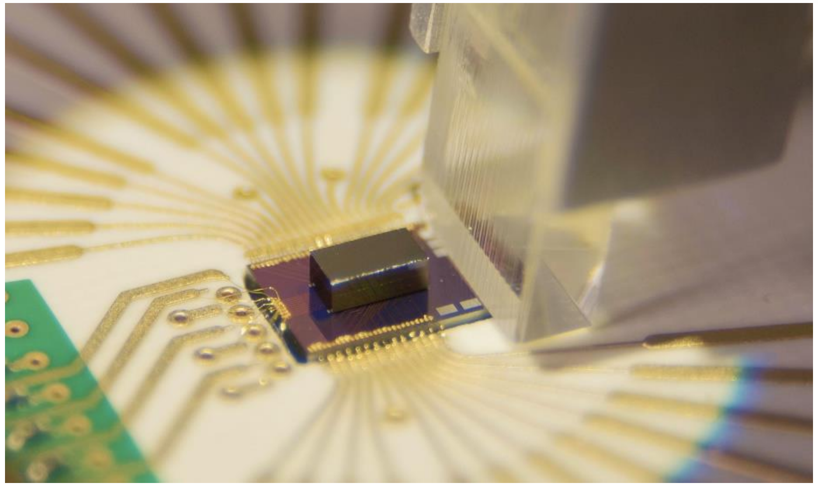
FROM RESEARCH TO INDUSTRY

cea tech



FACE-TO-FACE INTEGRATION OF AN ELECTRO-OPTICAL LINK WITH CMOS DRIVERS AND THERMAL CONTROL

D43D Workshop – Leti Innovation Days 2018 | Yvain Thonnart

Silicon Photonics moves forward for long distance optical wireline transceiver

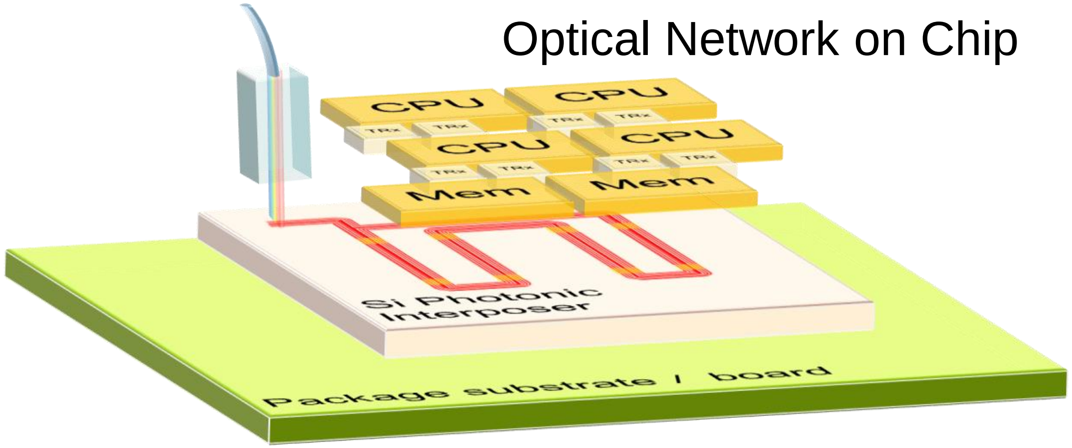
- 100 / 400 Gigabit Ethernet

Large-scale electronics longs for low-latency low-energy dense communication

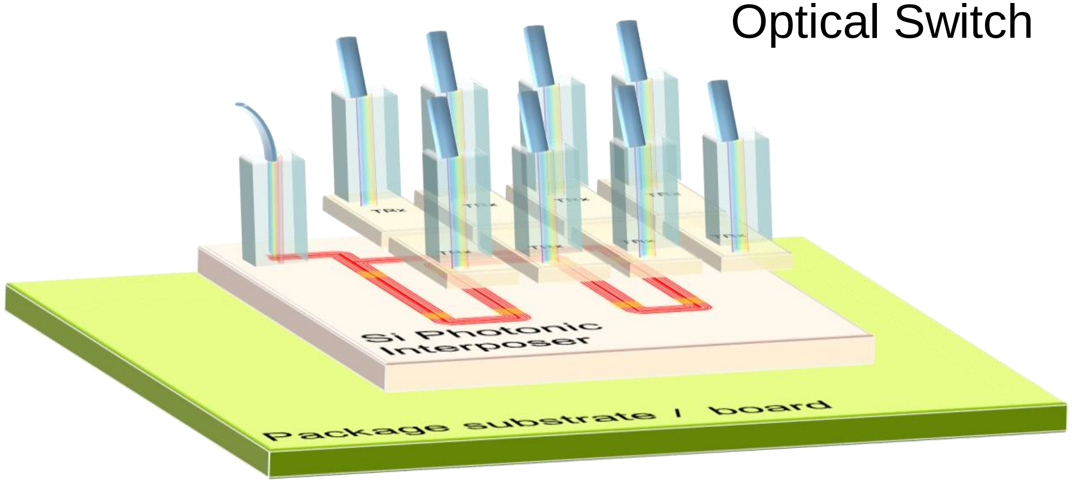
Optical short-range communication has been a long-term target for years

- Needs compact optical devices to maximize bandwidth per mm²
  ➔ **Microring optical resonators**

