PIC Report – FALAPHEL Meeting

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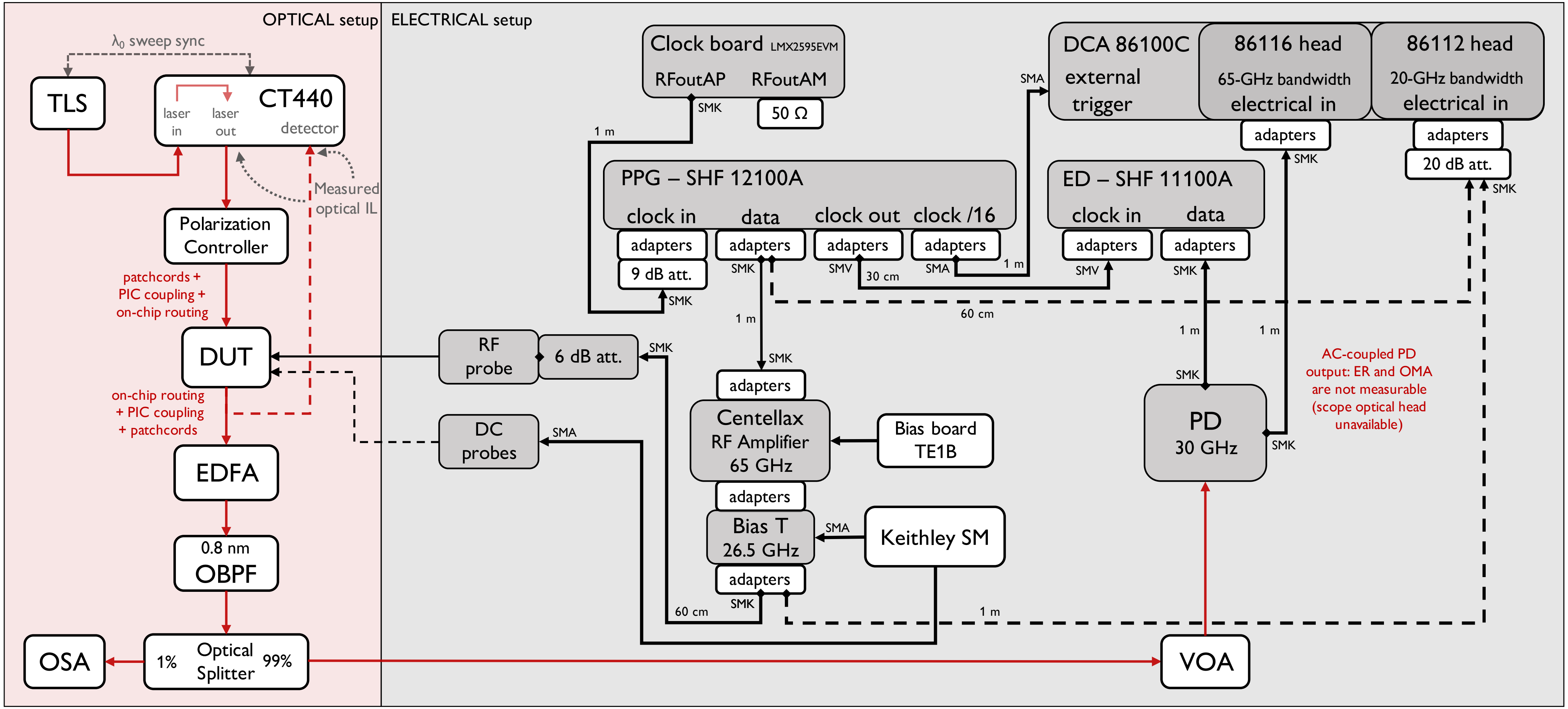
Pisa, 08 June 2022

Outline

- Measurements
  - Modulators
  - Test structures
  - PCB traces
- Discussion
  - PIC-EIC integration
  - Irradiation campaigns
  - New PIC submission
  - Interposer

