Karlsruhe Institute of Technology

Institute for Data Processing and Electronics

Silicon Photonic Components on the COTTONTAIL Chip

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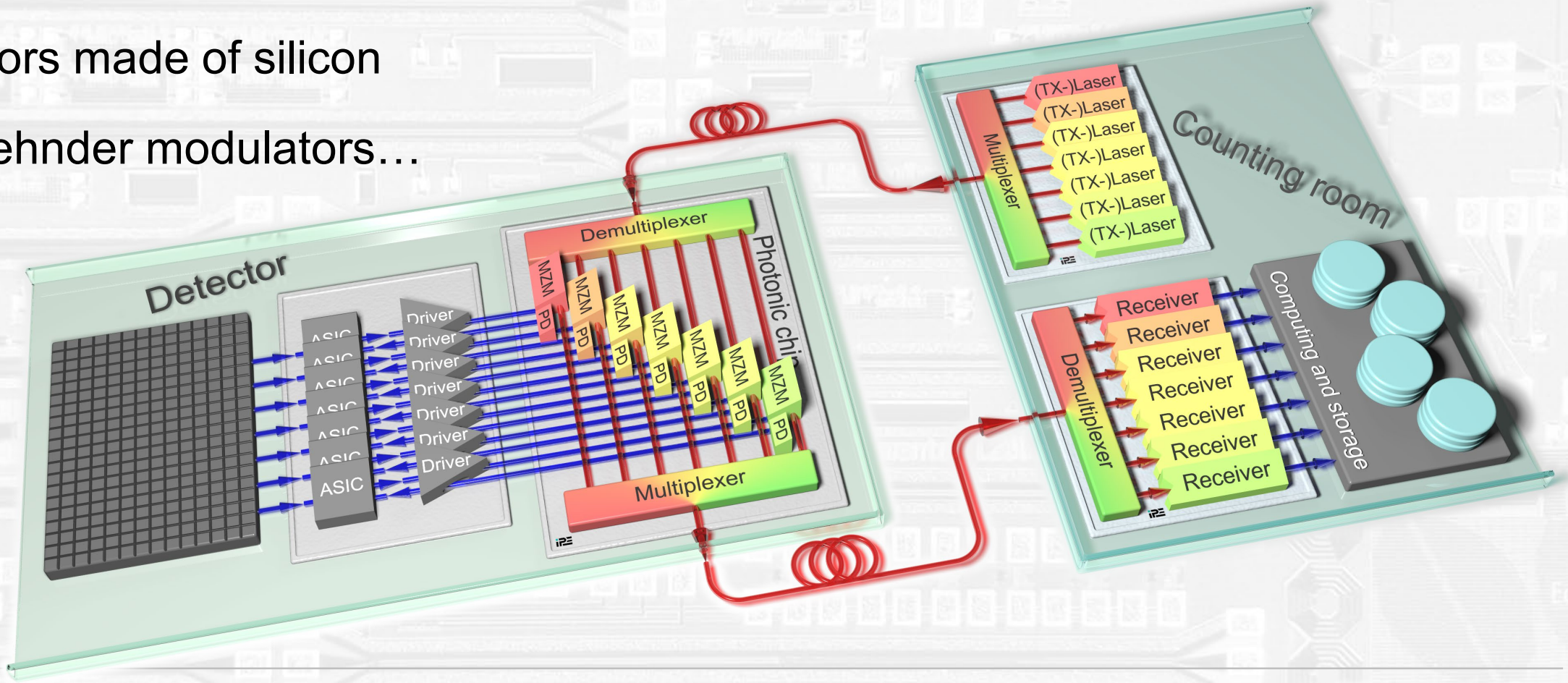
Future optical links

- Wavelength division multiplexing (WDM) for higher bandwidth per fiber
- Electrooptic modulators with external lasers
- Modulators made of silicon
- Mach-Zehnder modulators…



Future optical links

- Wavelength division multiplexing (WDM) for higher bandwidth per fiber
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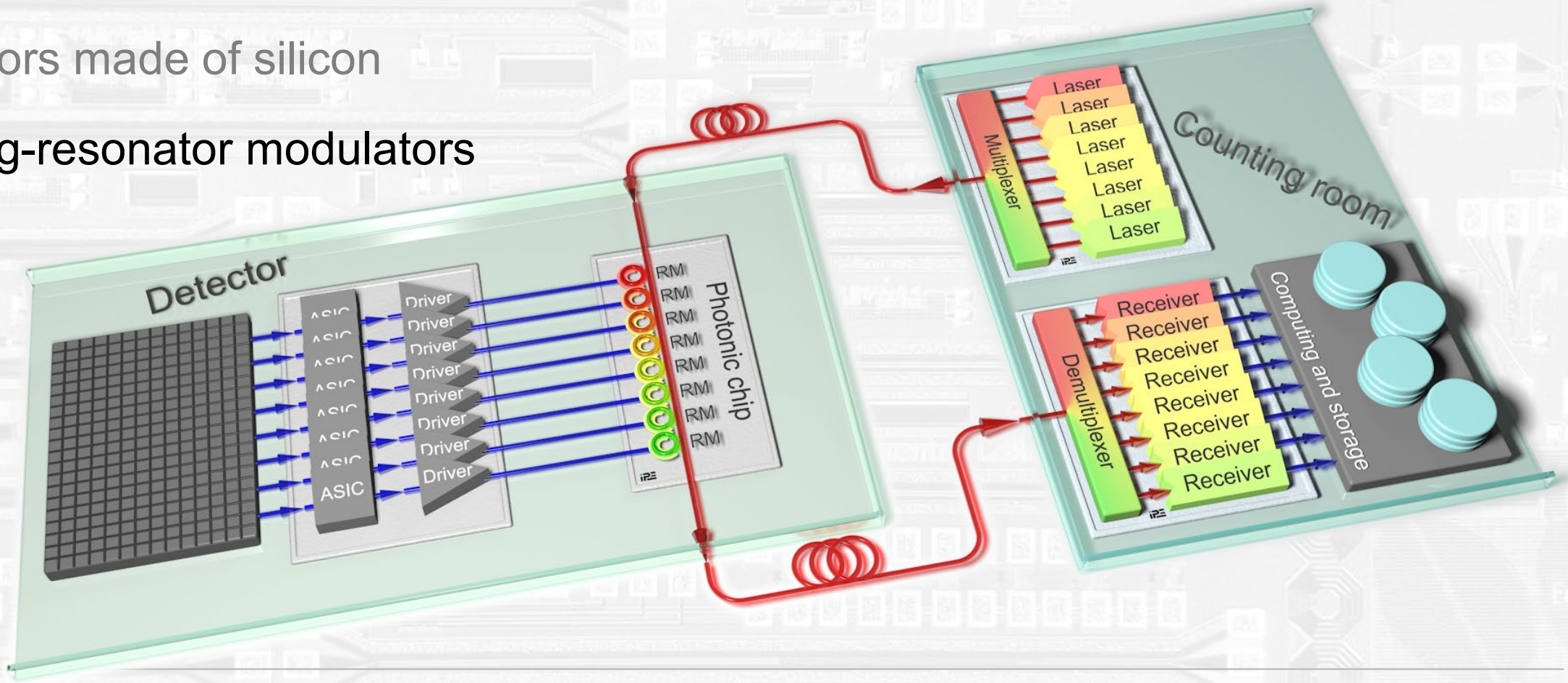
- Modulators made of silicon
- … or ring-resonator modulators