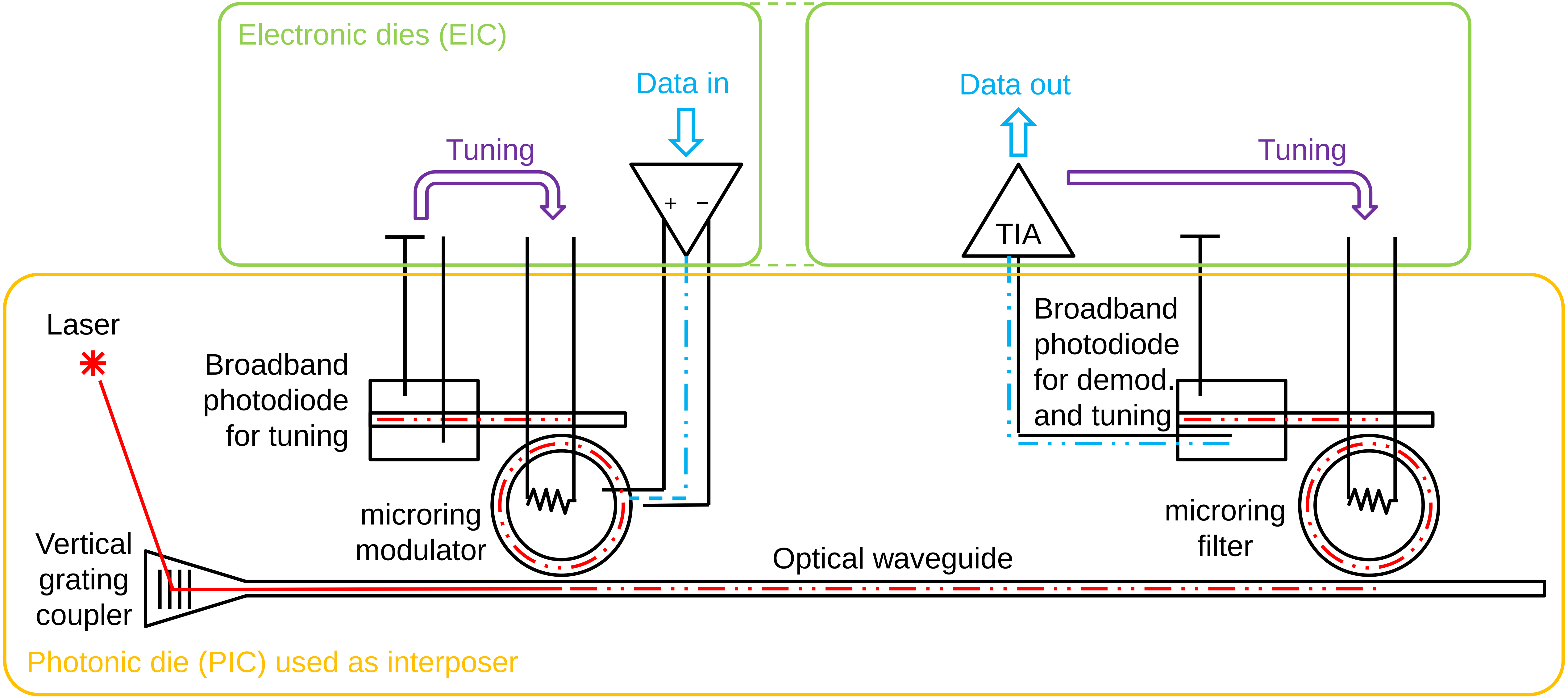
Optical Network on Chip



Optical Switch



MICRORING MODULATOR BASED LINK



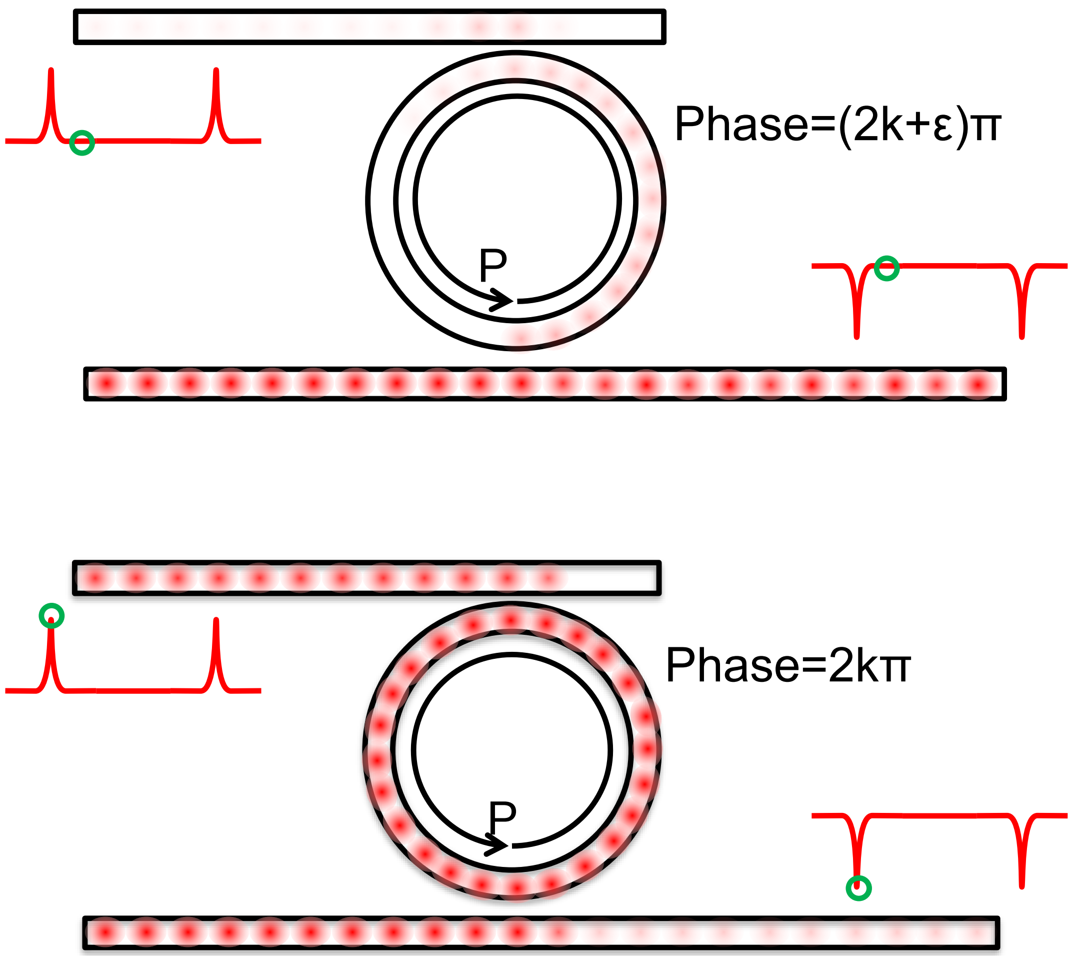
MICRORING: OPTICAL RESONANT CAVITY

Compact optical devices

- Highly resonant: Q-factor 10,000–30,000

$$\lambda_{res} = \frac{P\, n_{eff}}{k}$$

Any refractive index change shifts the resonant wavelength



PN or PIN diode junction can be created inside the ring for electrical control

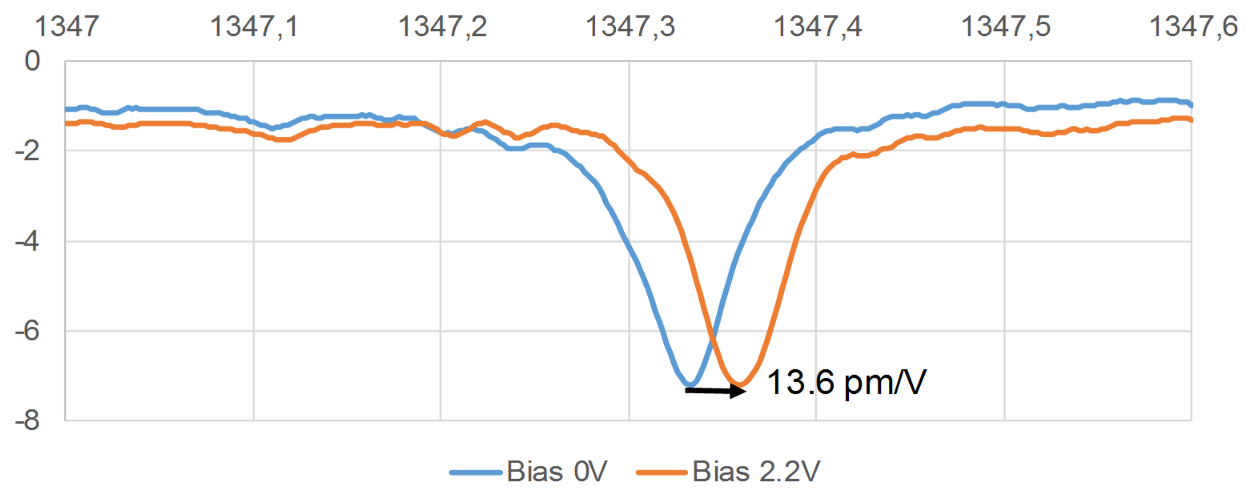
- Different uses depending on diode
  - PN rings can be used as modulators (> 10 Gbps)
  - PIN rings can be used as filters (<500 MHz) for routing and wavelength demultiplexing

<u>But</u> Subject to Temperature variations

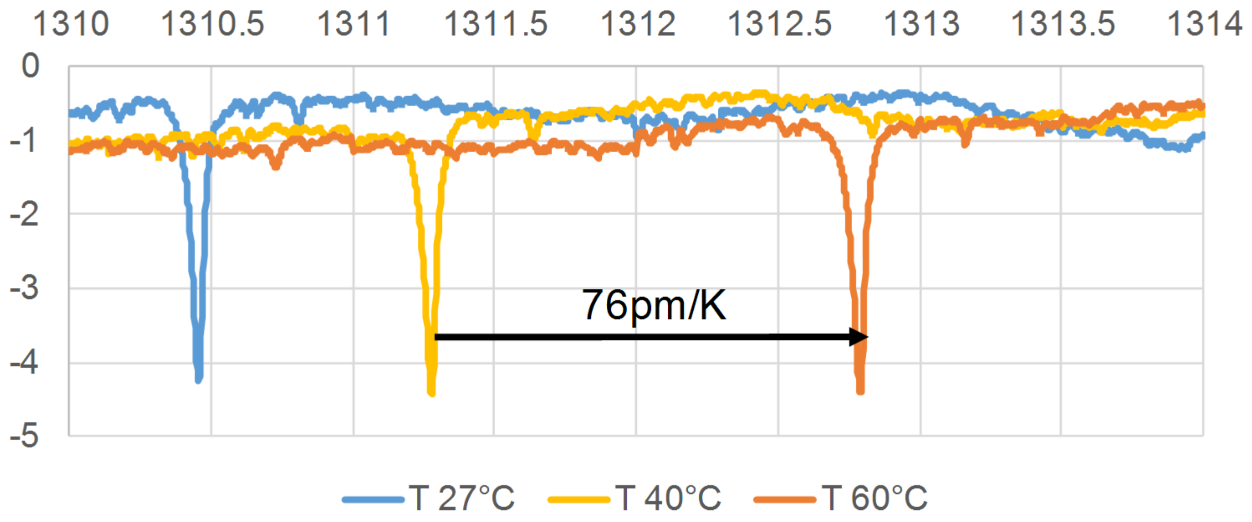
➔ Low-frequency resonance shift

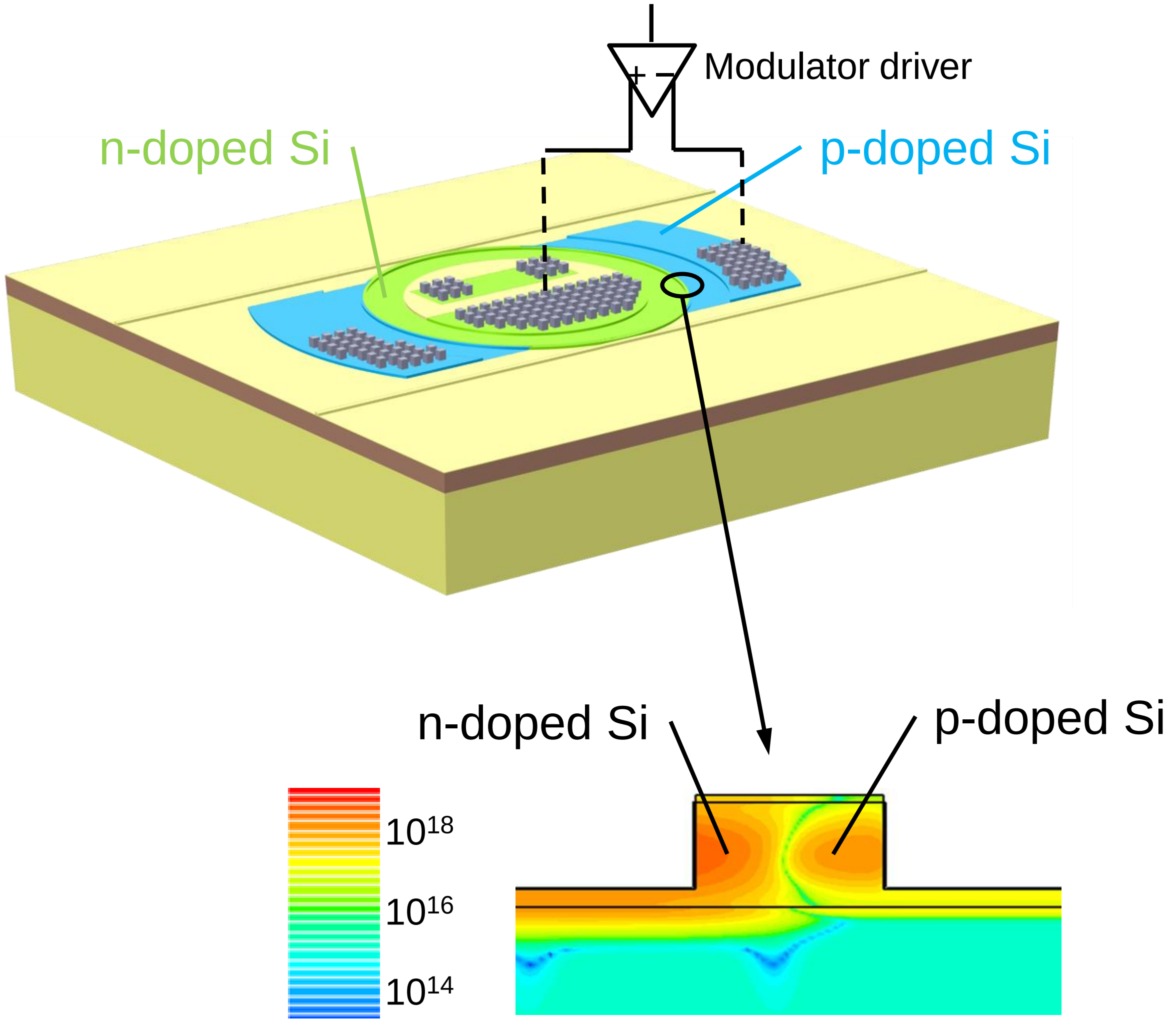
MODULATOR PRINCIPLE, THERMAL SENSITIVITY DΛ/DV & DΛ/DT MEASUREMENTS

13.6 pm/V modulation efficiency



76 pm/K thermal sensitivity





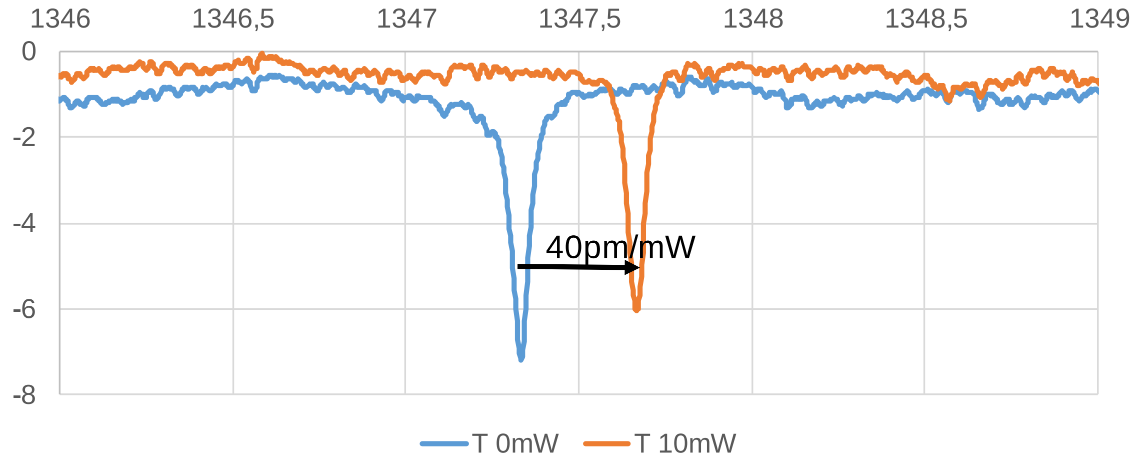
Heating using doped Silicon

- Resistive path inside the ring

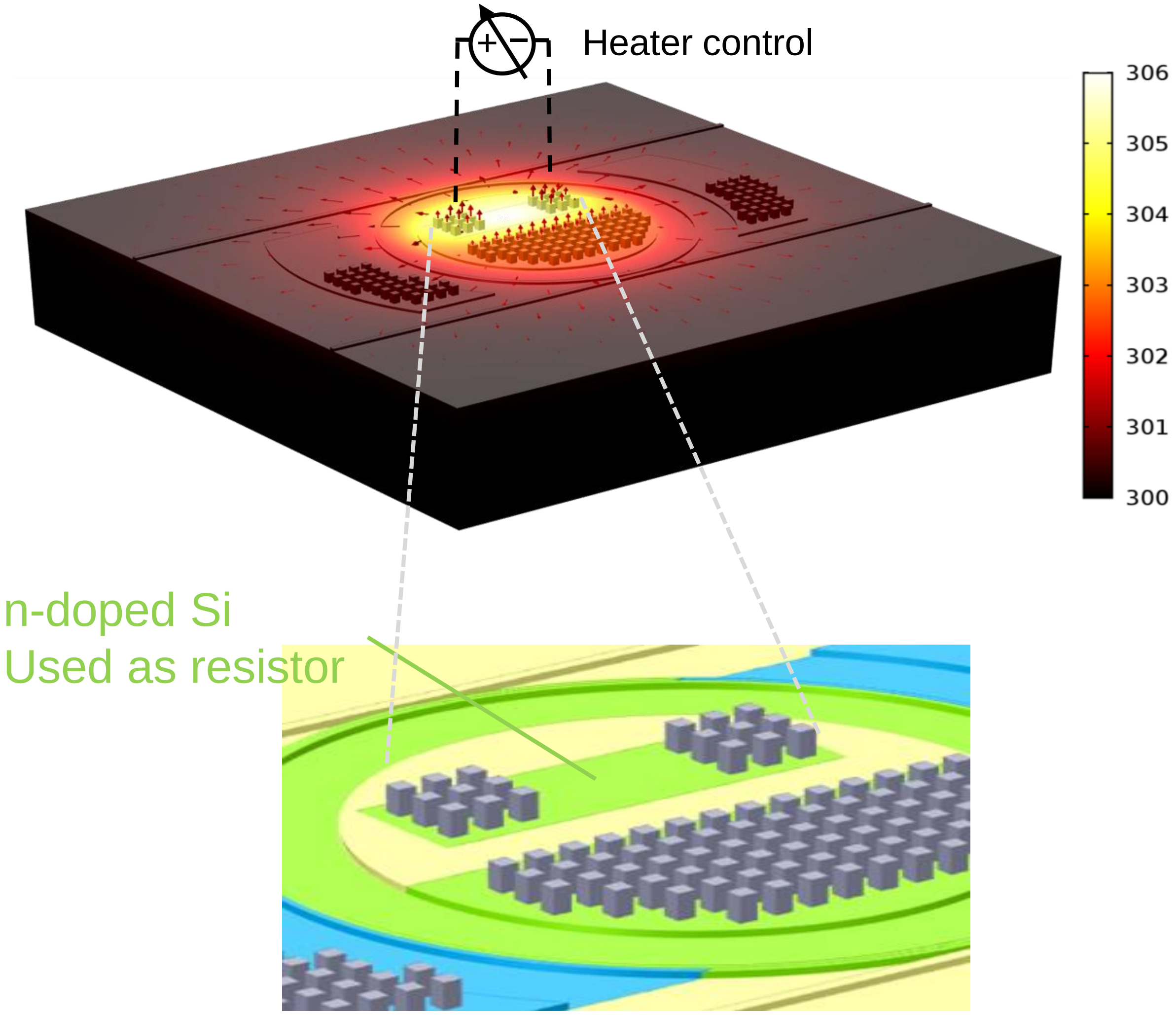
Average ring temperature increase:

- Simulation: dT/dP ~ 2K/mW
- Measurements: dλ/dP ~ **40pm/mW**

Resonance shift under 10mW heating



Temperature (K) and Heat Flux under 1mW heating



RING MODULATOR OPERATION (TUNING+MODULATION)

Ring resonant wavelength unpredictible at design time

- 1 nm thickness variation
  ≈ 1 nm resonance shift

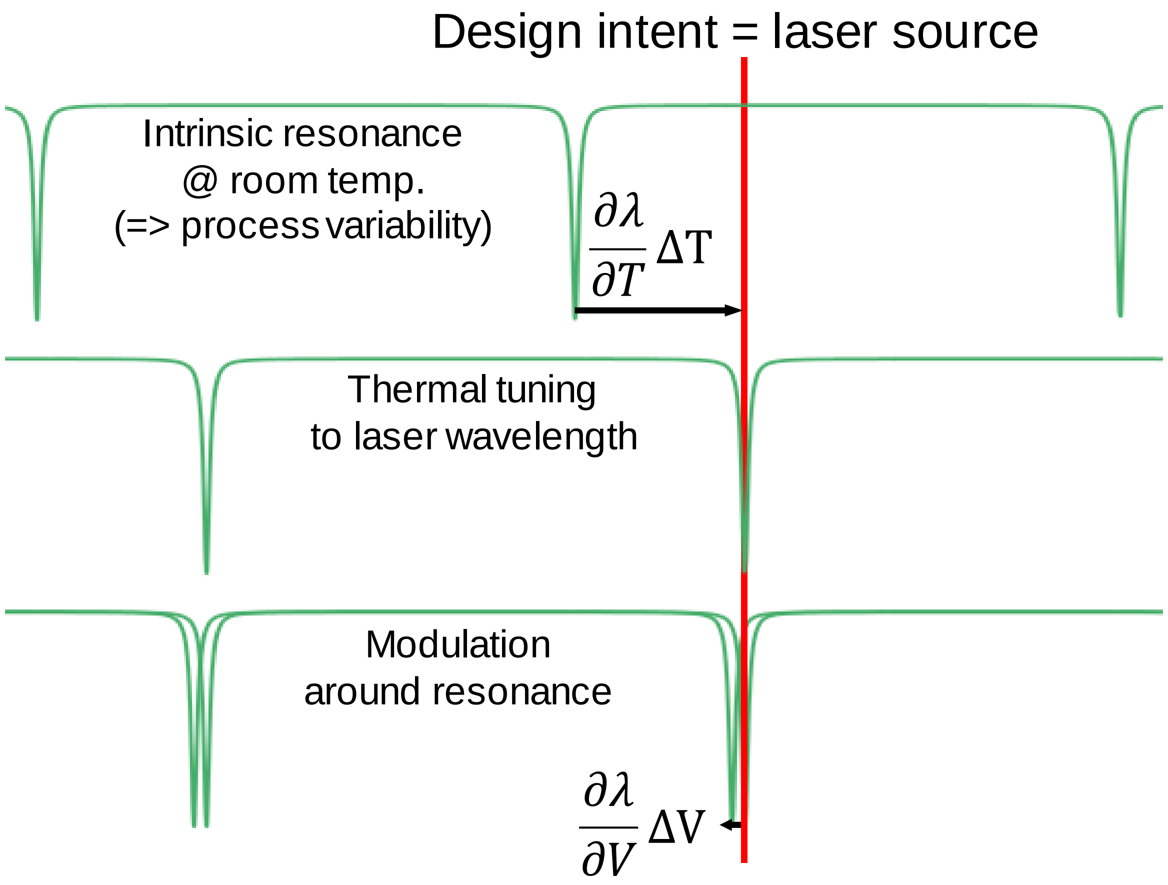
But finesse, free-spectral-range & amplitudes are well-controlled

Thermal tuning is used to align ring resonance on laser source

- Low-frequency control

Voltage is used to modulate light

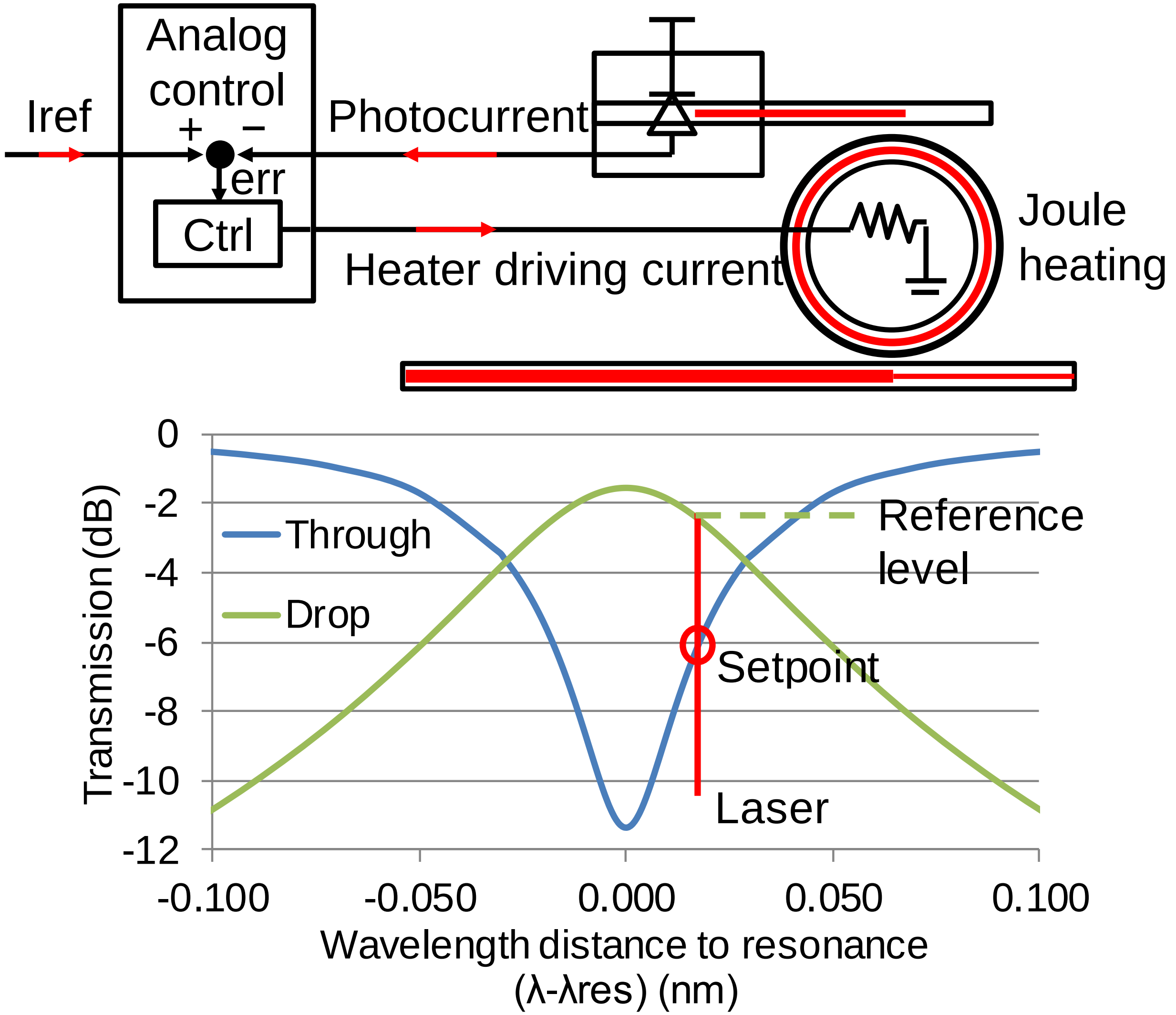
- High frequency modulation

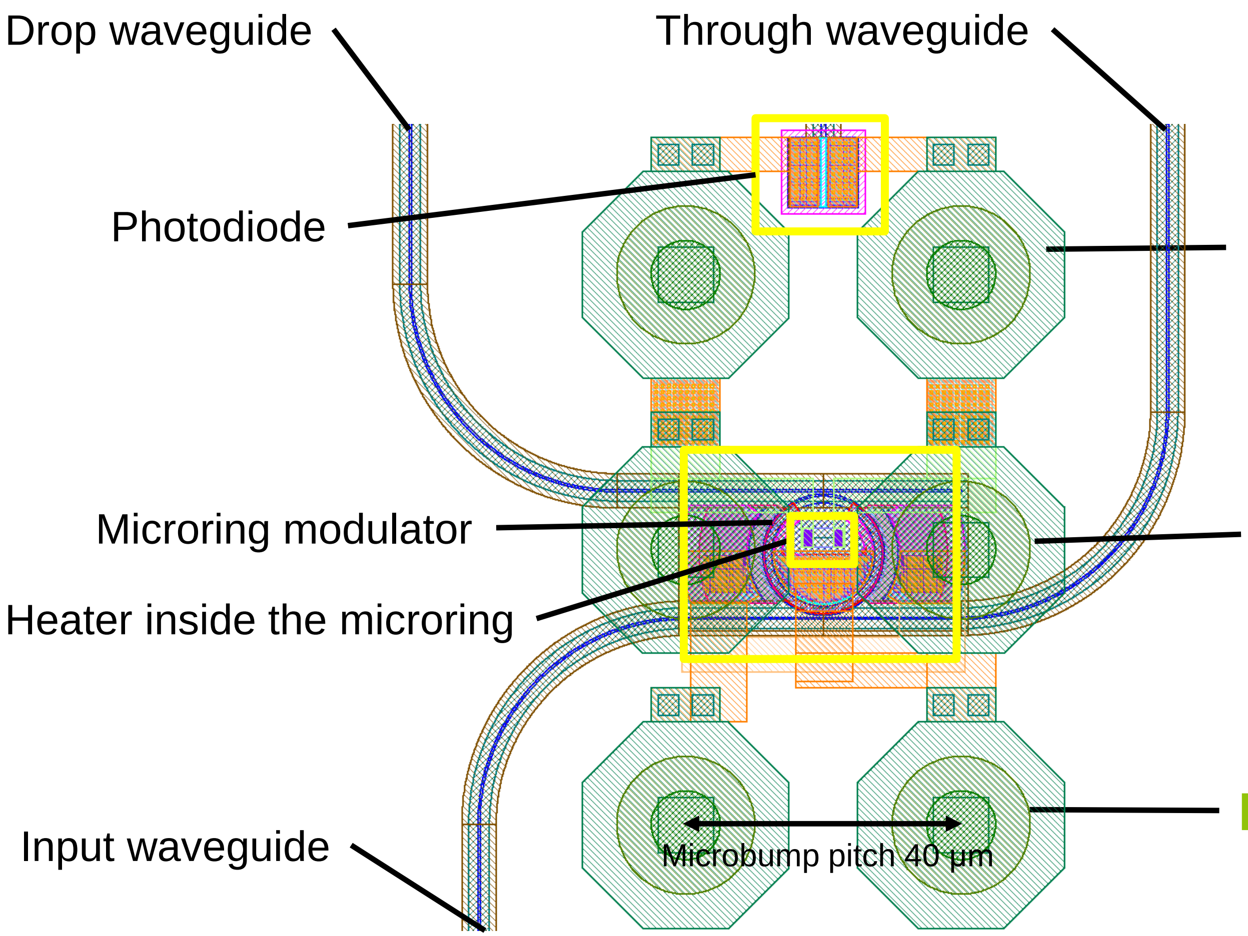


LOCKING ON REFERENCE CURRENT LEVEL VIA USE OF DROP PORT & PHOTODIODE

Ring resonance can be tracked by transmission on drop port

- Setpoint on through port corresponds to a power value on drop port
- Photodiode converts this to photocurrent
- Analog control used to match photocurrent with reference
- Joule heating by resulting heater driver current