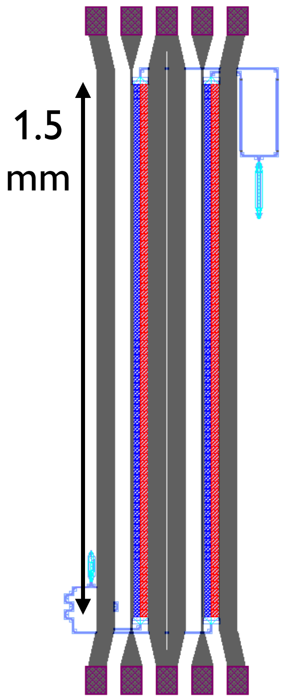
Imec PIC – Overview

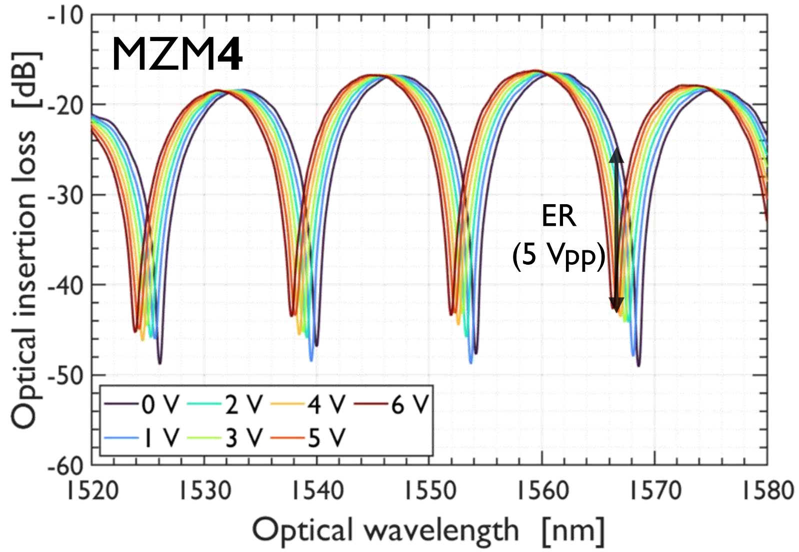
Electro-Optic Characterization Setup @ SSSA

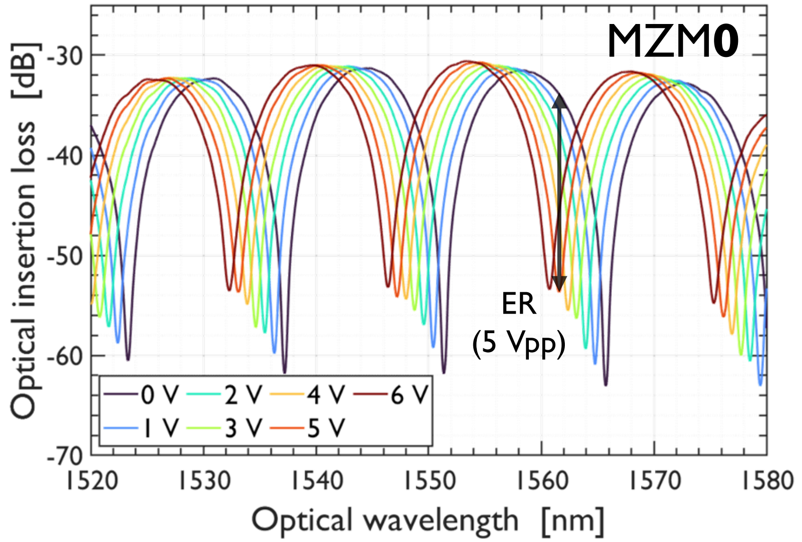


Mach-Zehnder Modulators (MZMs)

- Mach-Zehnder modulators (**MZMs**): phase modulation converted in amplitude modulation through interference. Waveguide-embedded depletion-driven PN junctions used as phase shifters
- Device-level radiation-hardening by design (**RHBD**) techniques:
  1. Shallow-etch rib waveguides
  2. Doping concentrations increase
  3. Periodic application of forward-bias
- Shallow-etch 1.5 mm-long MZMs results:
  - MZM**0**: high-doping, $V_\pi L_\pi$ ~ 1.2 V·cm
  - MZM**4**: low-doping, $V_\pi L_\pi$ ~ 2.6 V·cm
  - Insertion loss difference around 14 dB
- RF high-speed characterization not available yet