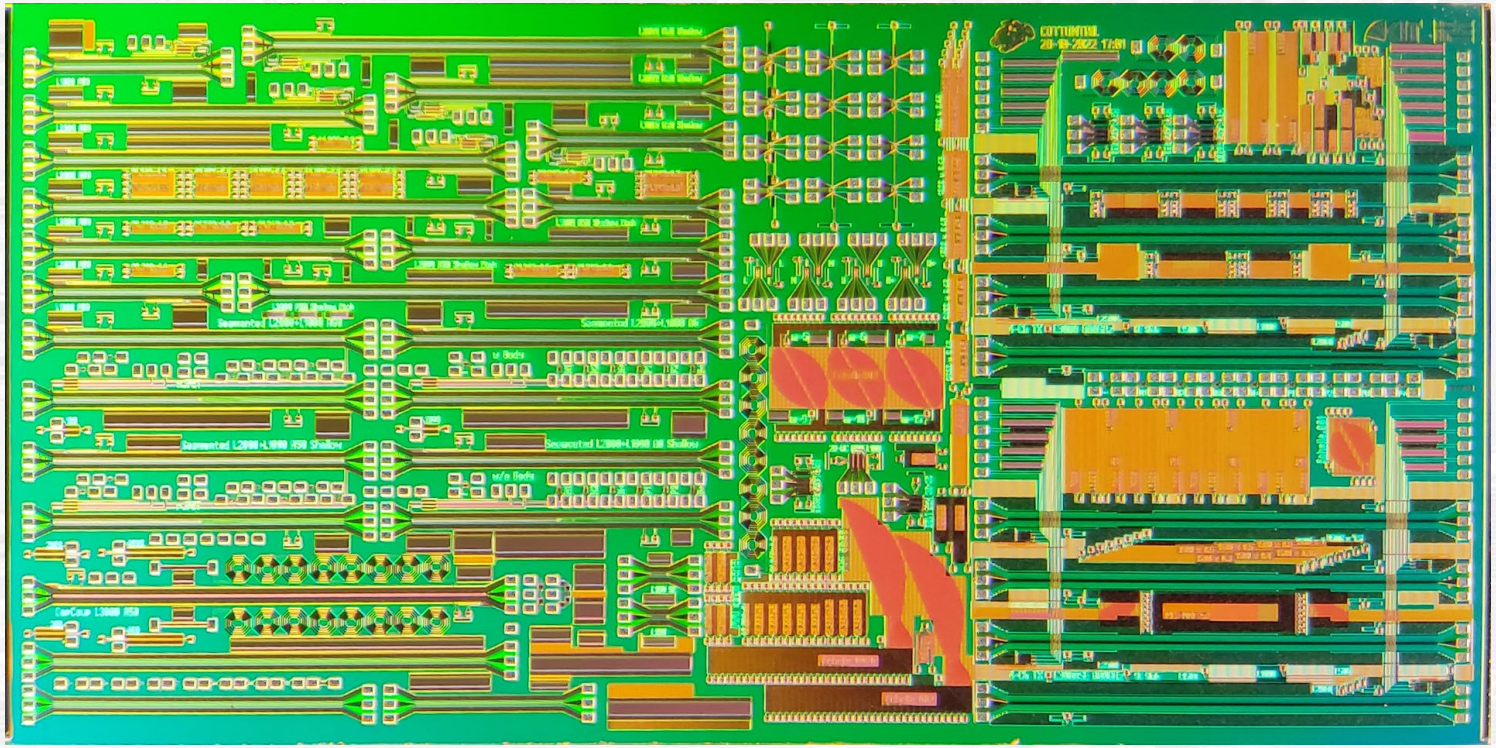


New test chip: COTTONTAIL

Cottontail
Chip for detector instrumentation with wavelength division multiplex

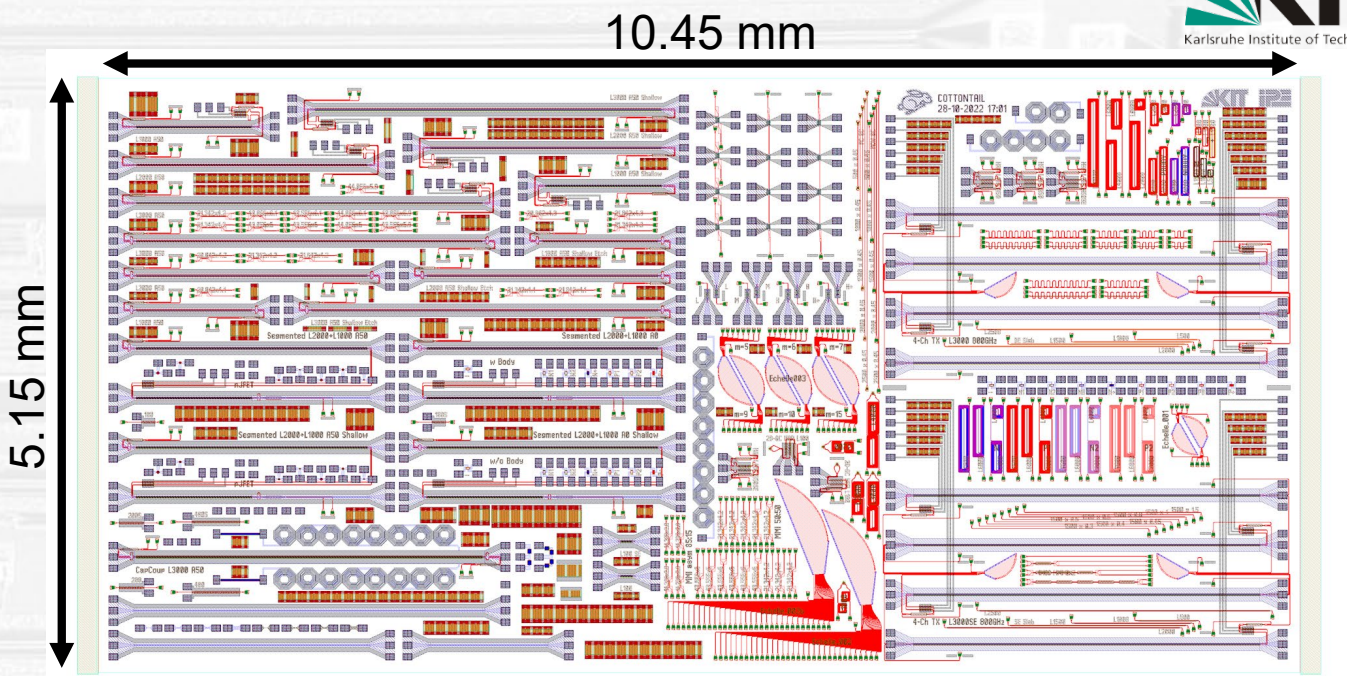
Acronym found with the help of some acronym generator

- IMEC ISIPP50G process
- C-band (1550 nm ± 30 nm)
- Several different modulator types
  - Mach-Zehnder
  - Ring resonator
- Photodiodes
- Optical (de-)multiplexers: planar concave gratings



The COTTONTAIL Chip

- Size: 10.45 x 5.15 mm²
- MZM: standard, radiation hardened, segmented, integrated biasing, thermal, 4-channel WDM
- RM: standard, 4-channel WDM
- Thermal: standard, radiation hardened
- Photodiodes
- Planar concave gratings (Echelle gratings): 4-ch, 8-ch, 32-ch



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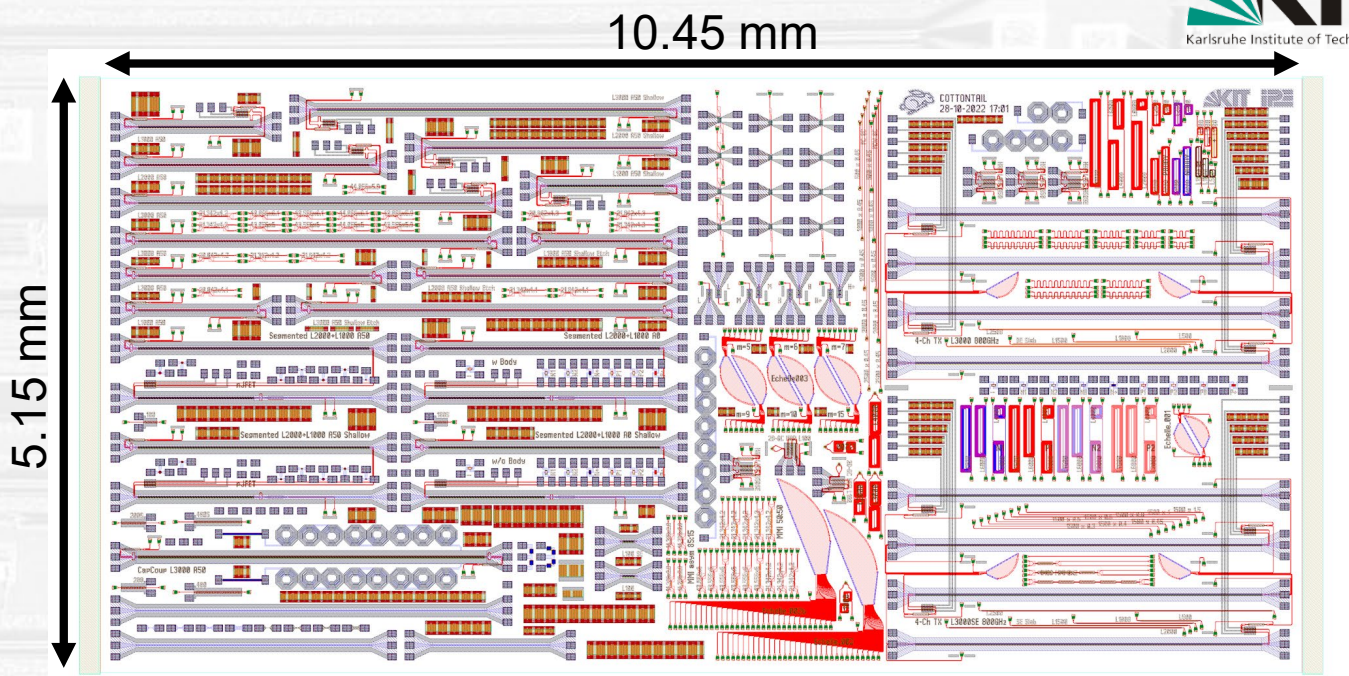

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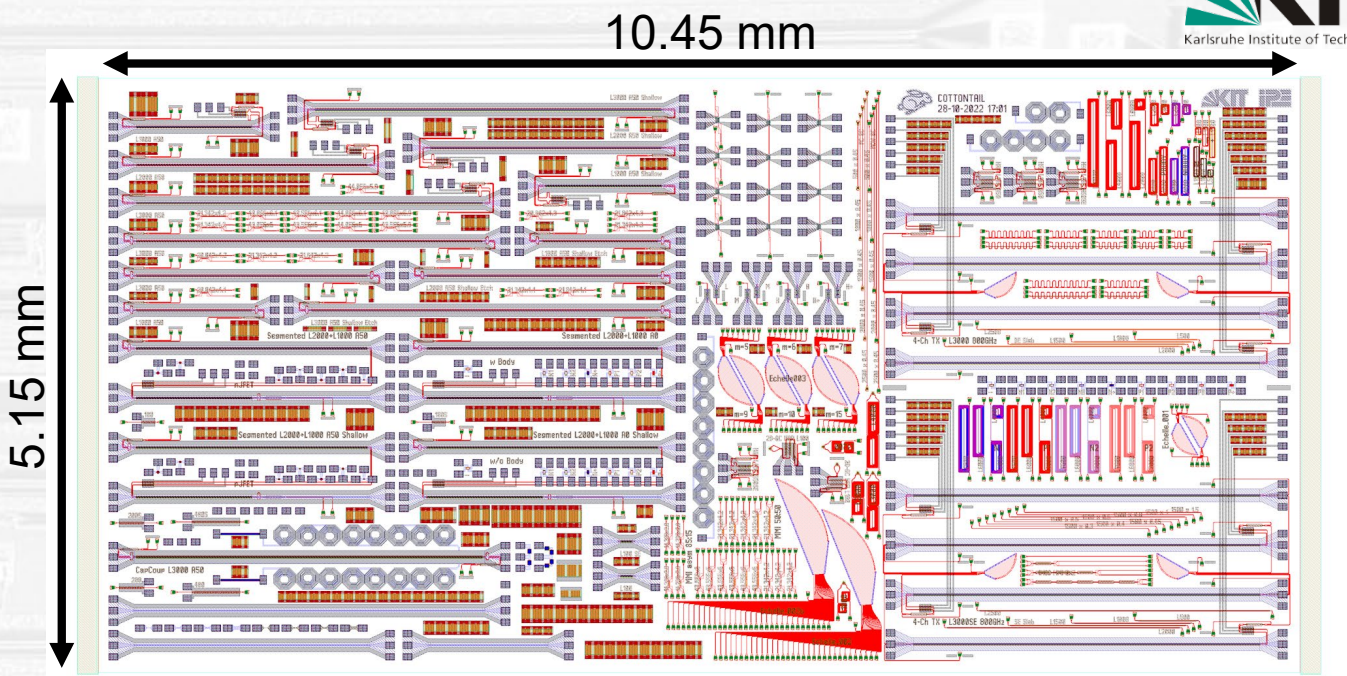