- 6 microbumps per wavelength
- 3 Kinds, different constraints:

Photodiode microbumps

➔ Photocurrent: 10-100µA @ DC-10Gbps

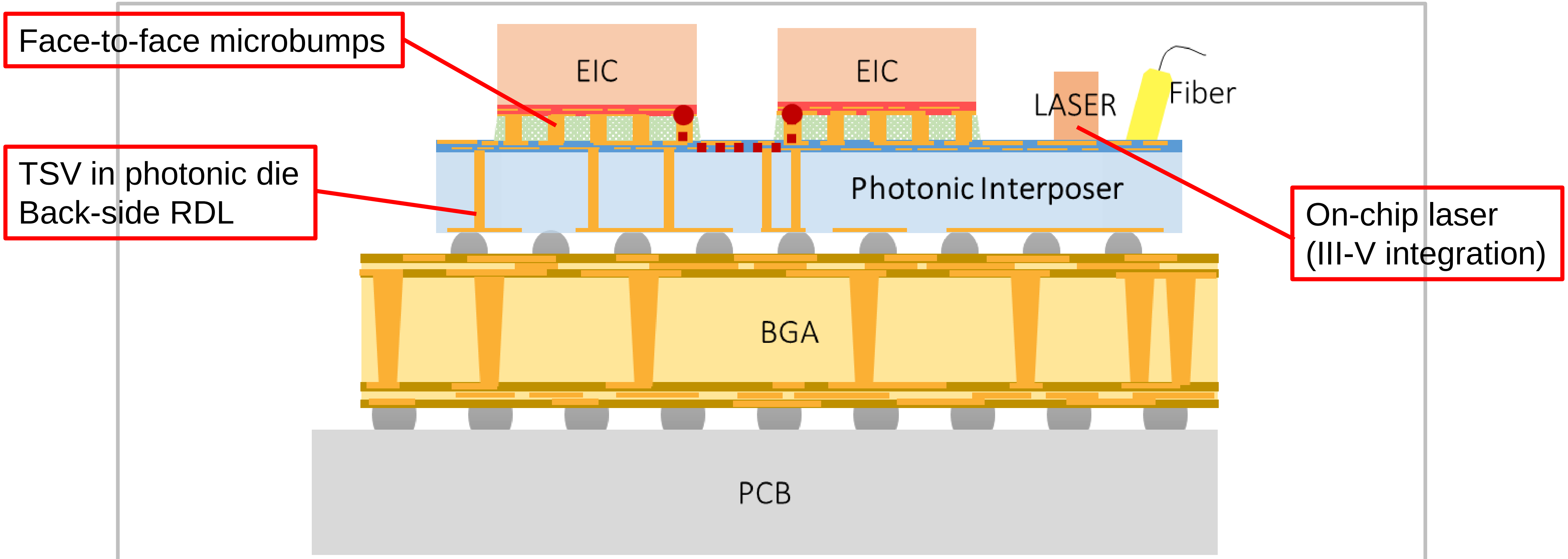
Heater microbumps

➔ Joule current: 0-2mW @ DC

Modulator microbumps

➔ Modulation voltage: 0-2.4V @ 10Gbps

LONG-TERM INTEGRATION PLAN



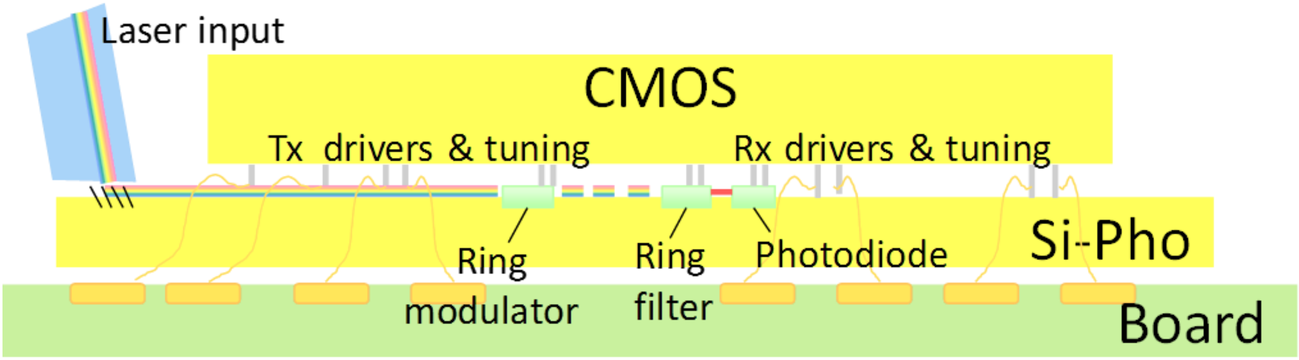
Kevin Morot,
Intégration et modélisation RF des interconnexions 3D pour l'interposeur photonique,
PhD dissertation