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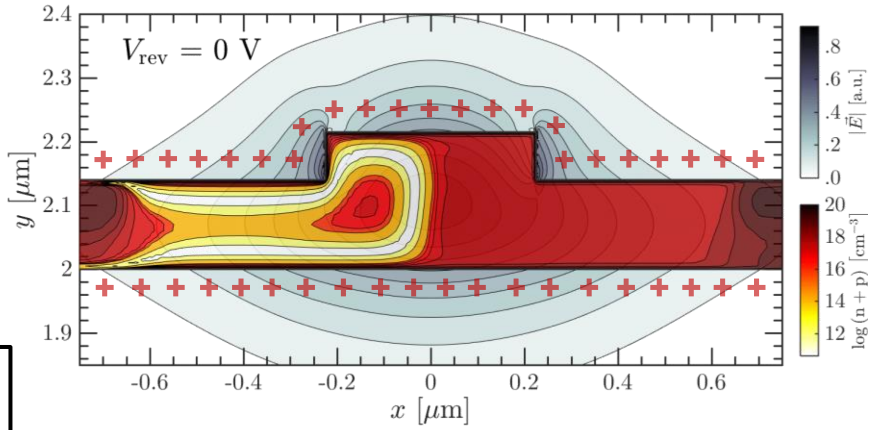
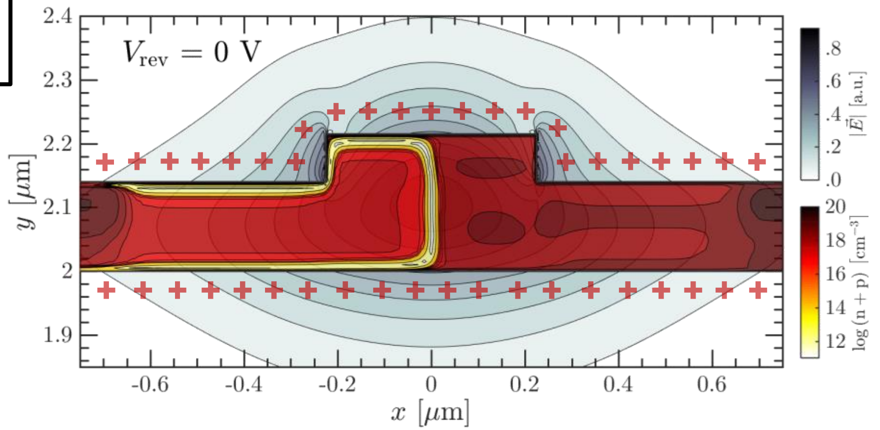
1 MGy TID exposure simulated in Sentaurus™ TCAD

MZM**4**

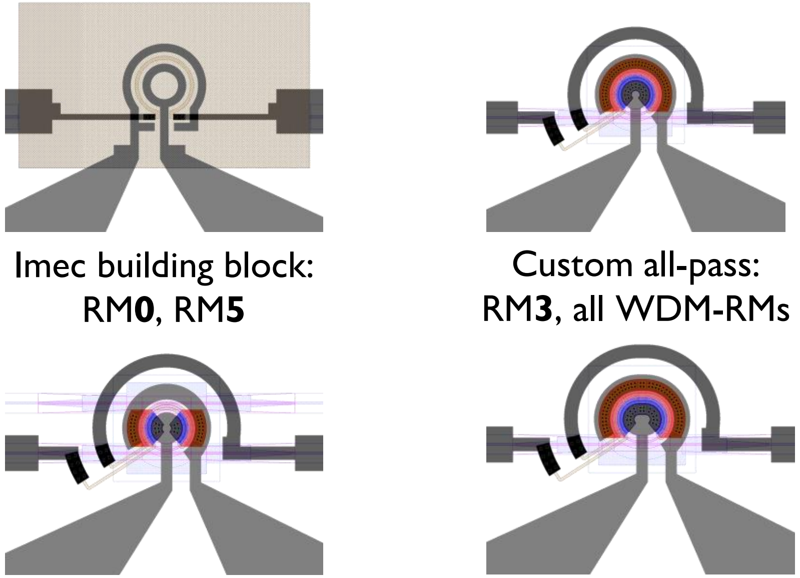


MZM**0**



Ring Modulators (RMs) – BER Test Comparison

- BER testing carried out for bitrates ranging from 10 to 35 Gb/s due to clock source/BER tester limitations: **25 Gb/s** operation achieved for all RMs
- Imec's device outperforms the custom ones: wrong estimation of intra-RM losses during design