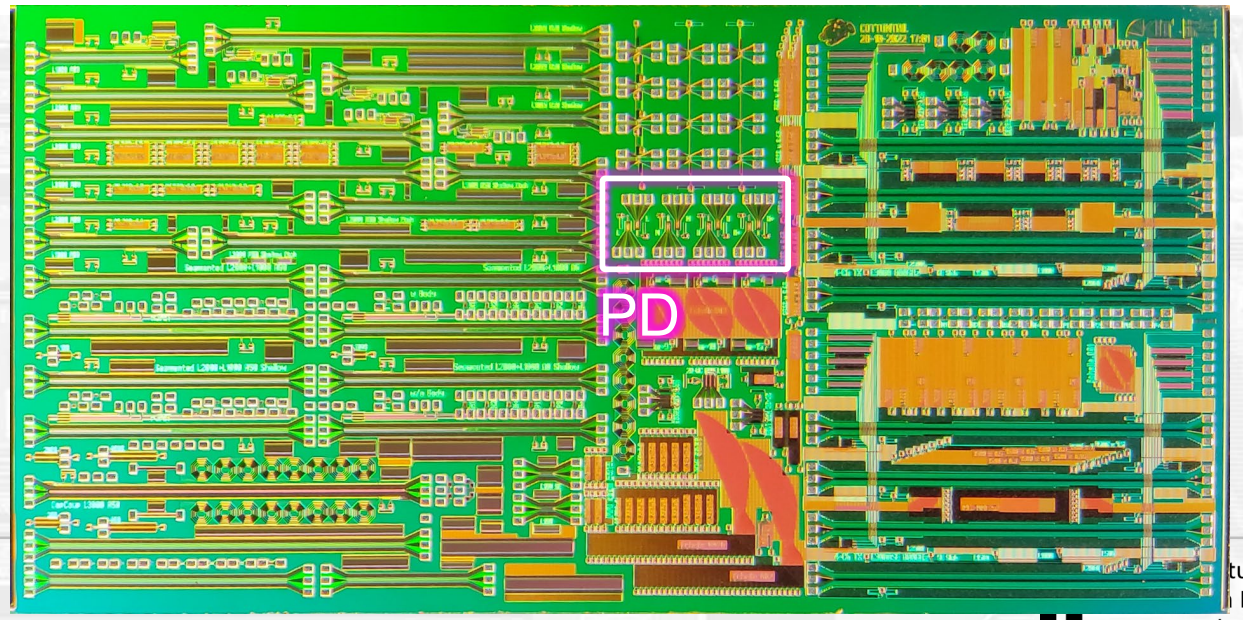

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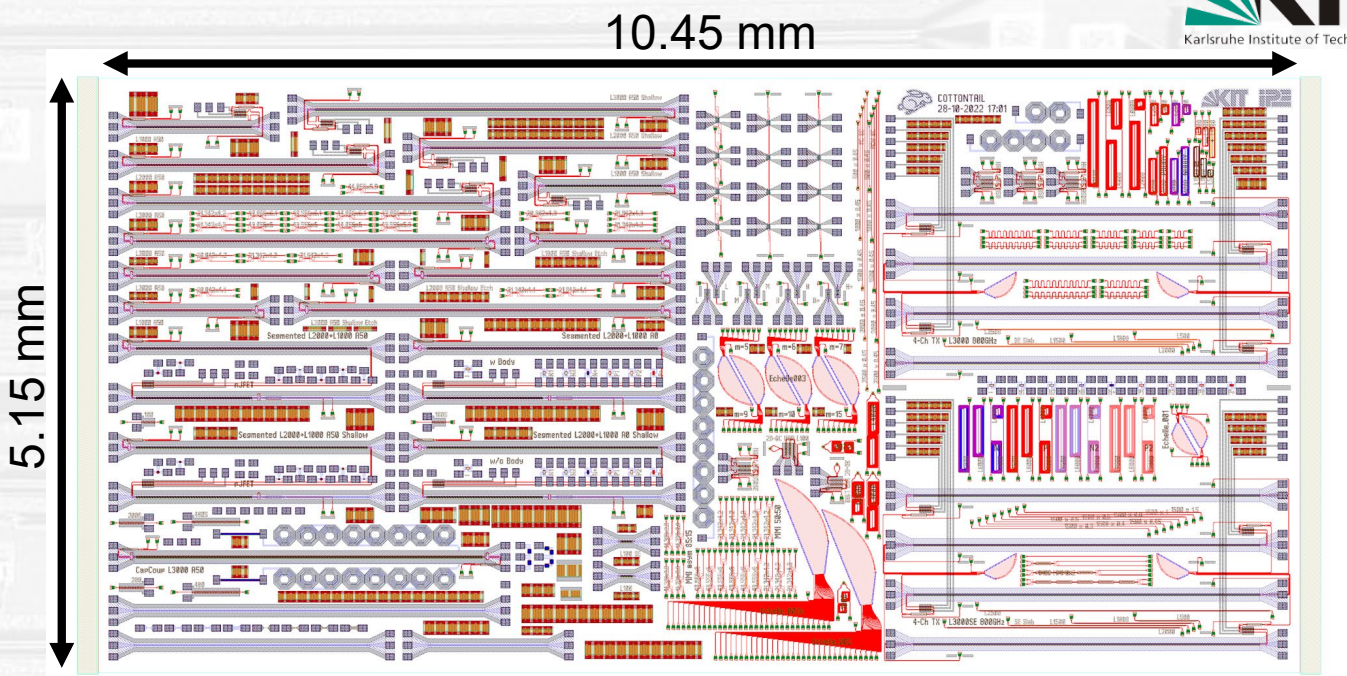
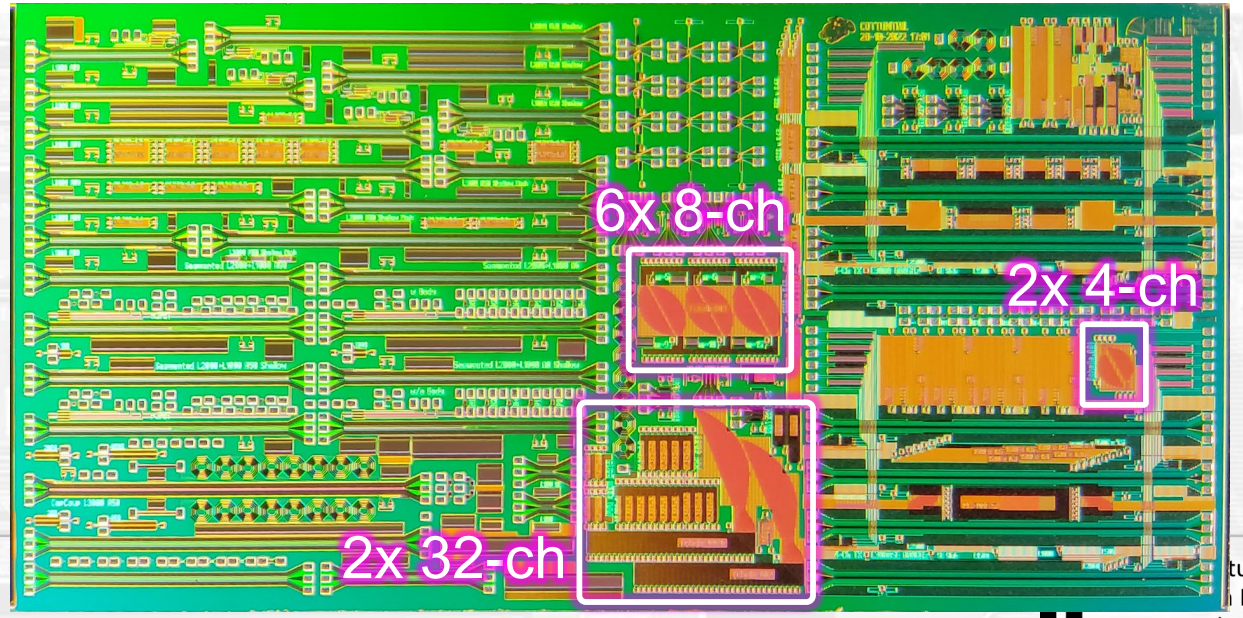
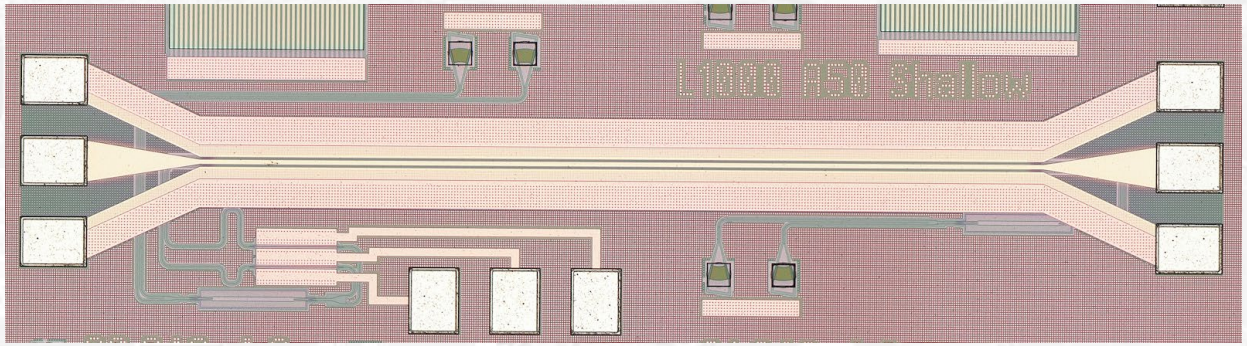


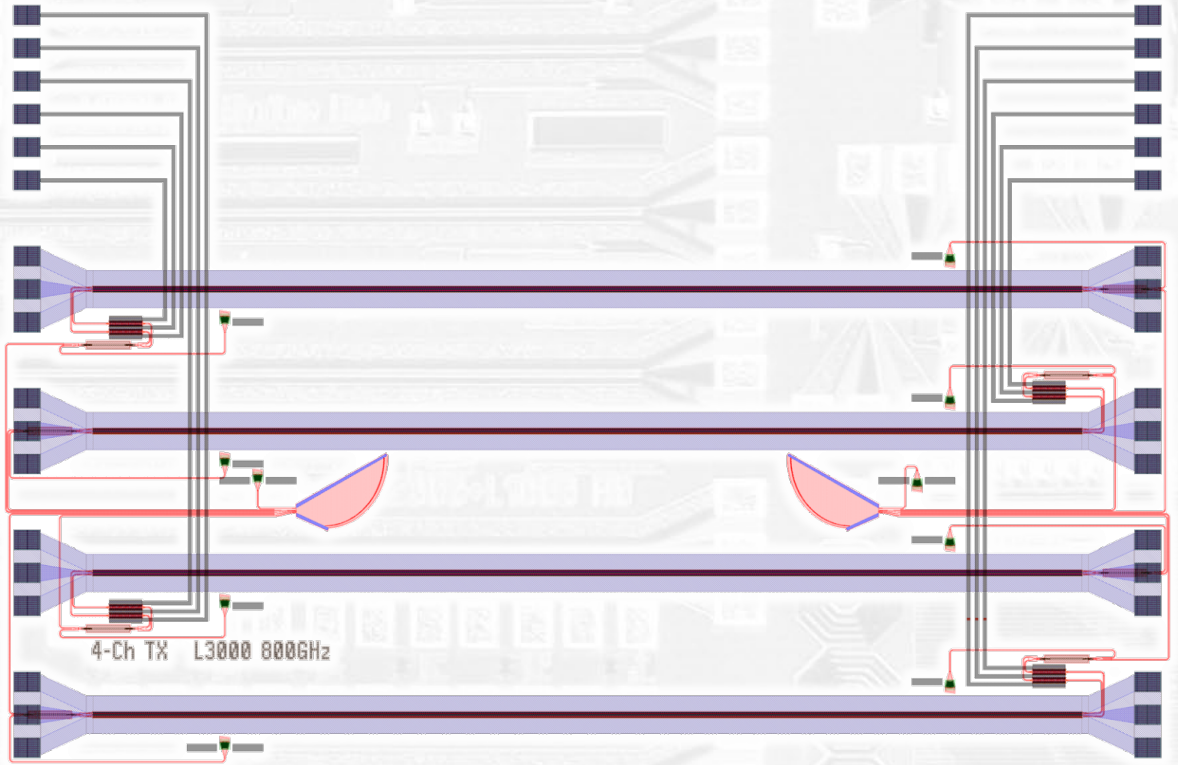


Mach-Zehnder Modulators

- pn-phase shifters in gaps of coplanar waveguide: single ended driving
- Additional thermal phase shifters for working point control
- Standard and radiation hardened versions