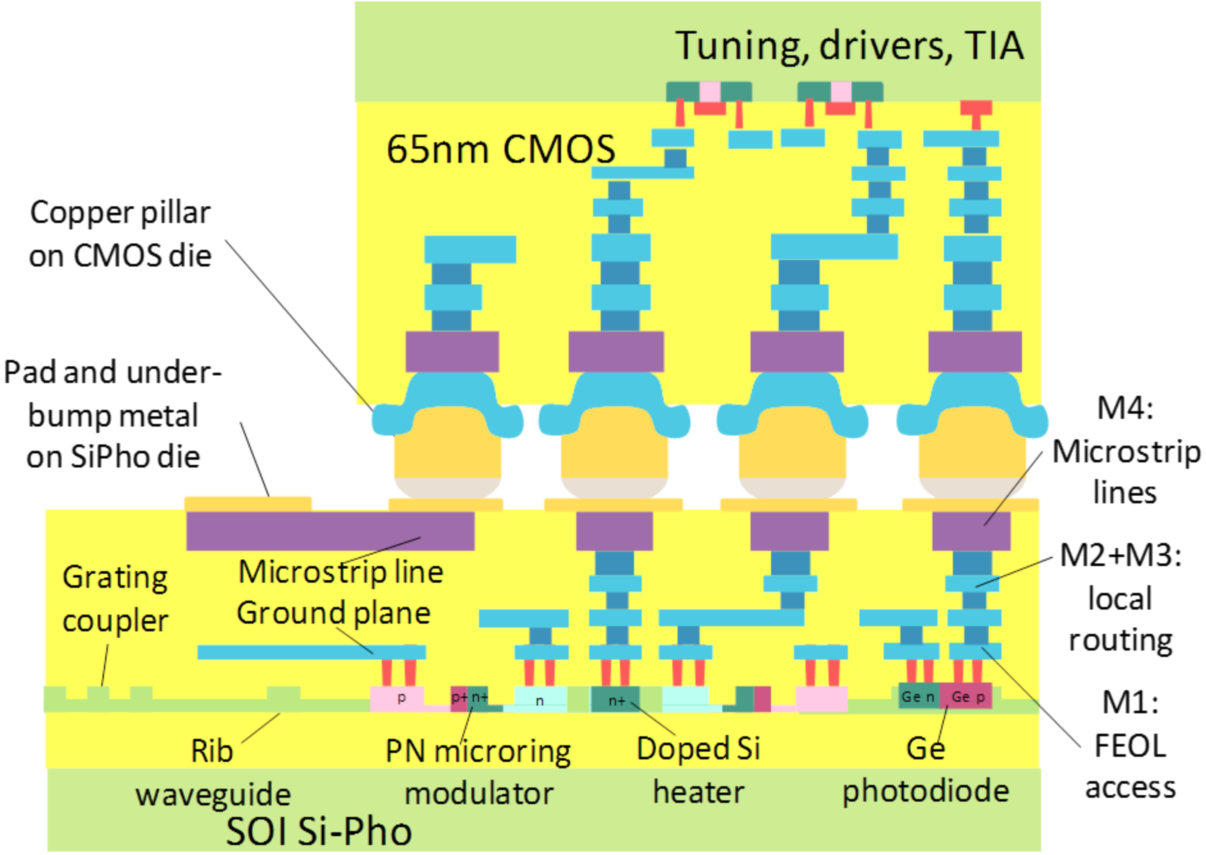
Copper-pillar Face-to-face assembly

- CMOS: STMicro. 65nm LP
- Photonic: STMicro. Internal 100nm SiPho

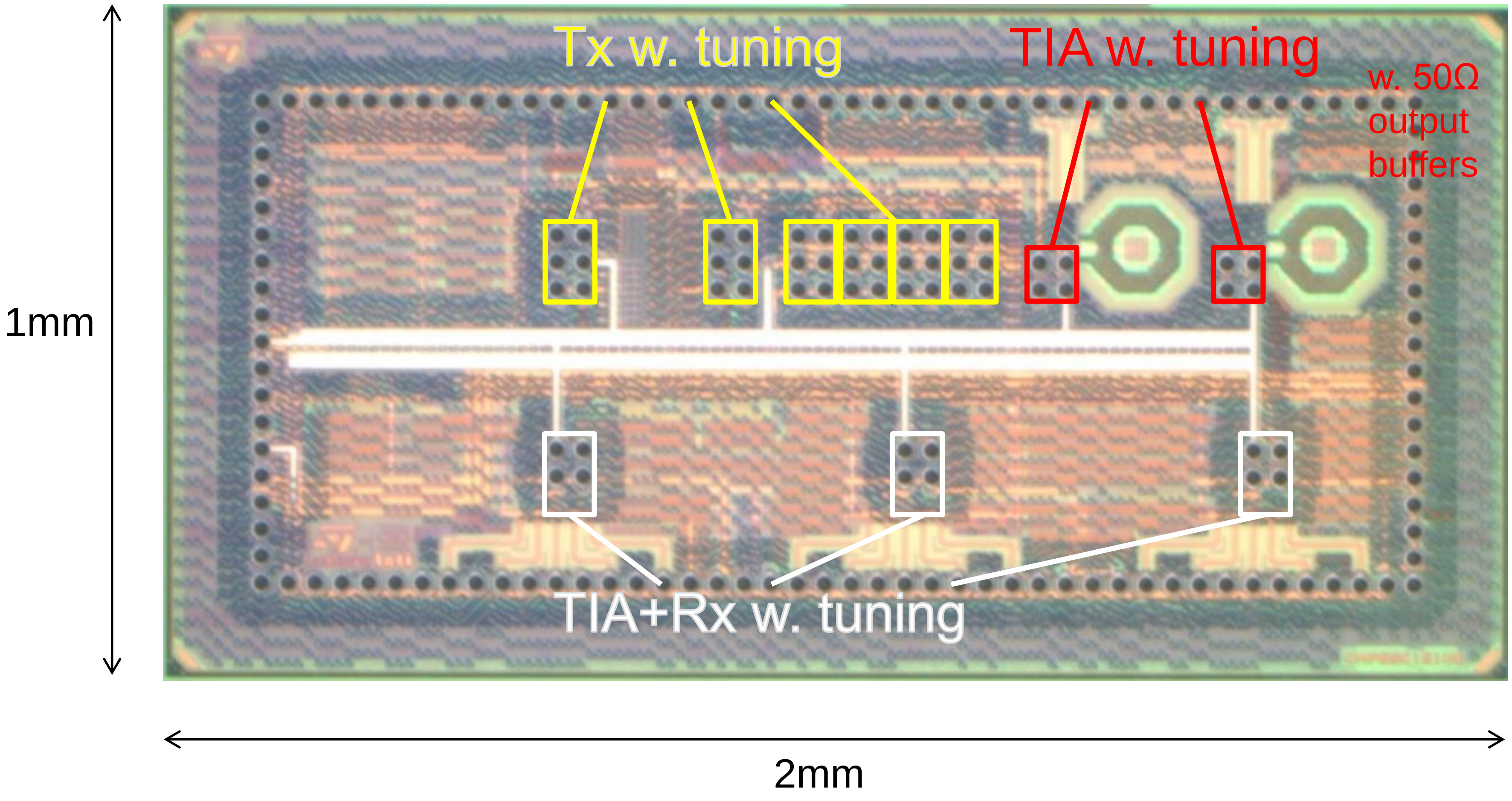
Wire-bonding on Photonic die

Vertical Fiber array on grating couplers





ELECTRONIC DIE



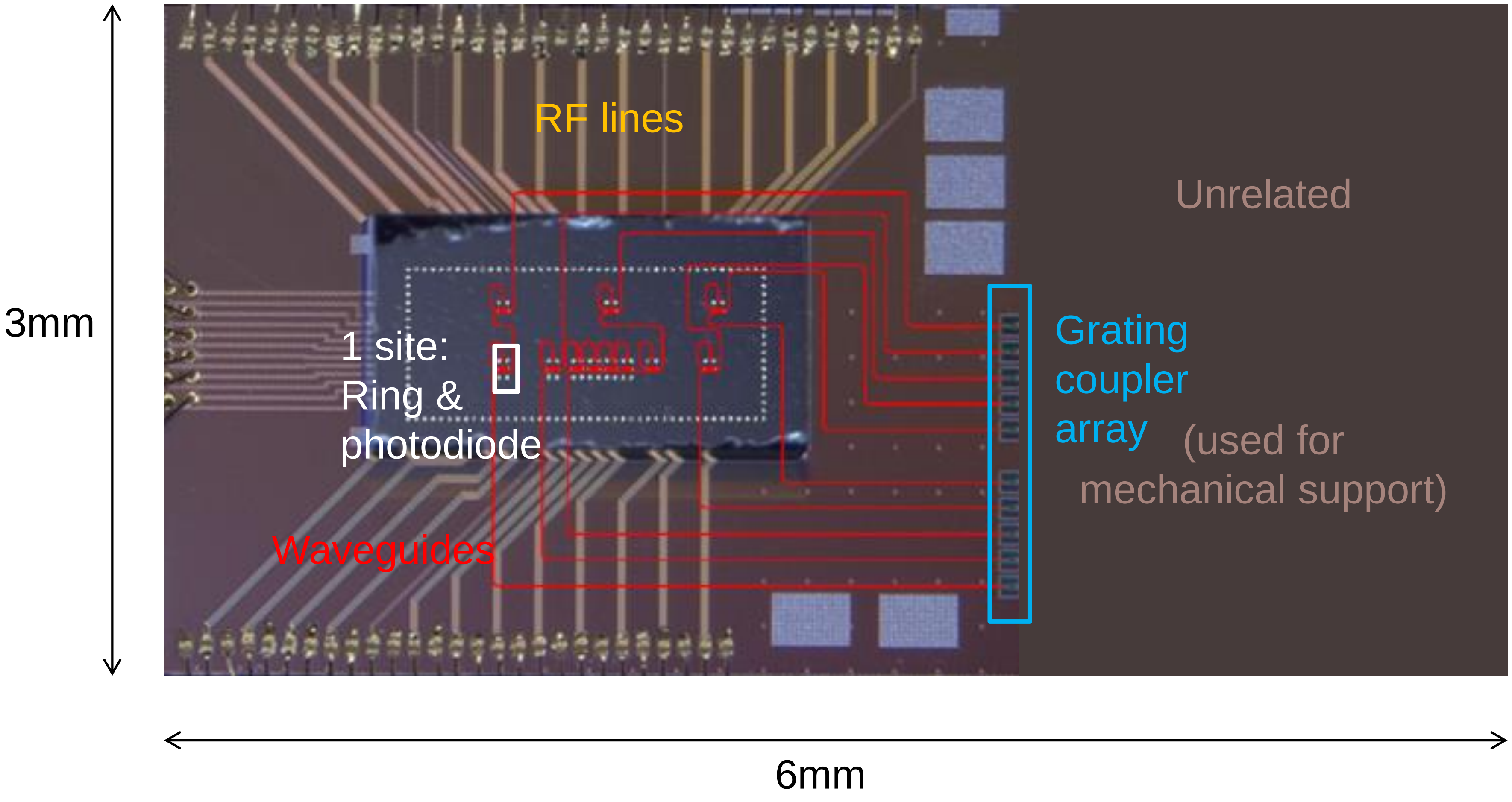
Functional area per λ

- Heater control
  - 40×40µm²/λ
  - 40×40µm²/WDM
- Tx Driver
  - 40×40µm²
- Rx Driver
  - 80×40µm²

Dominated by
6 Cu-Pillar area

- Pitch 40µm
- 2 for Modulator
- 2 for Photodiode
- 2 for Heater

PHOTONIC DIE



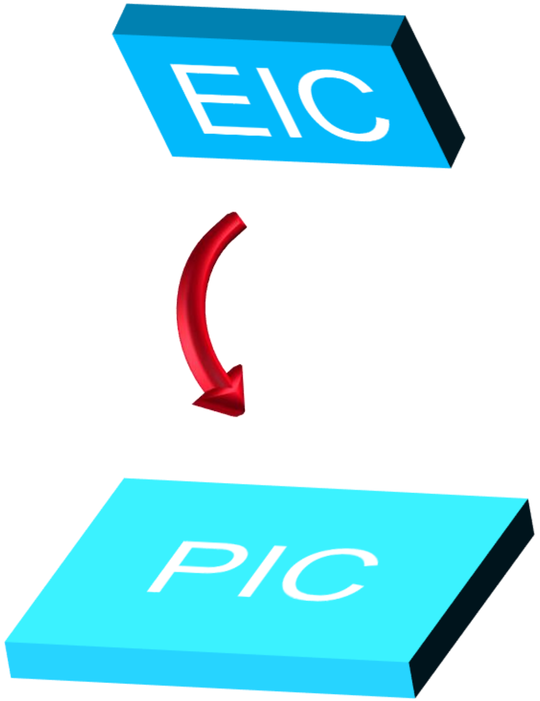
Functional area per λ

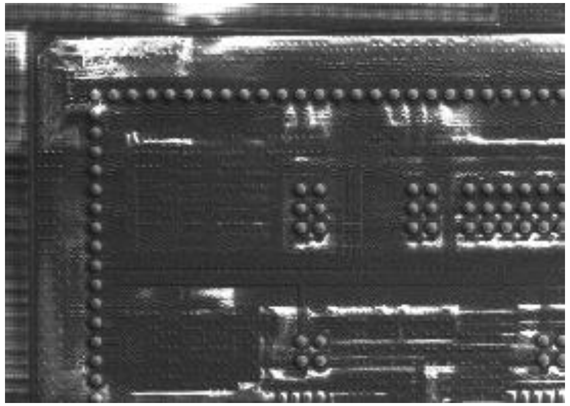
- 1 ring + 1 photodiode
  - 120×80μm²/λ

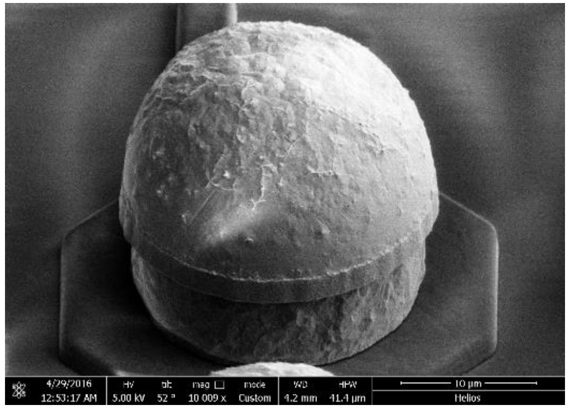
Dominated by
6 Cu-Pillar area

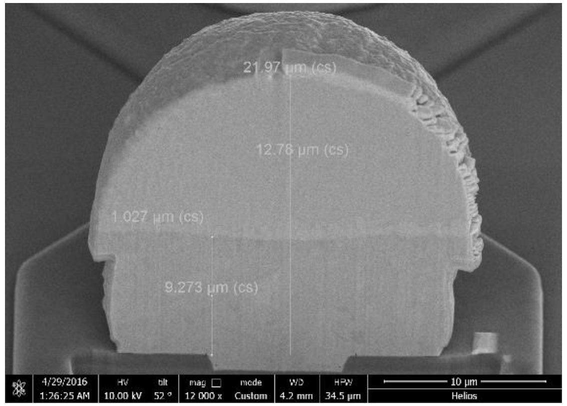
- Pitch 40μm
- 2 for Modulator
- 2 for Photodiode
- 2 for Heater