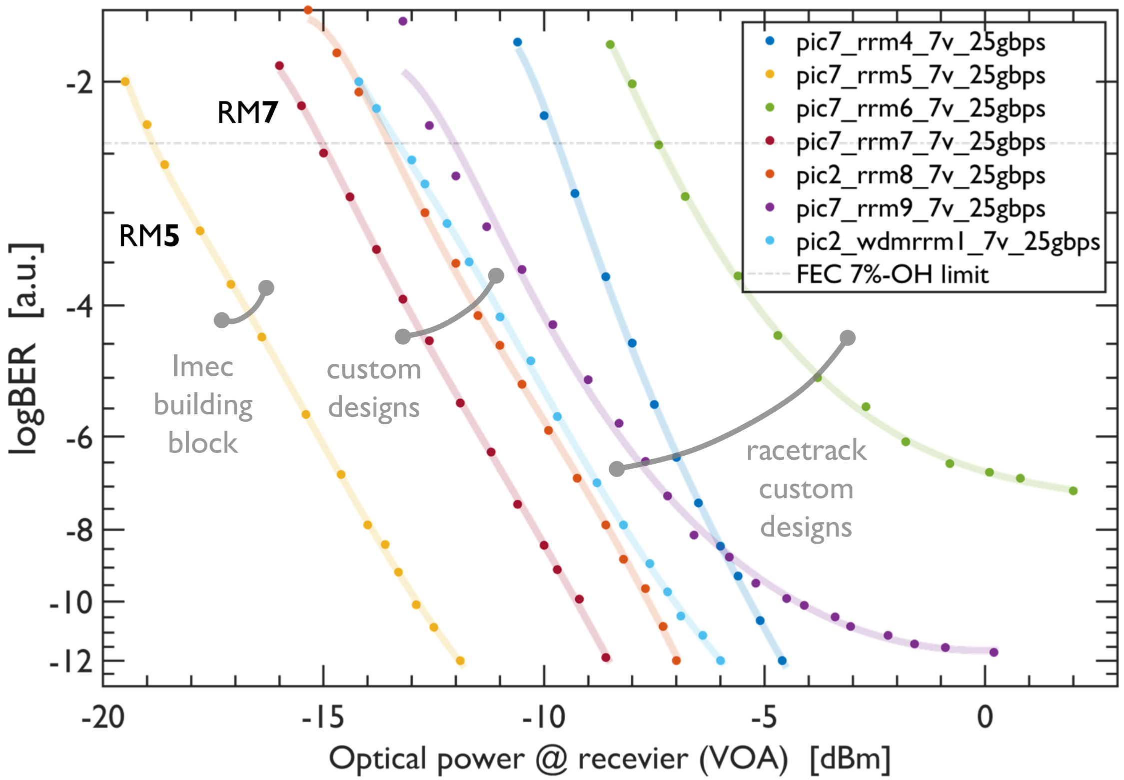


Imec building block: RM**0**, RM**5**

Custom all-pass: RM**3**, all WDM-RMs

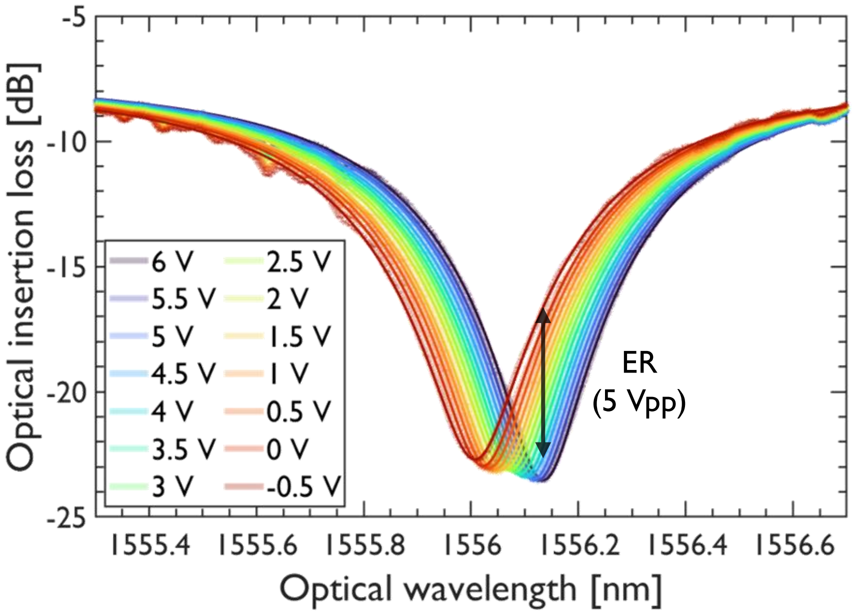
Custom add-drop: RM**1**, RM**2**, RM**7**, RM**8**,

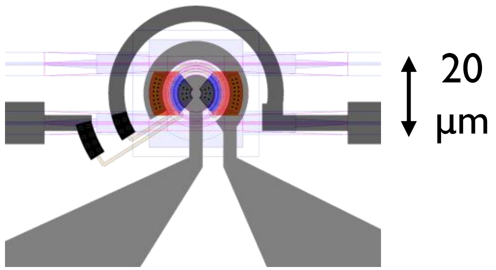
Custom racetrack all-pass: RM**4**, RM**6**, RM**9**



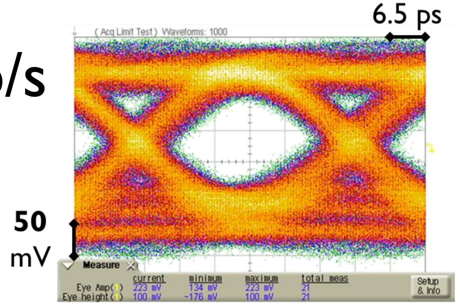
Ring Modulator – RM7

- Ring modulators (**RMs**): light intensity modulation is achieved via resonance shifts produced with a PN phase shifter.
- Testing conditions: λ = 1556.16 nm, Vbias = 1.7 V, Vpp ~ 5 V, T = 21.3 °C, P_{tls} = 13 dBm, $OSNR_{1nm}$ = 28.5 dB