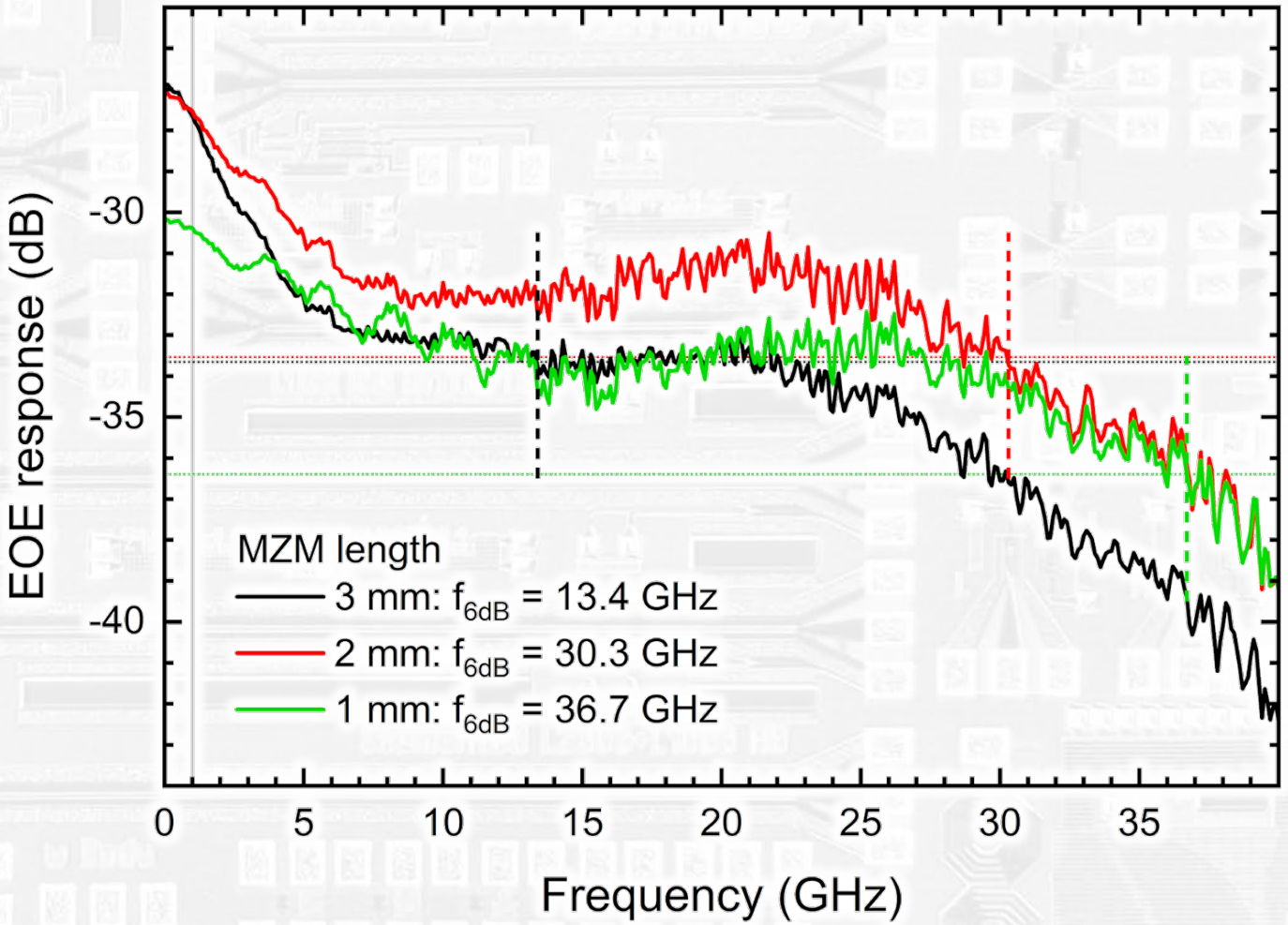
- Single modulators with different lengths (1 mm, 2 mm, 3 mm)
- 4-channel WDM-system (3 mm)
- Segmented modulators for optical PAM4 modulation and 2-bit parallel el. Input
- MZM with integrated biasing circuit



Mach-Zehnder Modulators

Standard MZM:

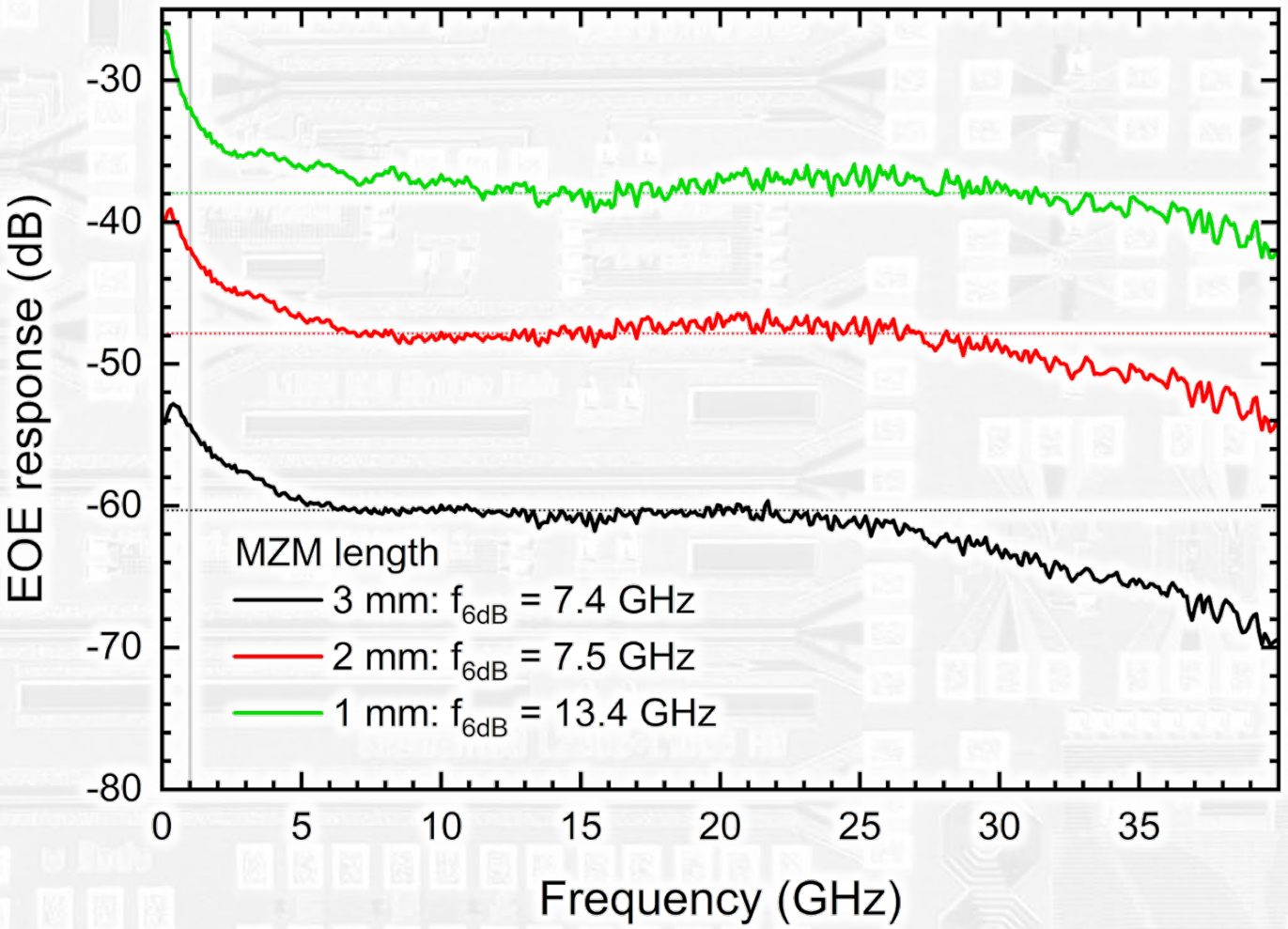
- Shorter MZM significantly faster
- f_{6dB}: 13.4 GHz, 30.3 GHz, 36.7 GHz
  (optical 3dB-cut-off frequency is 6dB-cut-off-frequency in Electrical-Optical-Electrical response)
- Reason for steep slope at lower frequencies unknown



Mach-Zehnder Modulators

Radiation hard versions:

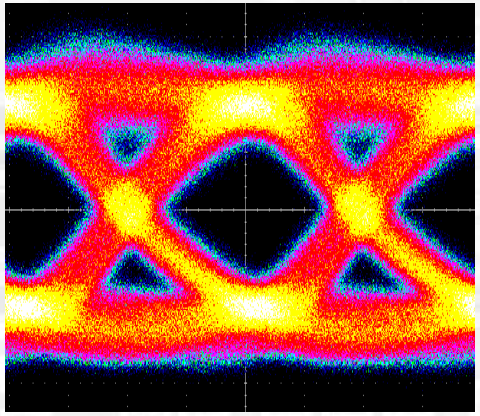
- Much slower
  f_{6dB}: 7.4 GHz, 7.5 GHz, 13.4 GHz
- Slope more pronounced
- Design fault causes high absorption