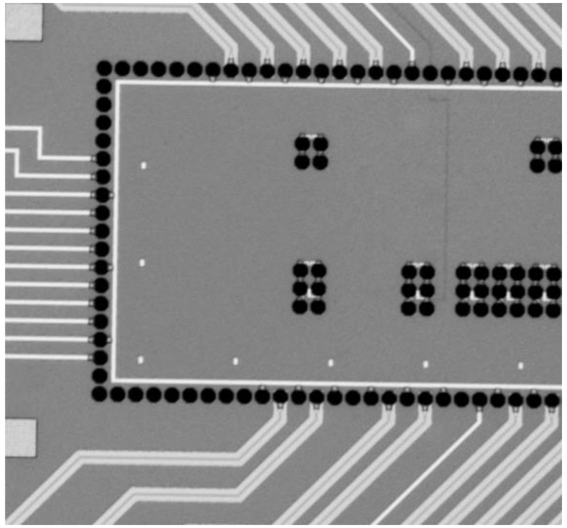
FACE-TO-FACE MICROBUMP ASSEMBLY

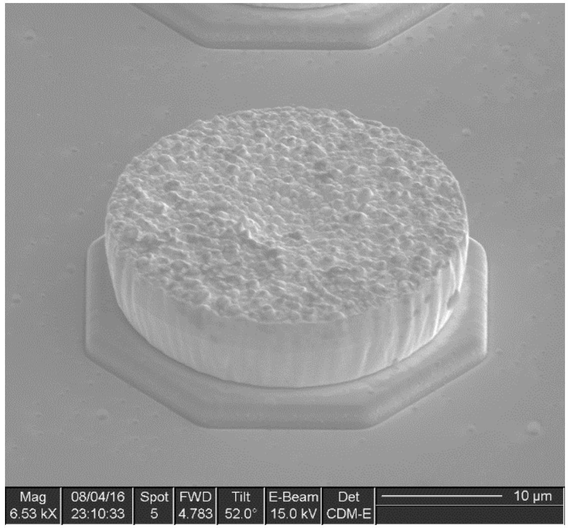


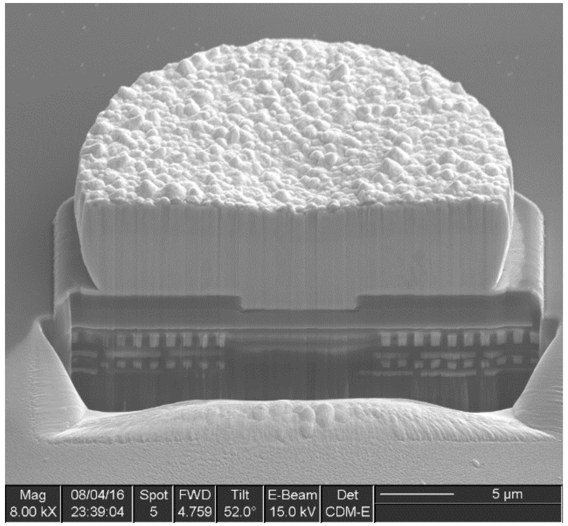








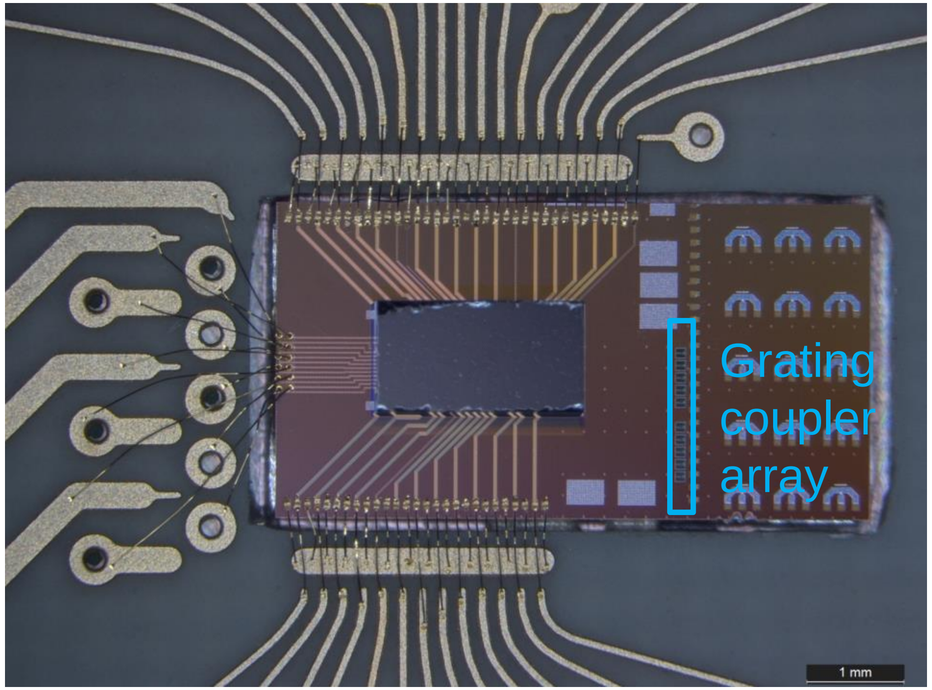




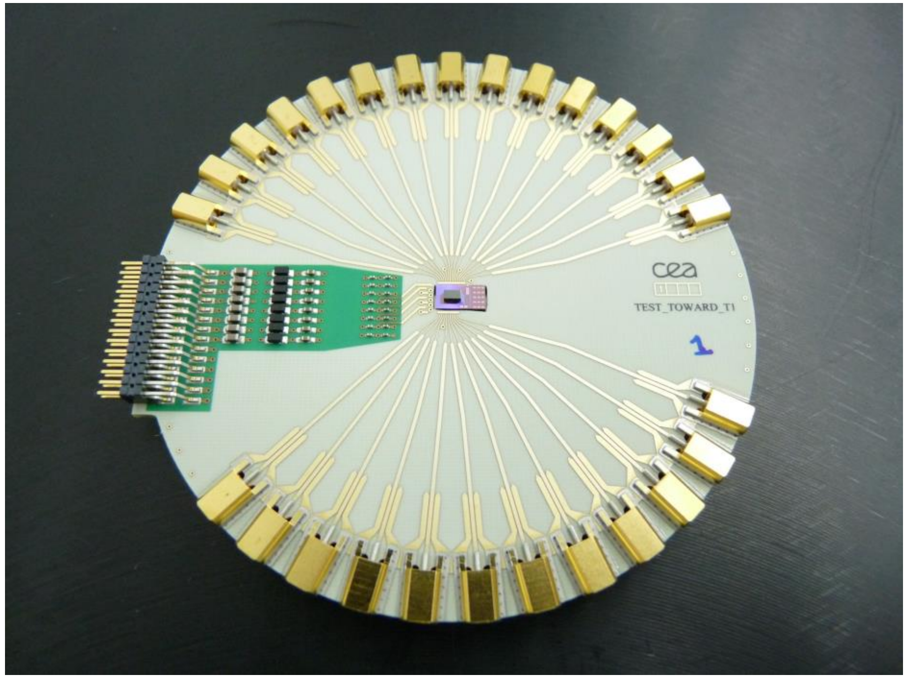
BOARD INTEGRATION

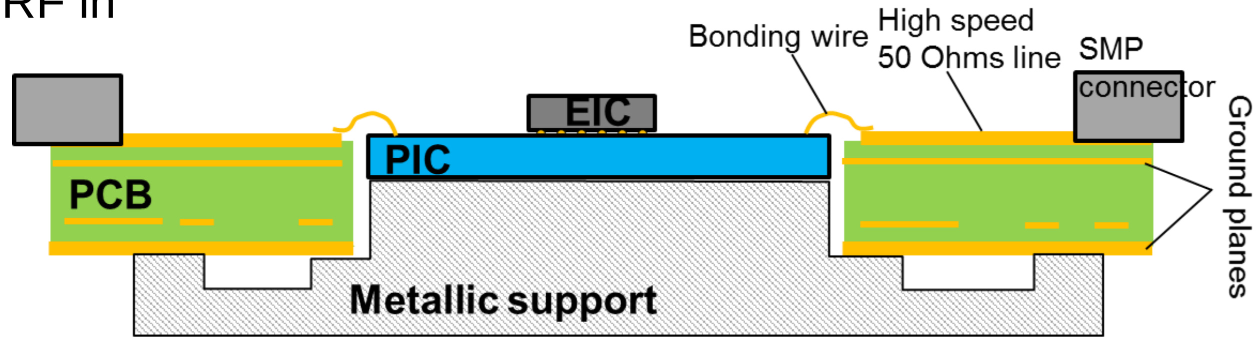
RF out

DC supplies & config.