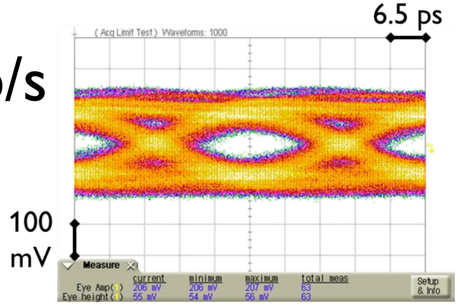


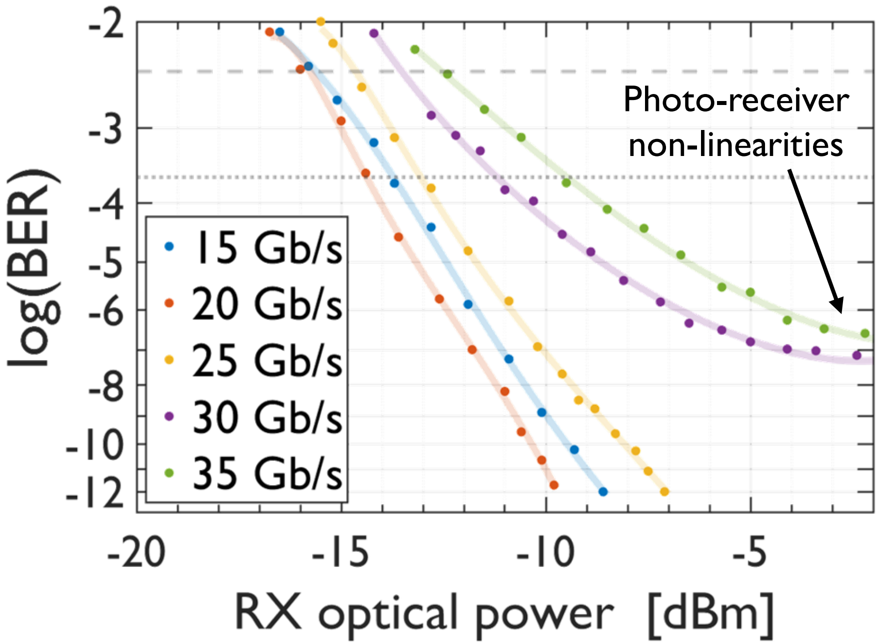


25 Gb/s



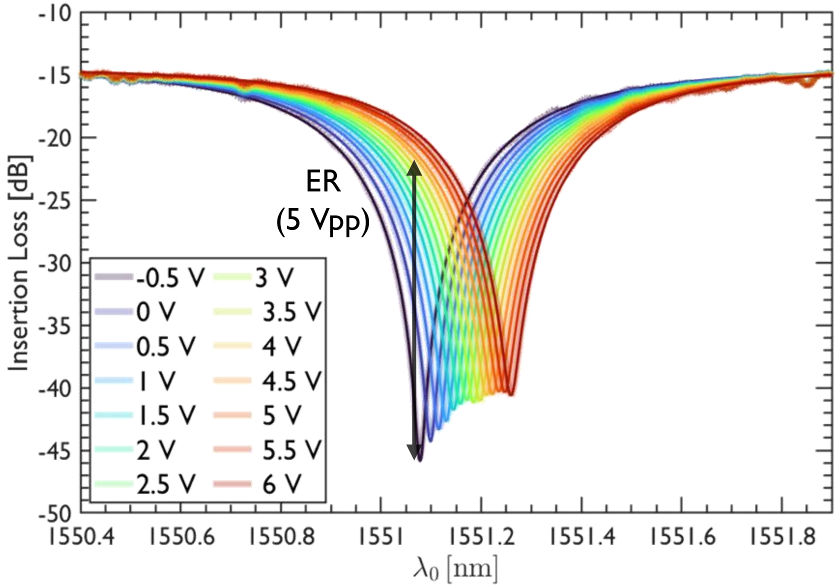
30 Gb/s



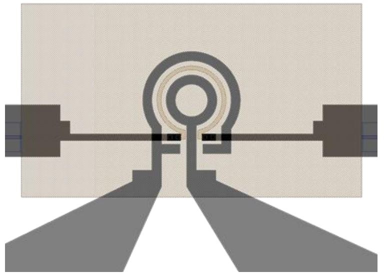


FWHM	~ 790 pm
Quality factor	~ 2000
Modulation **depth**	~ 15 dB
Modulation **efficiency**	~ 25 pm/V

Ring Modulator – RM**5** (imec)

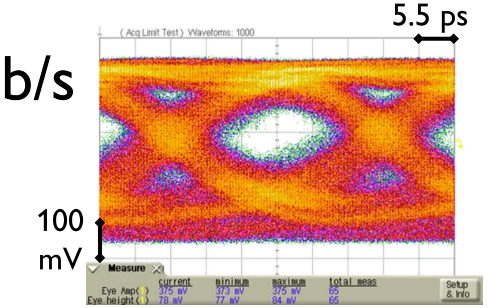


- Ring modulators (**RMs**): light intensity modulation is achieved via resonance shifts produced with a PN phase shifter.
- Testing conditions: λ = 1551.30 nm, Vbias = 1.7 V, Vpp ~ 5 V, T = 21.3 °C, P_{tls} = 13 dBm, $OSNR_{1nm}$ = 28 dB