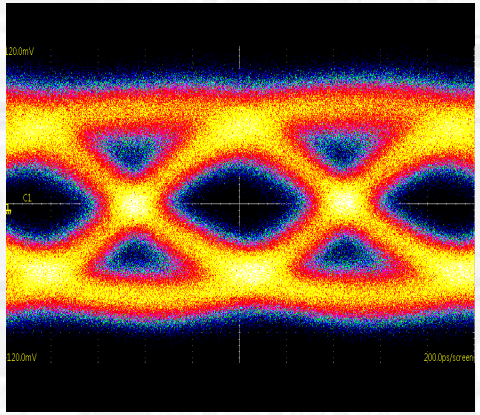
Mach-Zehnder Modulators

3 mm long MZM, U_{mod} = 1.1 V_{pp}:

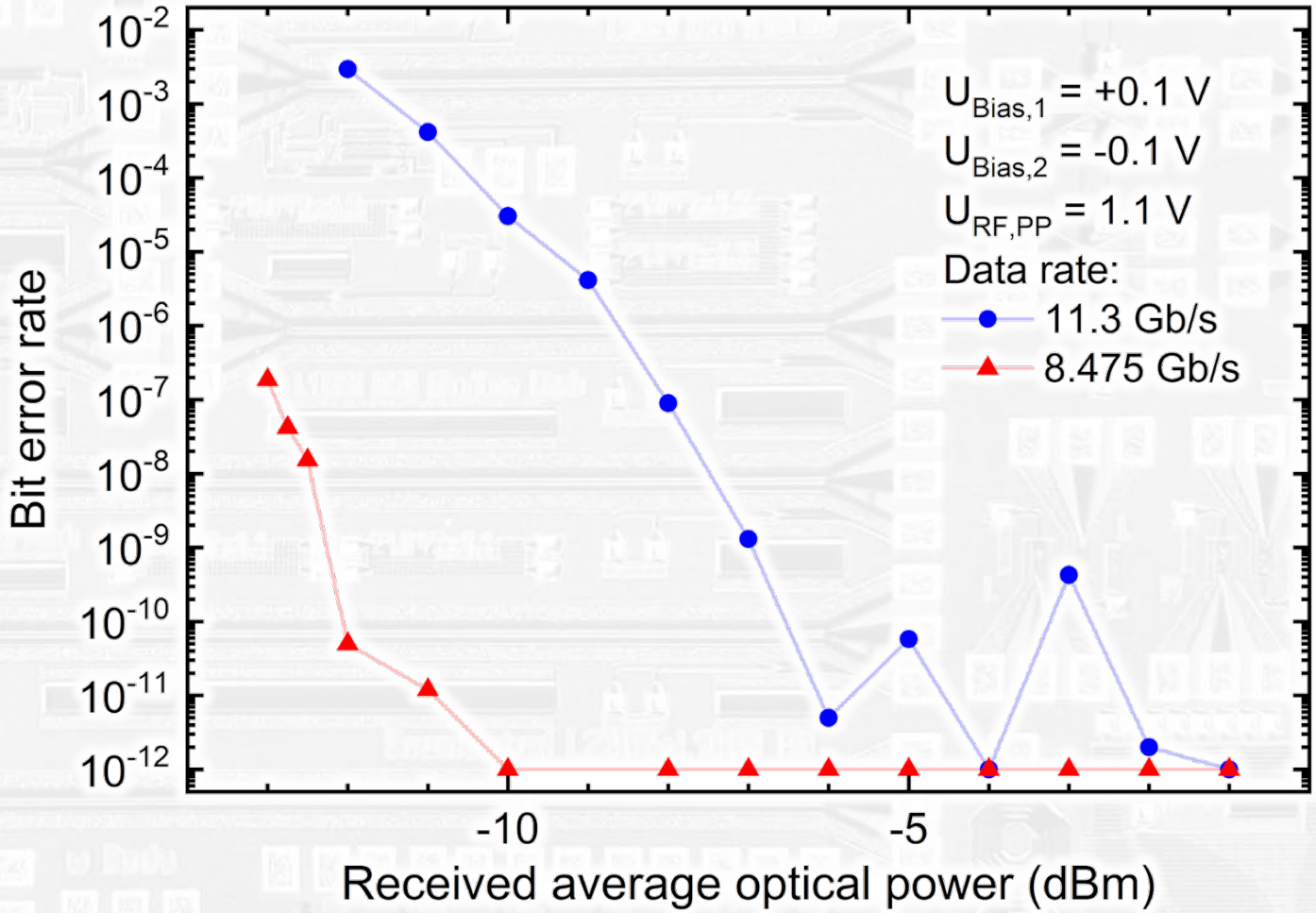
- 8.475 Gb/s: error free down to -10 dBm average optical power at detector
- 11.3 Gb/s: hardly error free, even at high powers
- Driving voltage too low