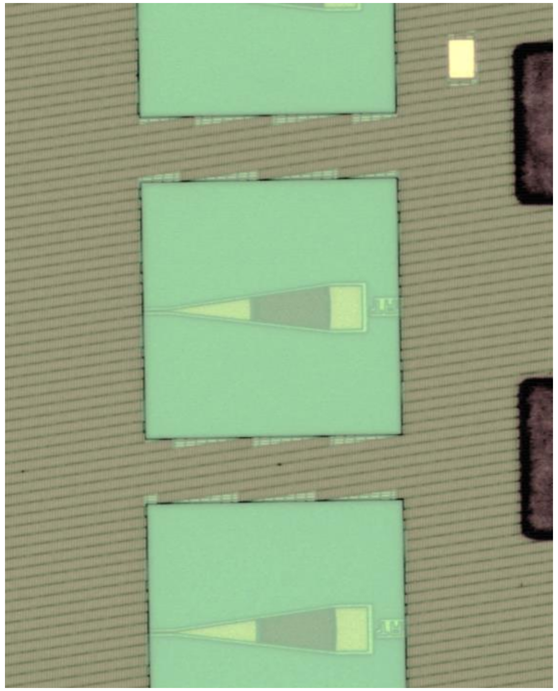


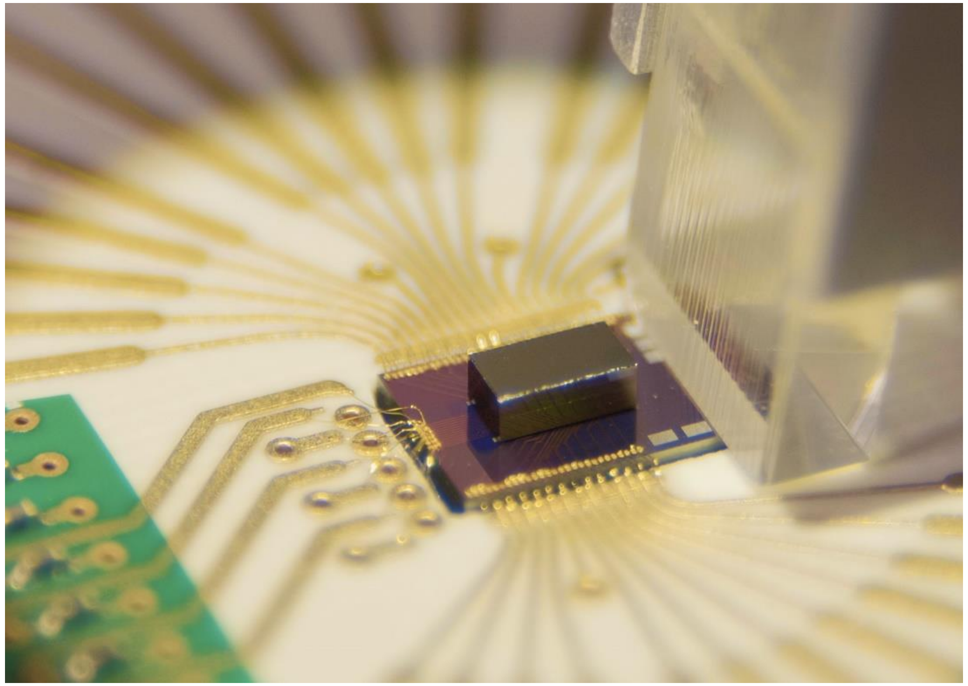
RF in

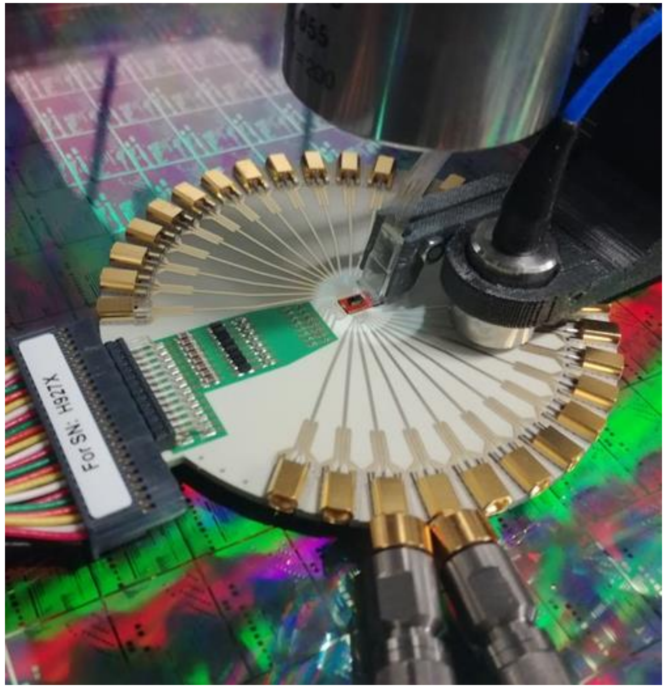


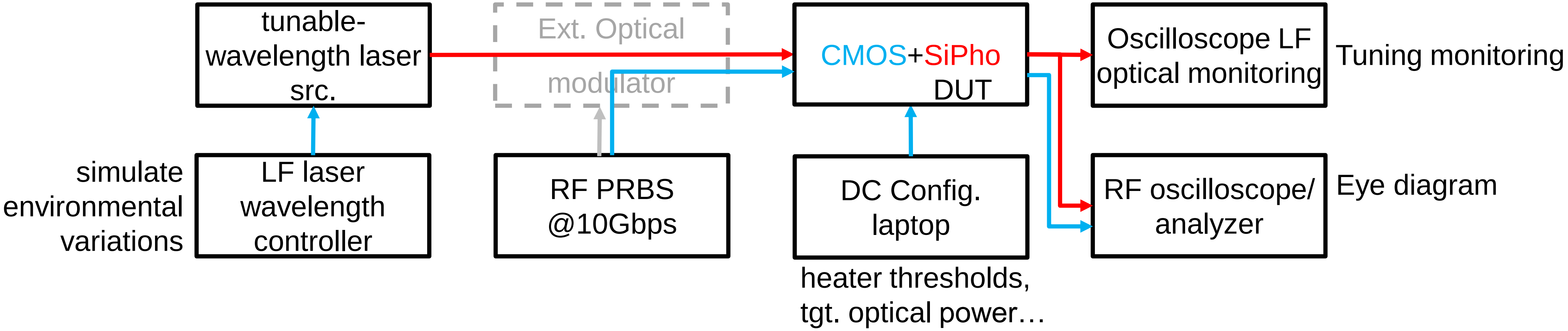


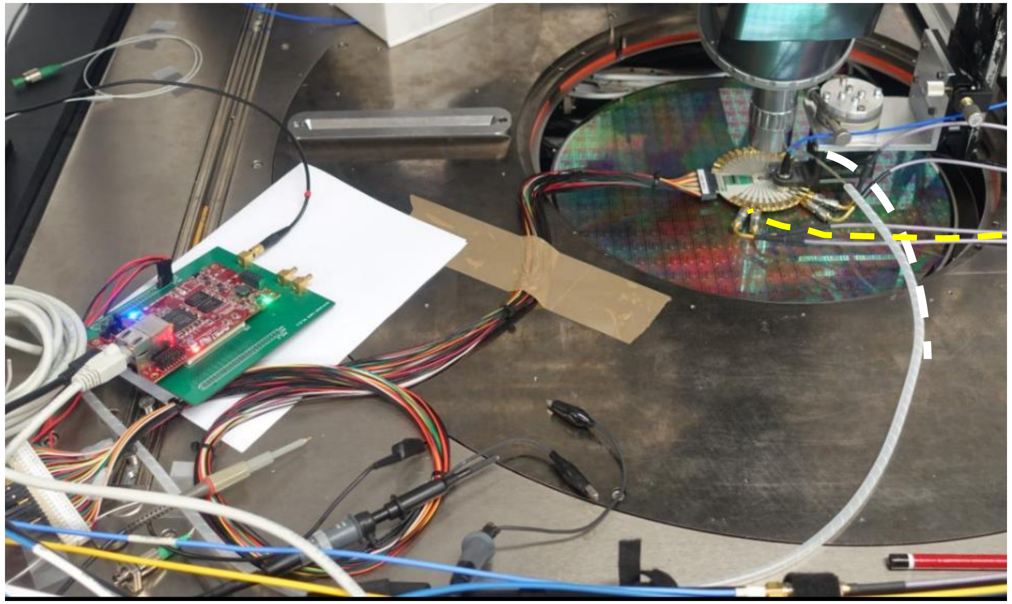
FIBER POSITIONING ON GRATING COUPLERS

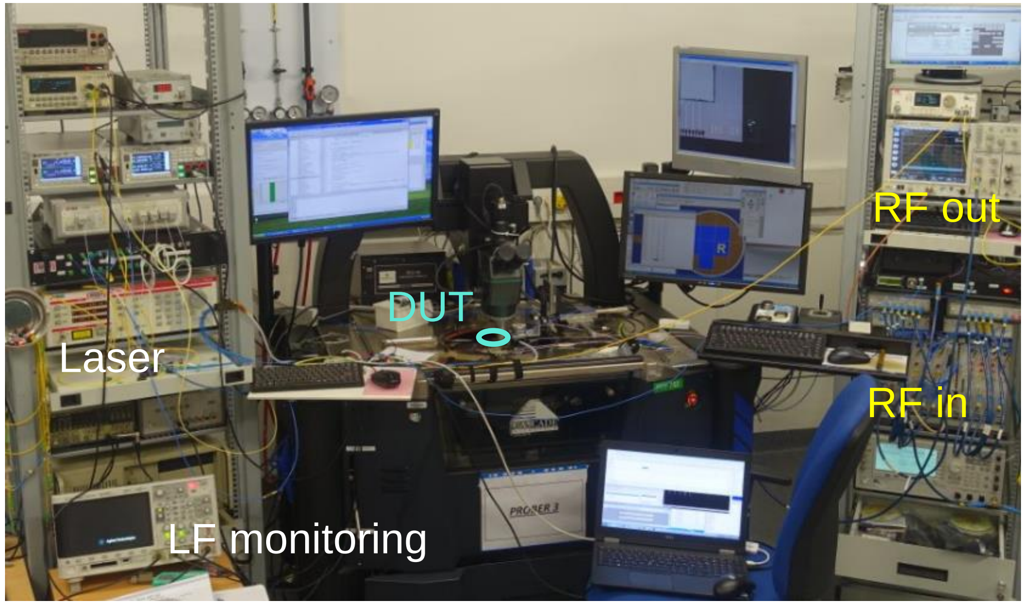






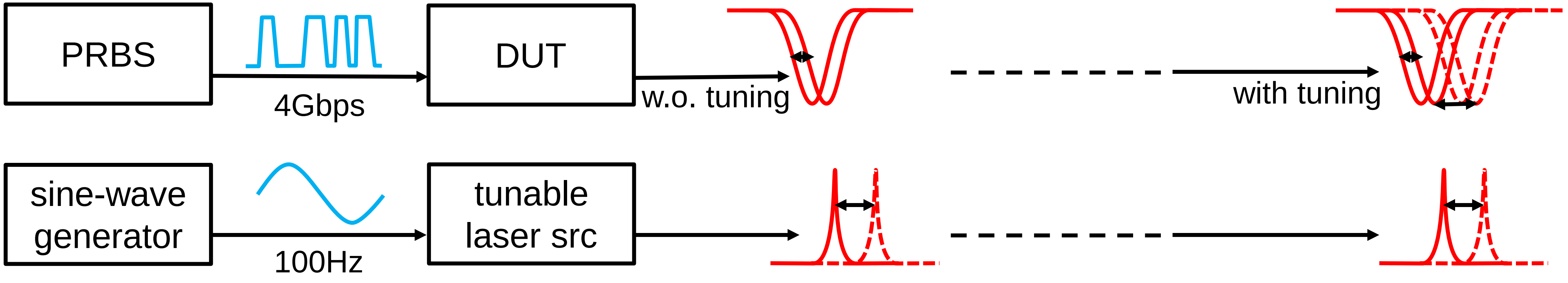

tunable-wavelength laser src.
Ext. Optical modulator
CMOS+SiPho DUT
Oscilloscope LF optical monitoring
Tuning monitoring
simulate environmental variations
LF laser wavelength controller
RF PRBS @10Gbps
DC Config. laptop
RF oscilloscope/ analyzer
Eye diagram
heater thresholds, tgt. optical power…



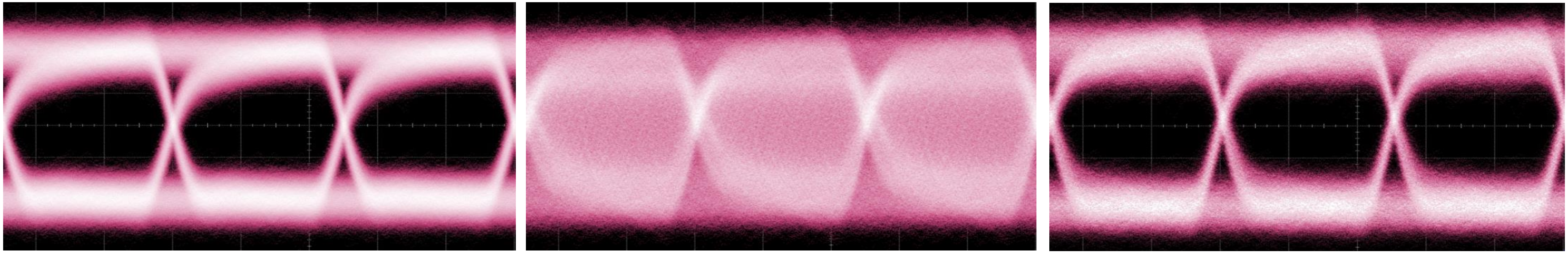

RF out
DUT
Laser
RF in
LF monitoring

CIRCUIT OBJECTIVE: PRESERVE COMMUNICATION DESPITE ENVIRONMENTAL PERTURBATION

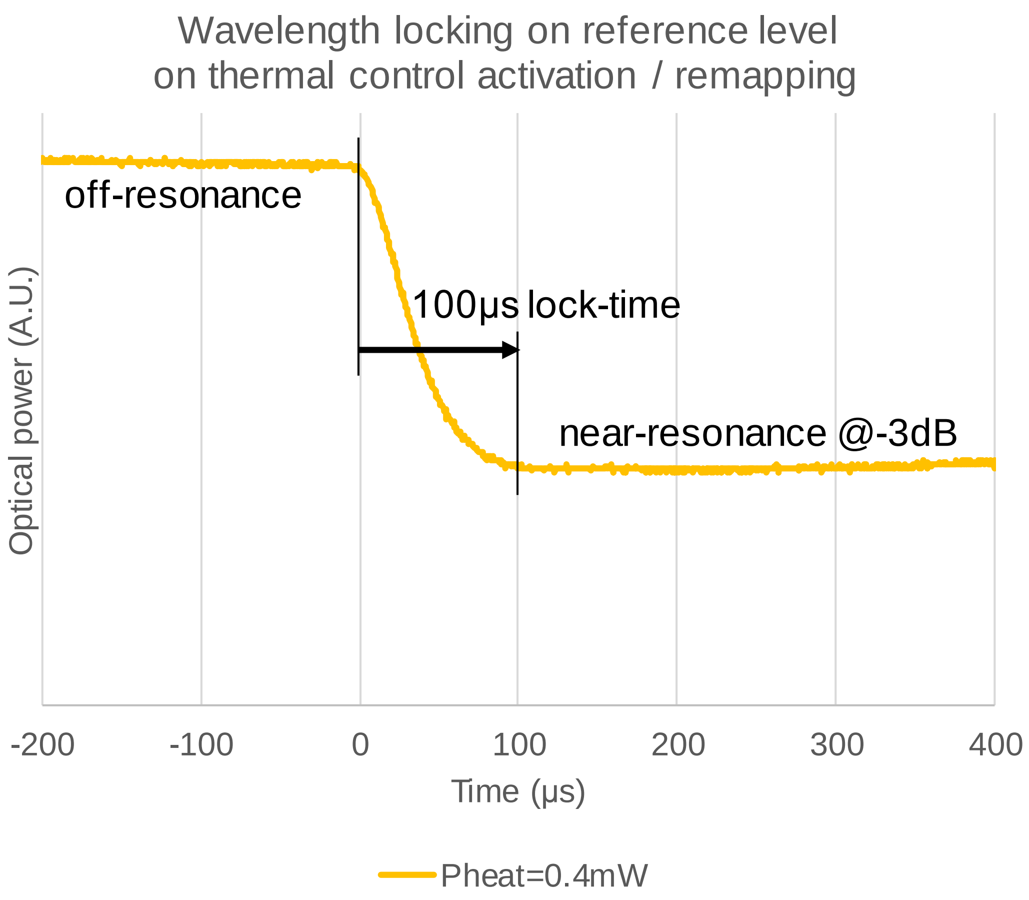
Experiment: 4Gbps modulation under laser wavelength wobulation 30pm$_{pp}$ at 100Hz
➔ Simulate thermal effect of workload changes on package (~1-10ms time constant)

