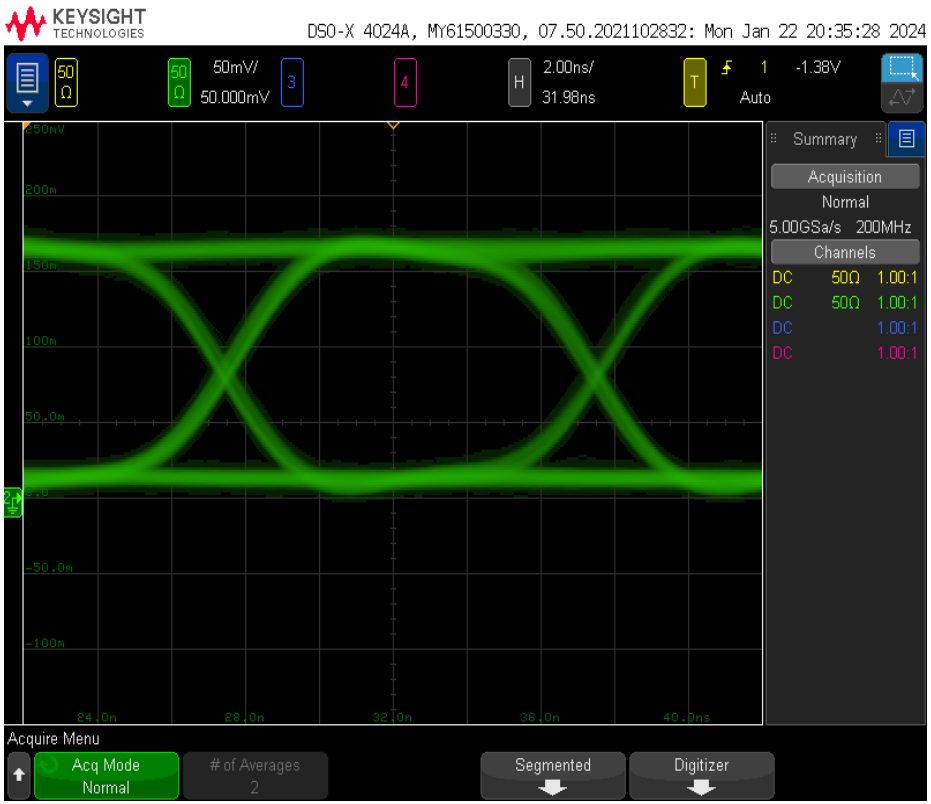


Transmission over 1 hour

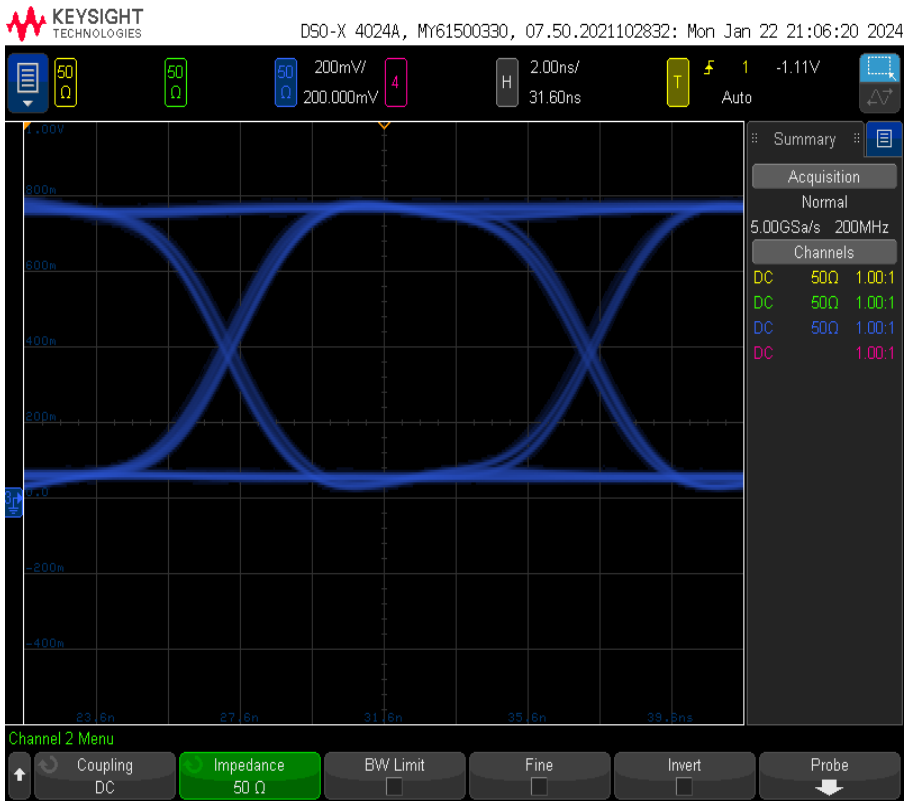


- **Optical power is equally distributed among 4 ports (- 6 dB)**
- **< 0.16 dB deviation over 1 hour**
  - **Cf. laser power fluctuation = 0.05 dB**
- **Tested under ambient conditions (no humidity/temperature control)**

Data transmission test (primary results)



At drop port

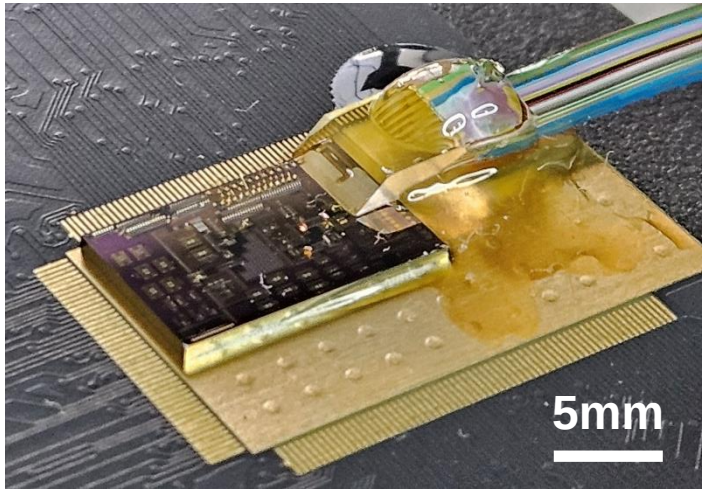


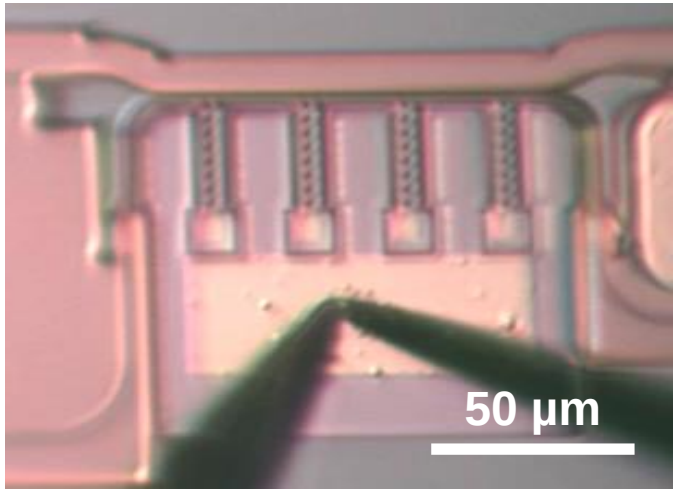
At through port

- Pseudorandom binary sequence (100 Mbps)
  - Getting a new setup for higher (~ 50 Gbps) data transmission tests
- No degradation of signal after the packaged switch

Summary

- 1x12 silicon photonic MEMS switch was fabricated.
- It was fully (electrically & optically) packaged.
- Several reliability tests were conducted with packaging.
- The device was very reliable even though the test was conducted under ambient conditions.





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<DGIST>

Prof. Sangyoon Han

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