8.475 Gb/s

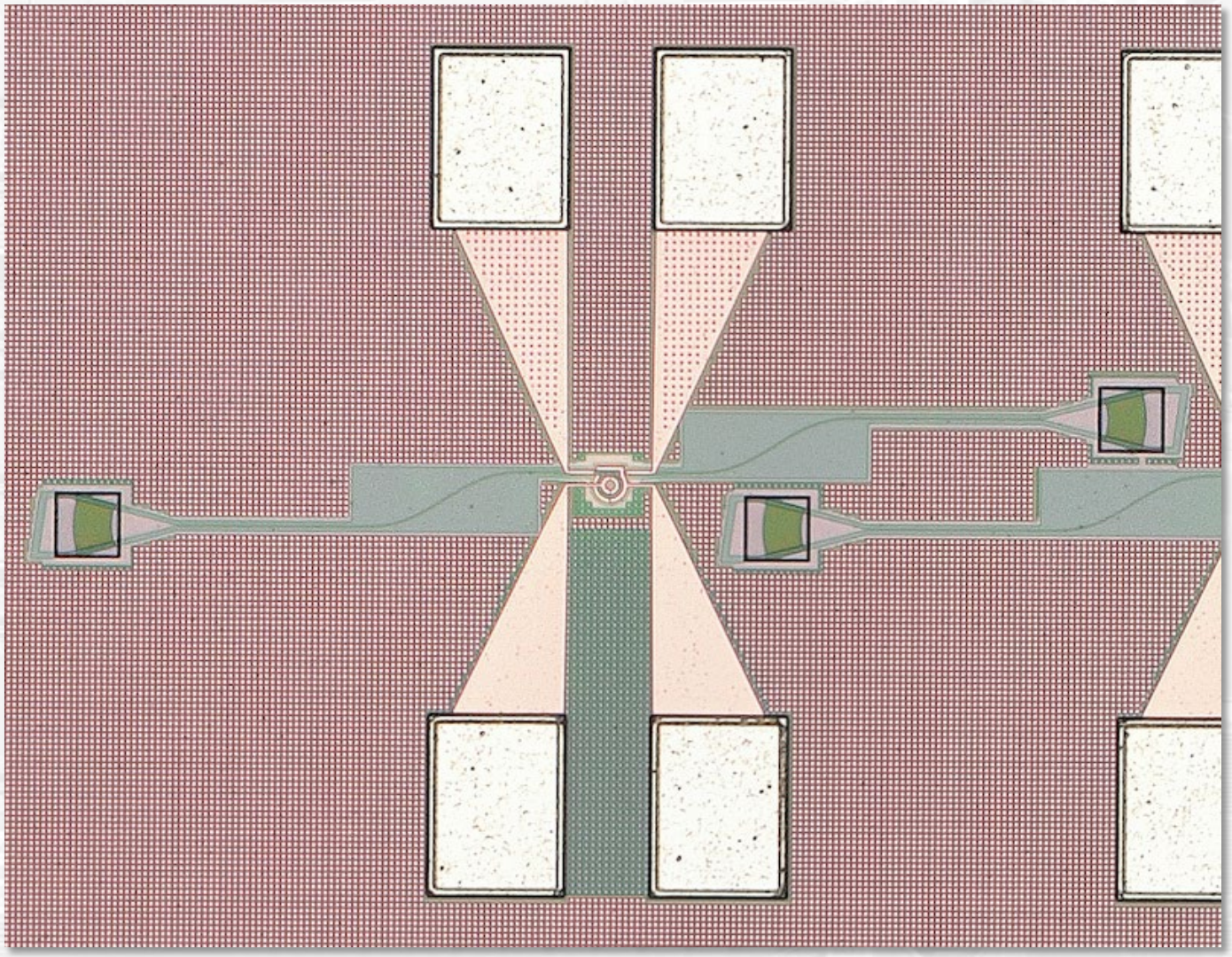


11.3 Gb/s

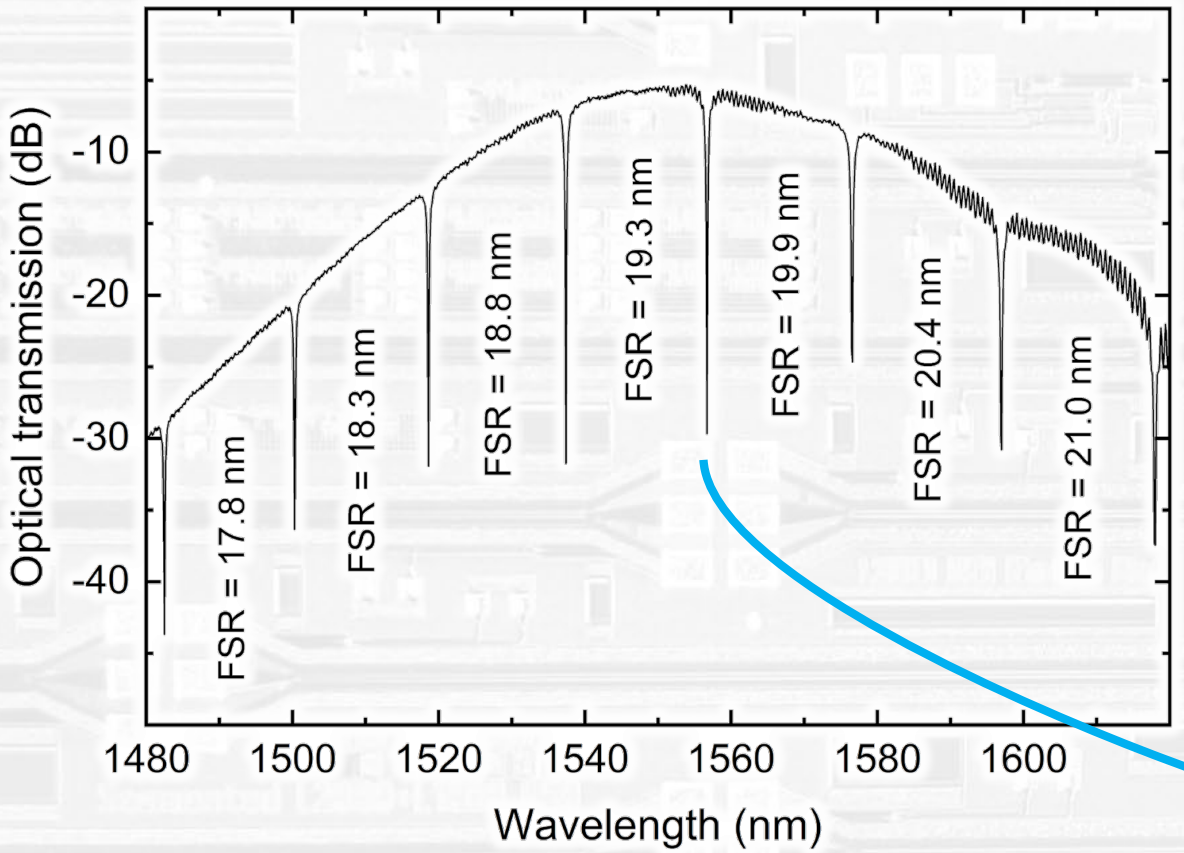


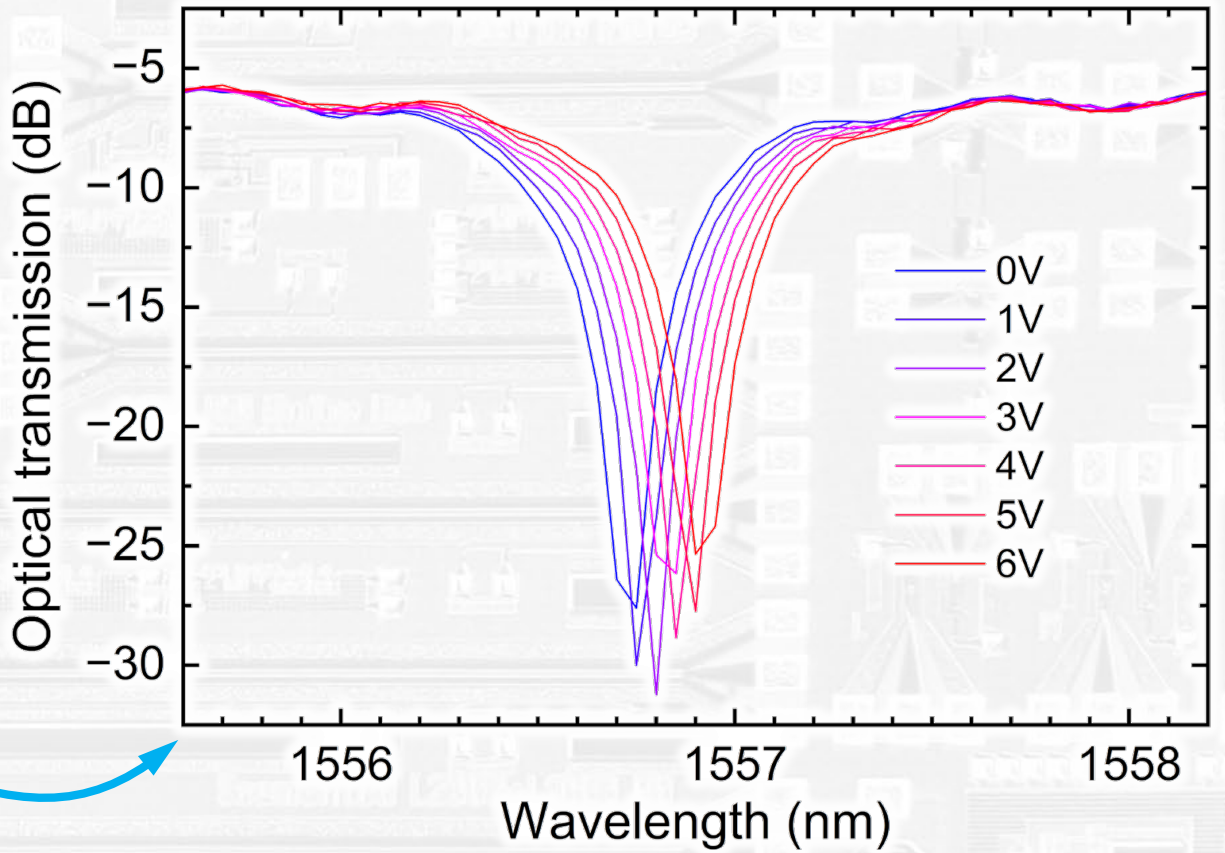
Ring Modulators

- Stock modulator from IMEC PDK
- Bandwidth >50 GHz
- Heater for working point control
- Electrical and optical contacts added