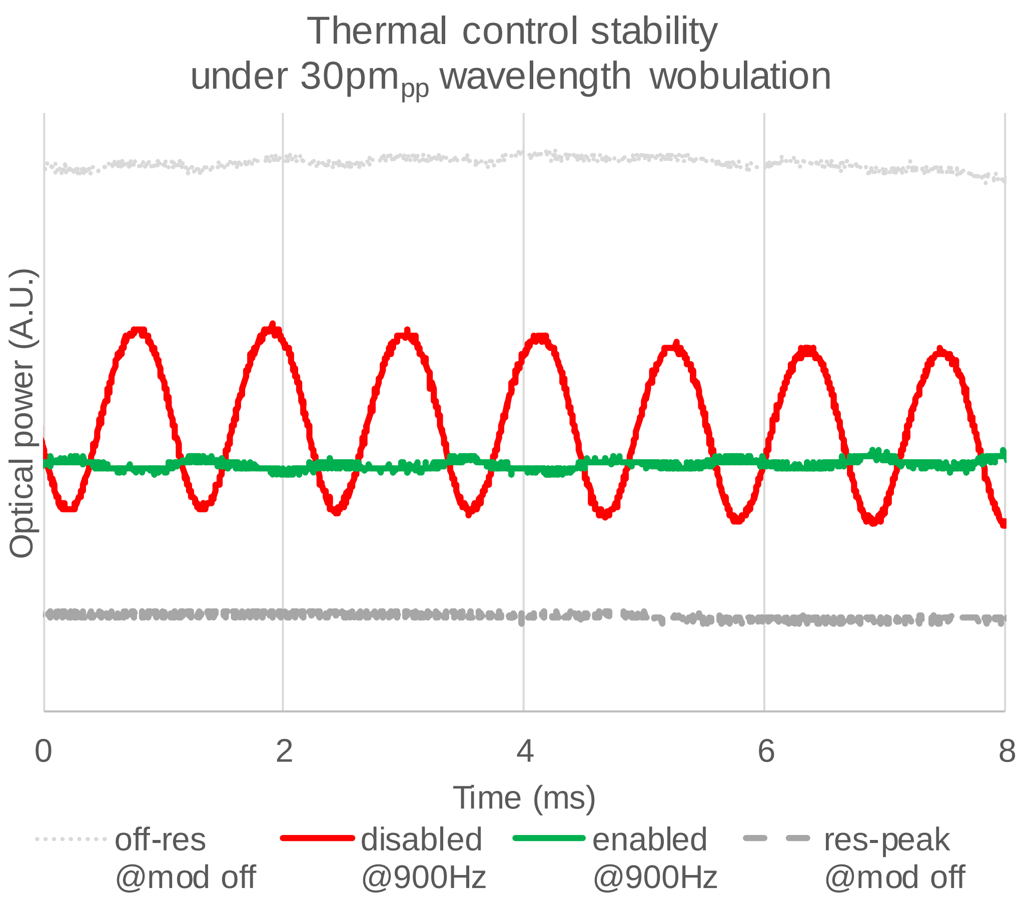


No wobulation | Wob+Thermal tuning deactivated | Wob.+Thermal tuning activated

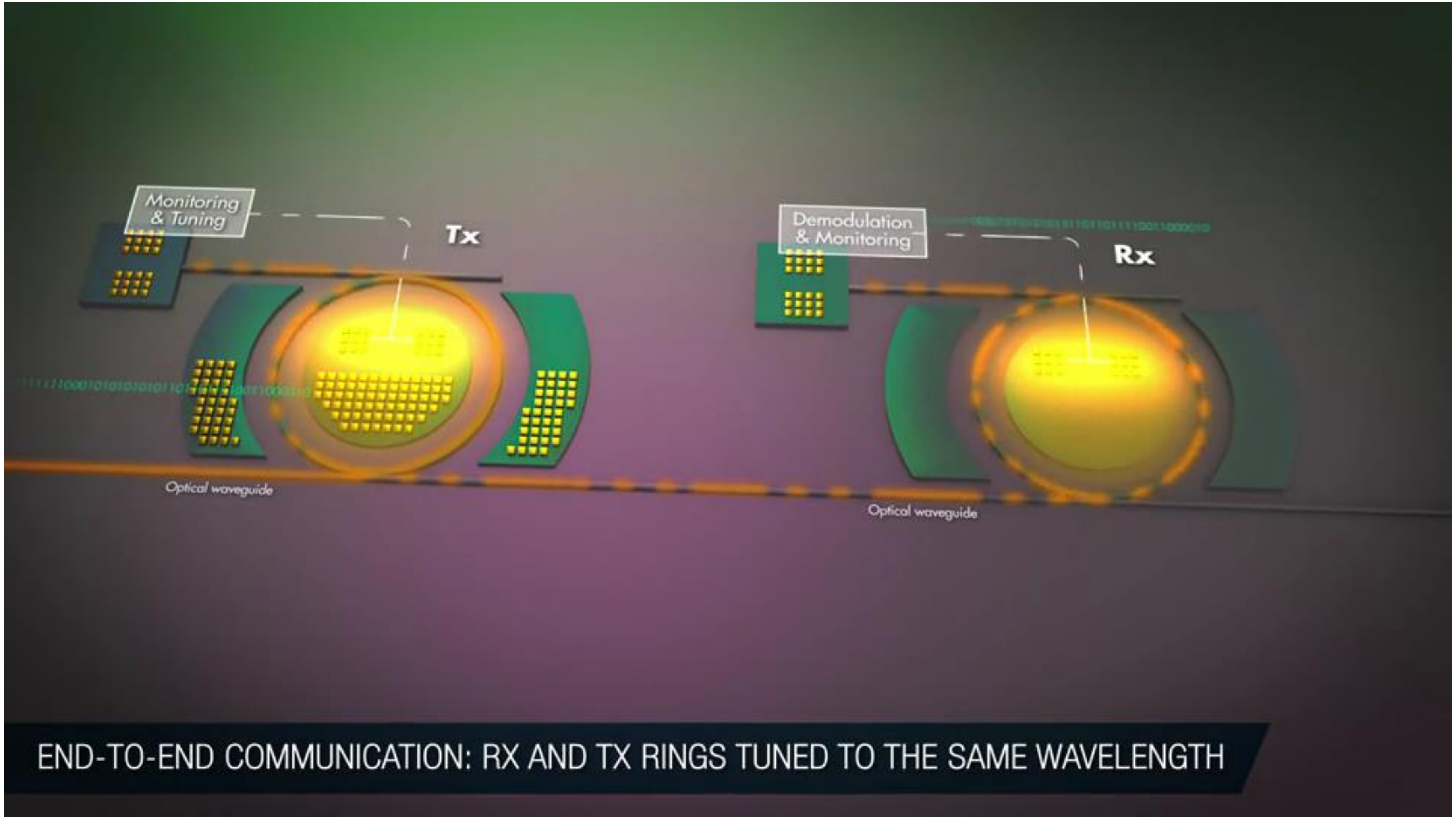


THERMAL LOCKING AND STABILITY

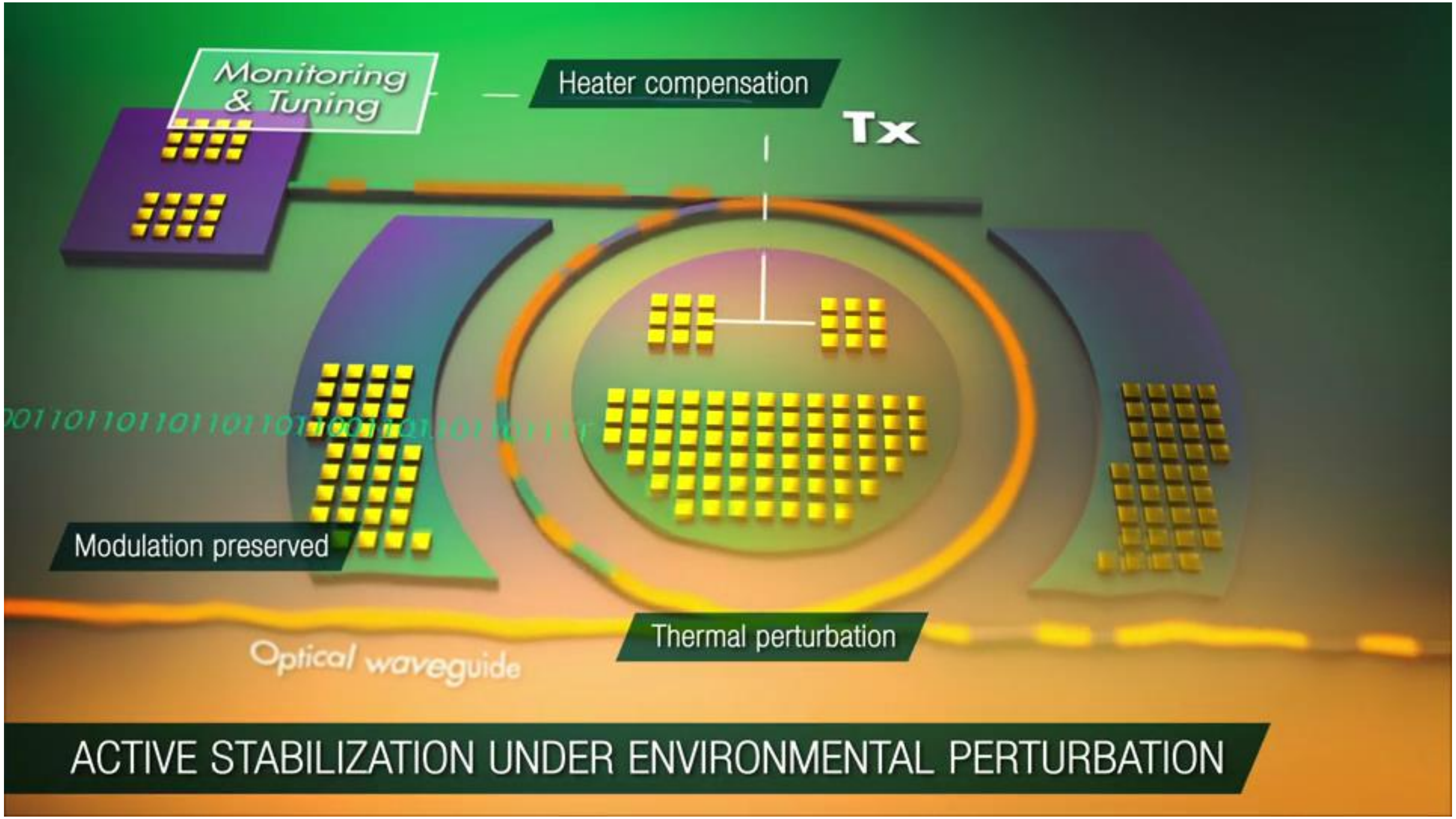




ROBUST ELECTRO-OPTICAL LINK OPERATION UNDER PERTURBATION



ROBUST ELECTRO-OPTICAL LINK OPERATION UNDER PERTURBATION



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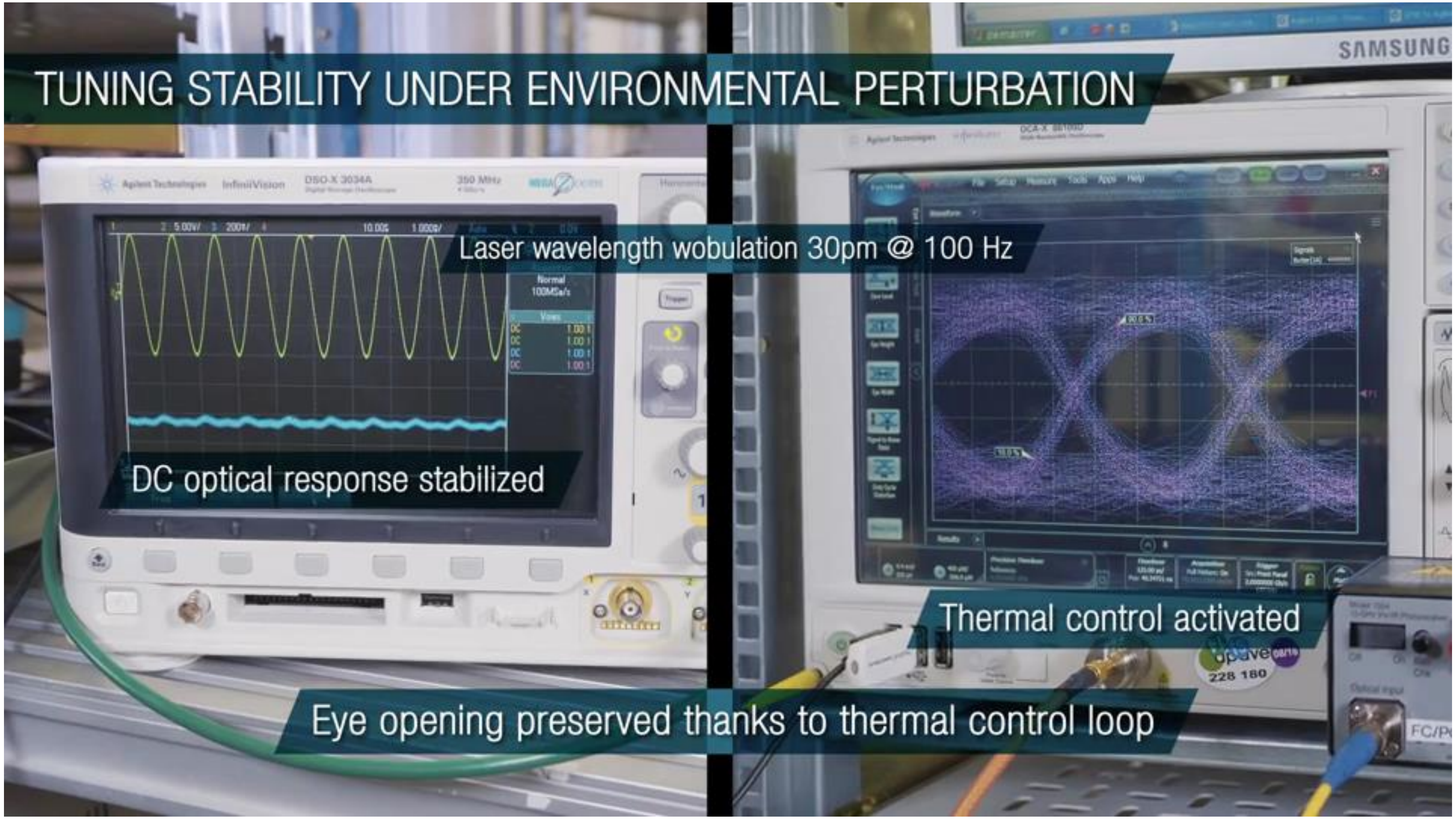
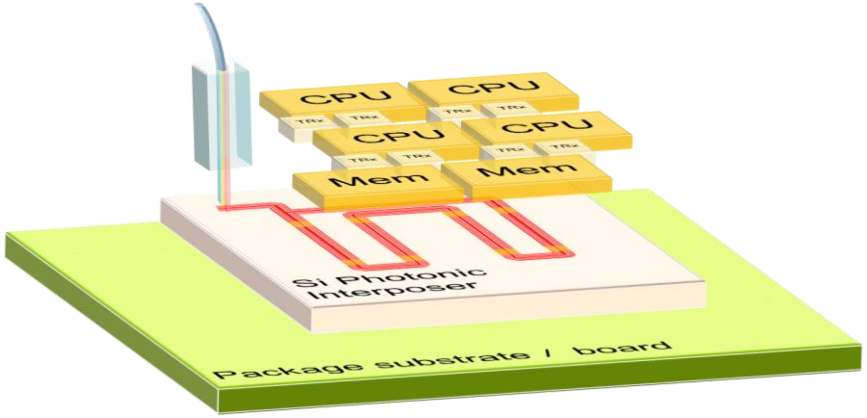


3D-stacked CMOS / SiPho for short-range optical communication

- 10Gbps transceiver chip presented at ISSCC'18
- Wavelength locking achieved in 120µs
- Stability maintained under 900Hz environmental fluctuation
- Total CMOS footprint 0.01mm^2 / microring ➔ up to 1Tbps/mm^2

Perspective

- all-to-all optical network on chip architecture on interposer
  for high-density optical communication in high-performance computing systems



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