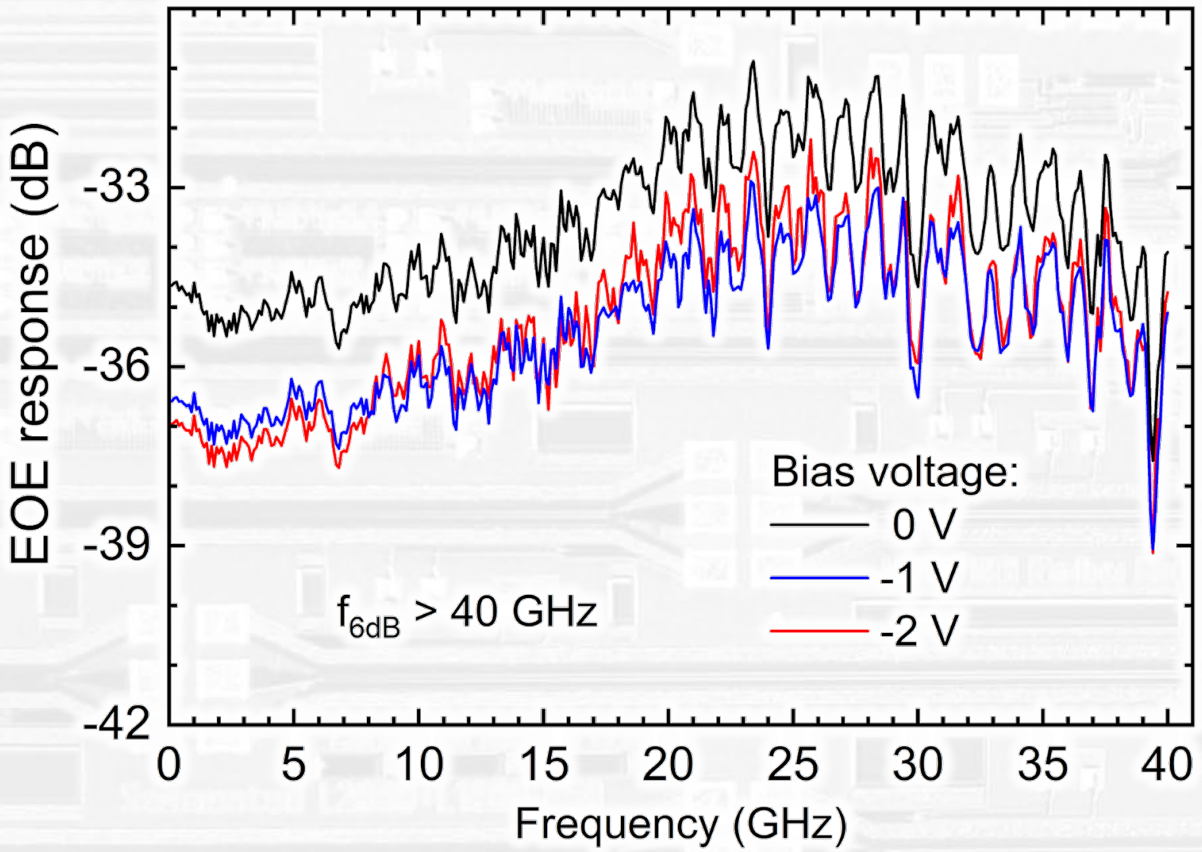
Ring Modulators

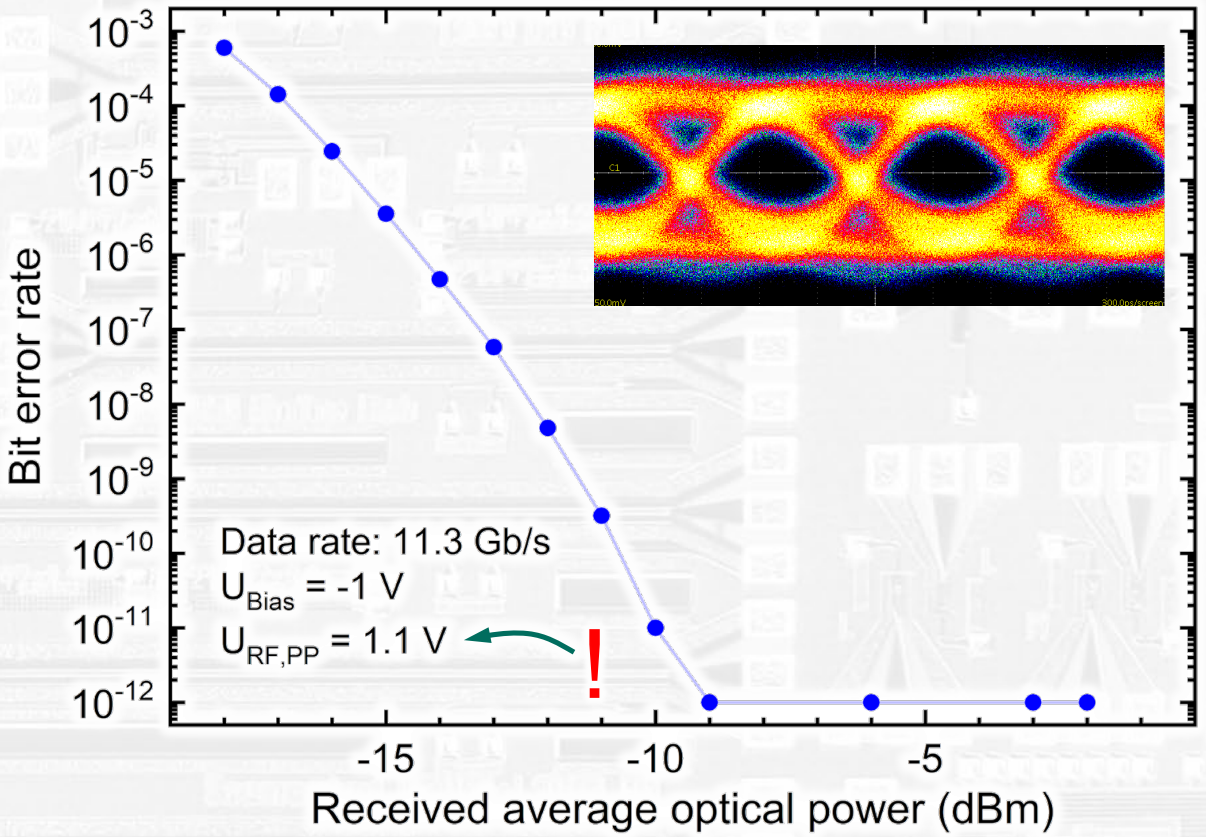




- Free spectral range: 18 – 21 nm
- Notch wavelength shift: ≈ 33 pm/V

Ring Modulators

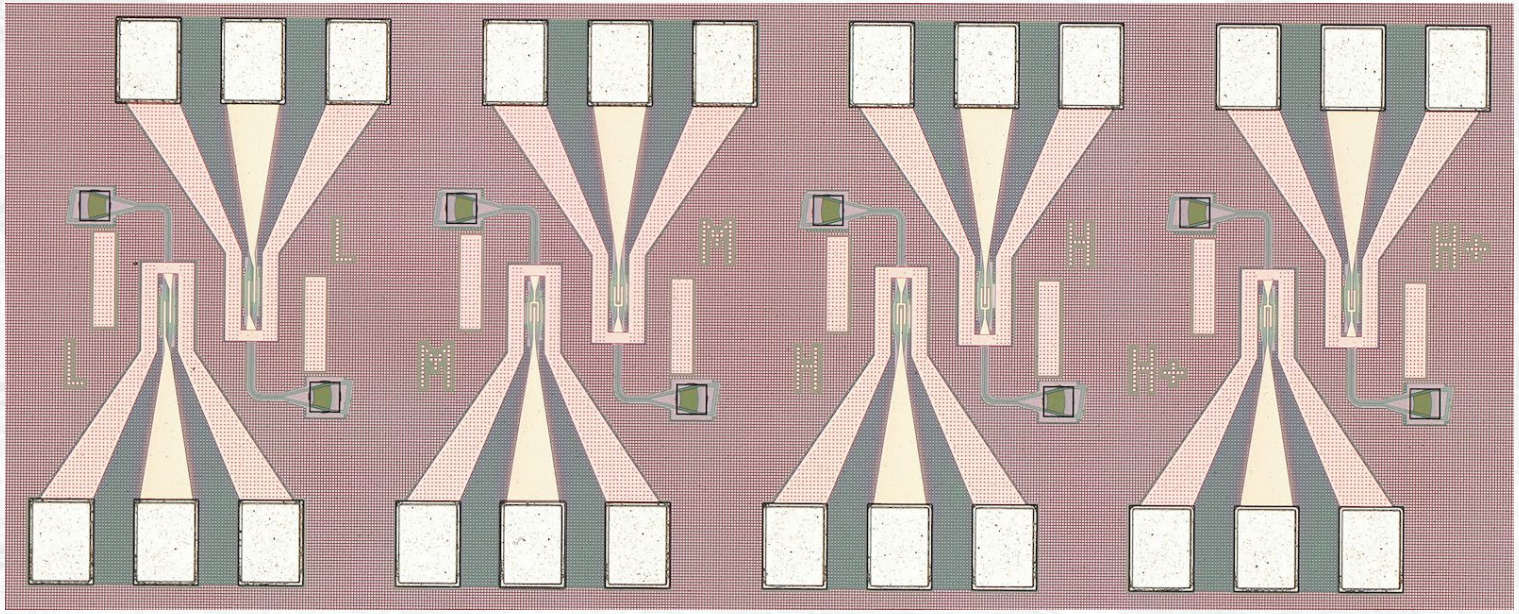




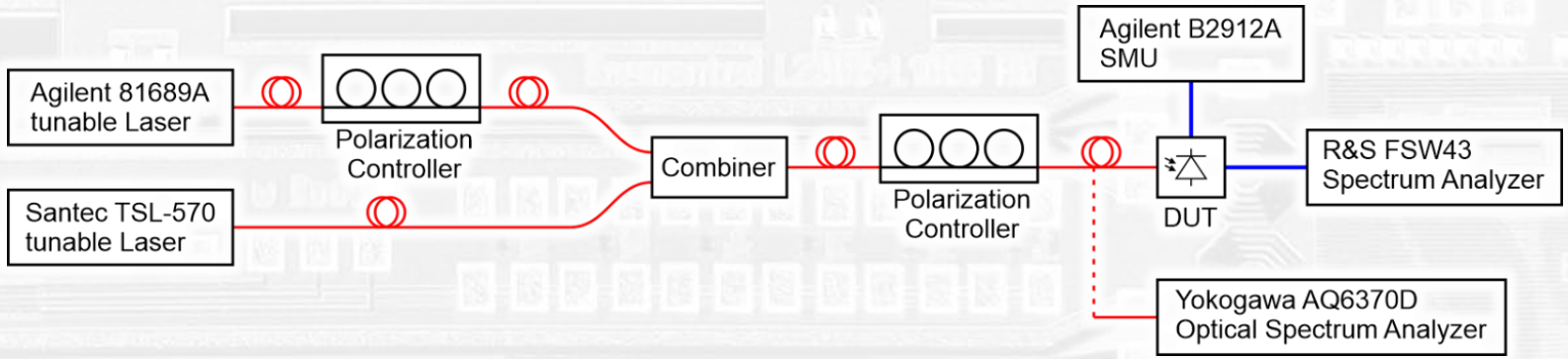
- 6dB cut-off frequency: > 40 GHz (beyond measurement capabilities)
- 11.3 Gb/s, U_{mod} = 1.1 V_{pp}: error free down to -9 dBm average optical power at detector

Photodiodes

- Germanium based photodiodes
- 4 different types:
  - Lateral PIN: monitoring
  - Vertical PIN:
    - High efficiency
    - High speed
    - Ultra high speed



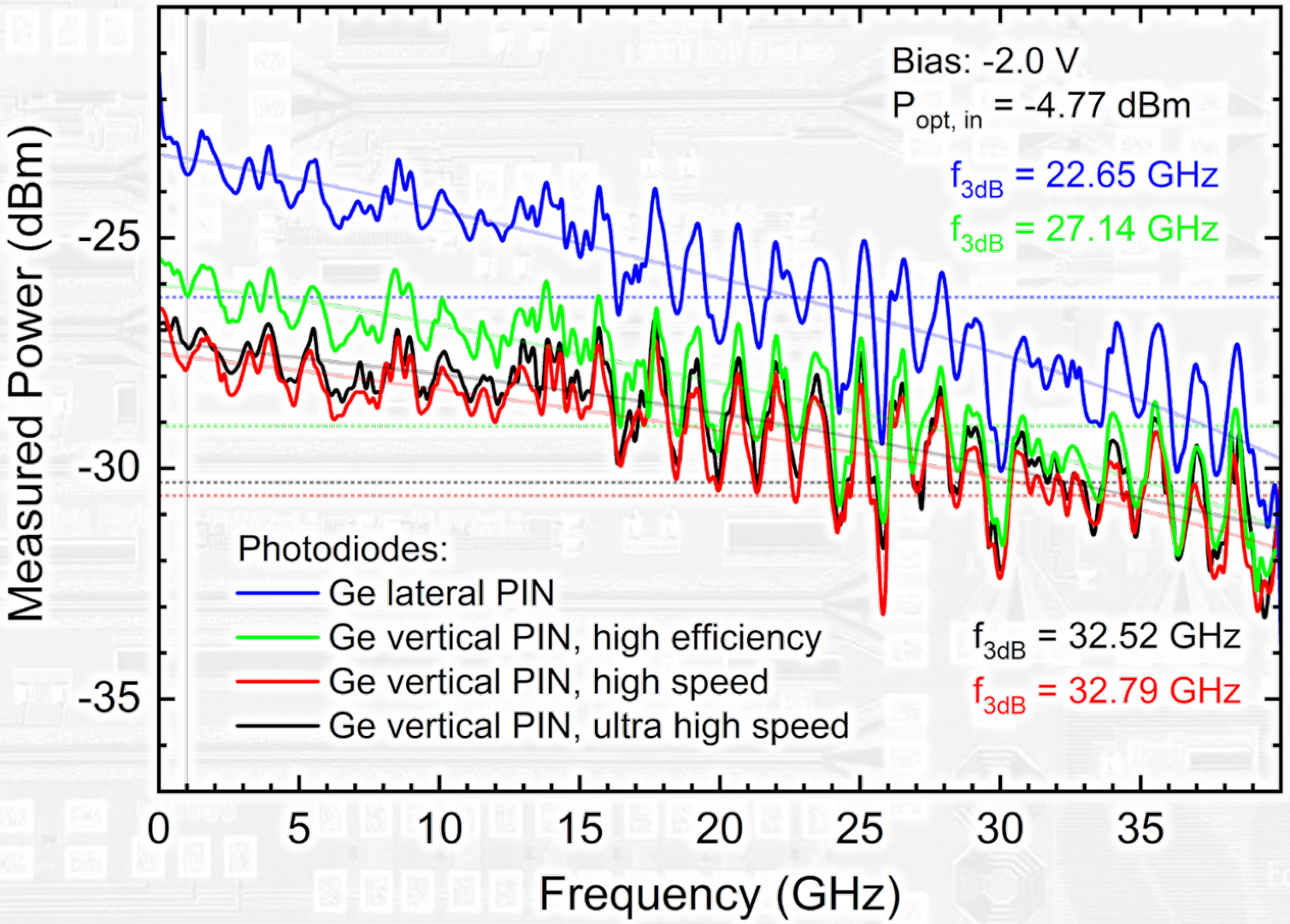
- Characterization using optical RF generation:
  - Mix two lasers with slightly different wavelengths
  - Measure beat signal



Photodiodes

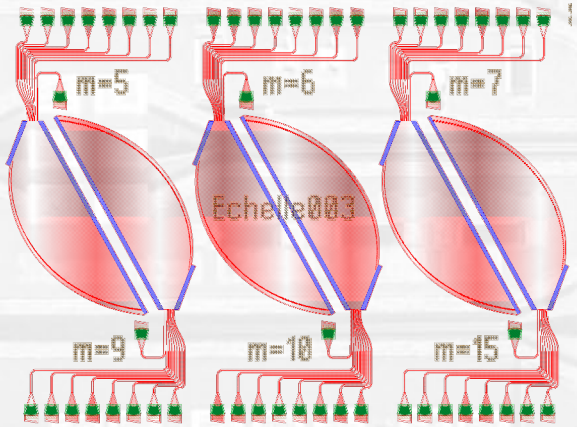
- Lateral PIN: f_{3dB} = 22.65 GHz
- Vertical PIN, high efficiency: f_{3dB} = 27.14 GHz
- Vertical PIN, high speed: f_{3dB} = 32.79 GHz
- Vertical PIN, ultra high speed: f_{3dB} = 32.52 GHz

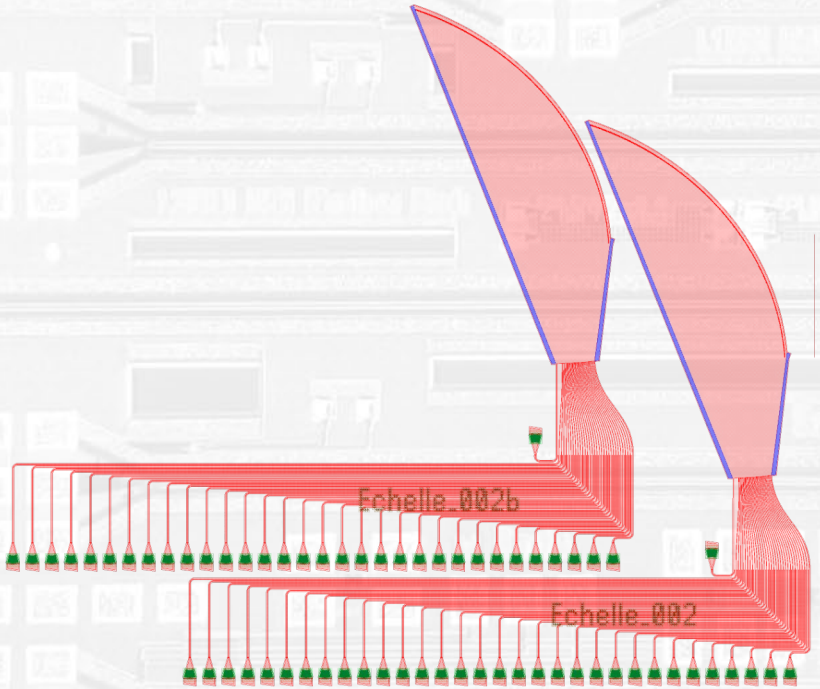
- All cut-off frequencies closer together than expected
- Fastest diodes slower than expected (>50 GHz), anybody able to check results?

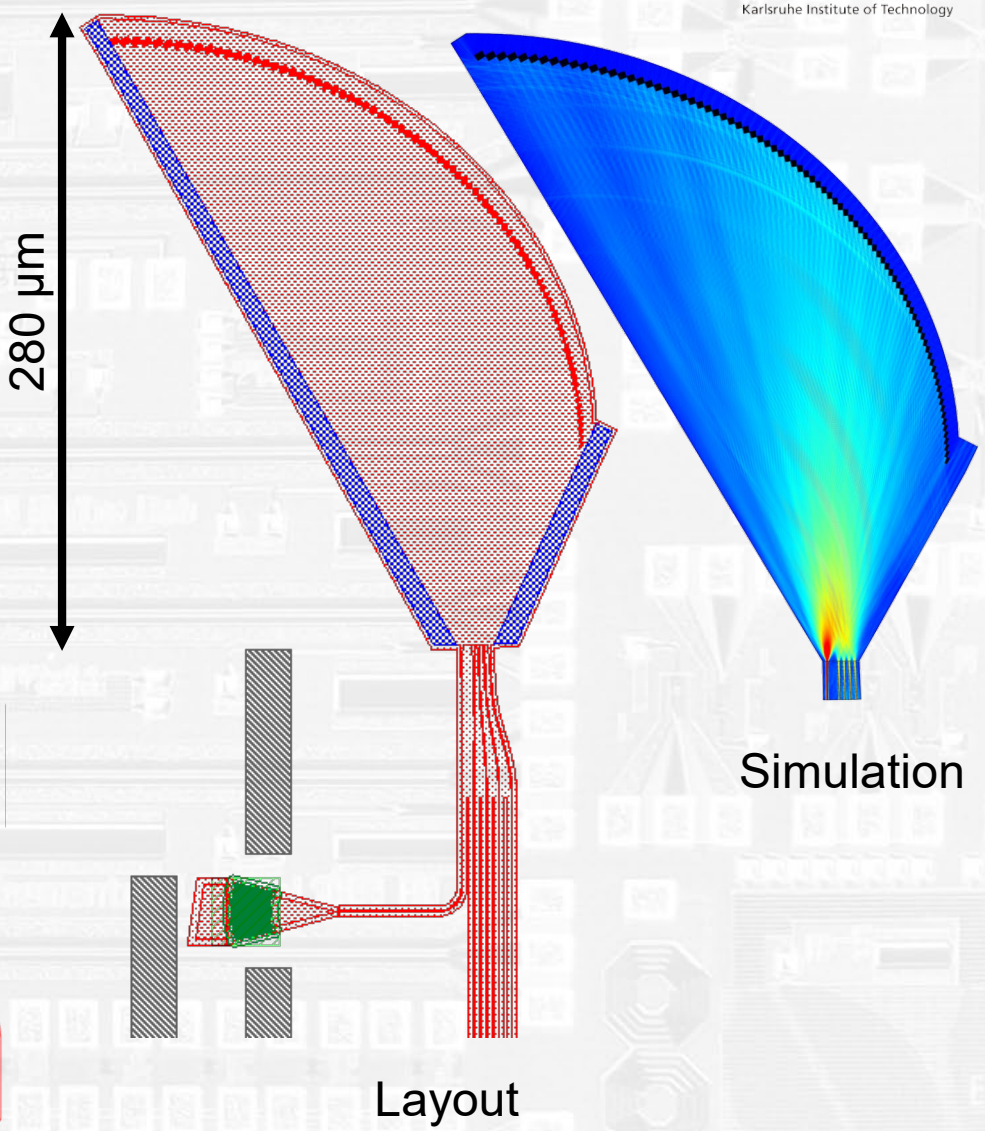


Planar Concave Gratings

- Different Types:
  - 4-channel (800 GHz channel spacing) for current WDM-systems
  - 8-channel (400 GHz channel spacing) and 32-channel (200 GHz channel spacing) for future WDM-systems





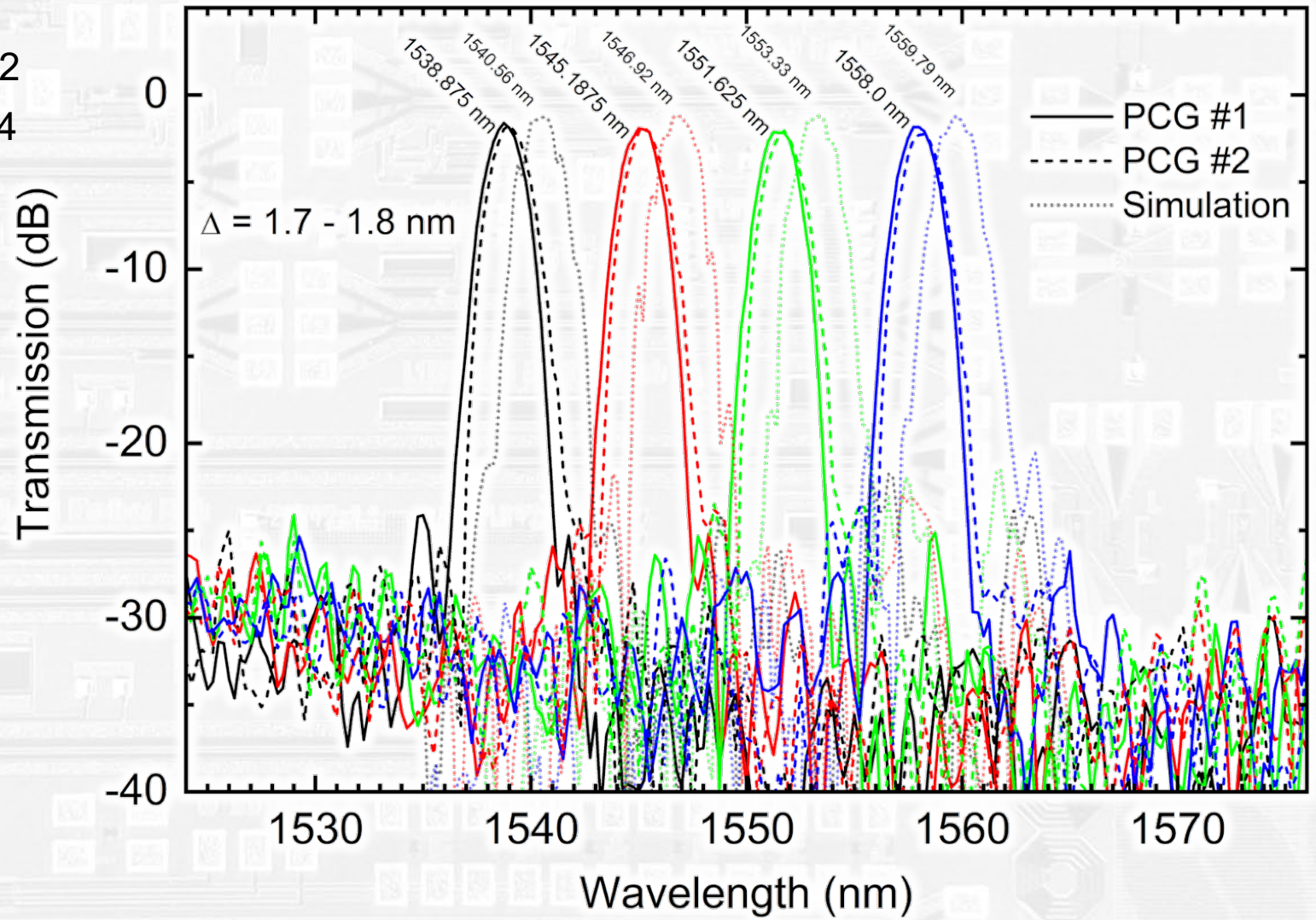


Planar Concave Gratings

- 1.7 – 1.8 nm shift
  - Designed: Ch 46, Ch 38, Ch 30, Ch 22
  - Received: Ch 48, Ch 40, Ch 32, Ch 24
- Shift by 2 channels (approx. 200 GHz)
- 1.6 – 2.3 dB loss
- <-25 dB crosstalk

Simulations with different silicon thicknesses to explain shift:

- Design thickness: 211.0 nm
- Fitting thickness: 209.9 nm
- 1.1 nm thickness variation well in fabrication tolerance



Summary

- Cottontail chip shows very promising results
- Standard MZM fast and efficient (f_{6dB}: 13.4 GHz, 30.3 GHz, 36.7 GHz)
- Radiation hard versions suffer from design flaw
- Ring modulators very fast and efficient
- Photodiodes fast enough for planned transmission speeds, some optimization required
  - Basis for ring modulators with drop port for monitoring, working-point control, and data reception
- PCG very efficient, but shifted wavelength; higher accuracy or tunability required


Thank you!
Q&A
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