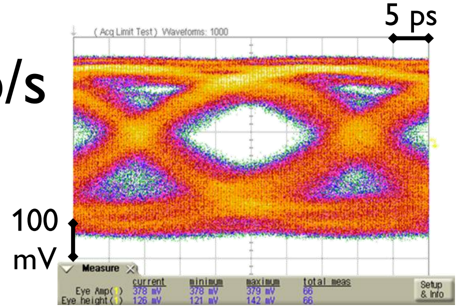


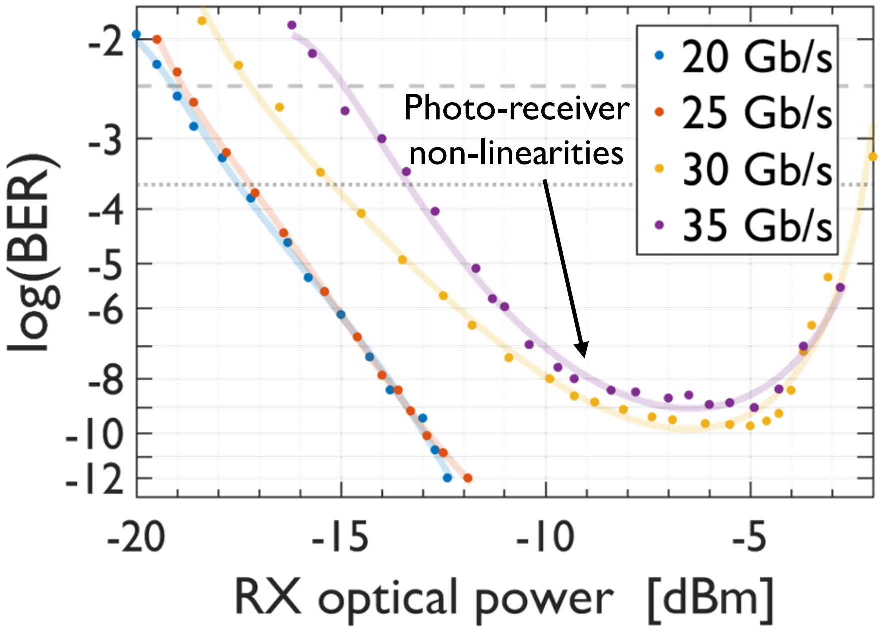
FWHM	~ 610 pm
Quality factor	~ 2500
Modulation **depth**	~ 32 dB
Modulation **efficiency**	~ 30 pm/V

30 Gb/s



35 Gb/s

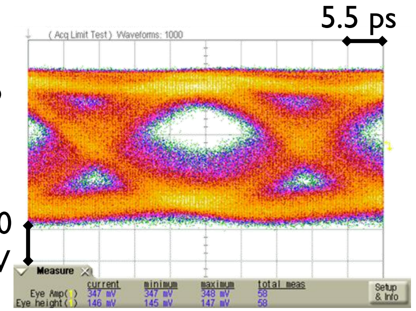




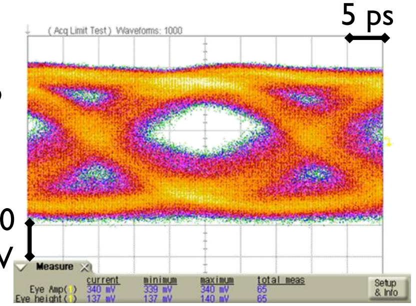
SiGe Electro-Absorption Modulator

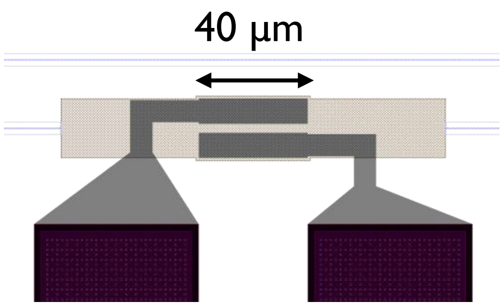
- Electric field-dependent photon absorption is harnessed for light intensity modulation. PN junction placed inside a SiGe rib waveguide to control optical power flow
- This foundry building block has been tested with RF probes up to 30 Gb/s. Operating conditions: λ = 1550 nm, Vbias = 2.2 V, Vpp ~ 5 V, T = 21.3 °C, P_{tls} = 13 dBm, $OSNR_{1nm}$ = 28 dB

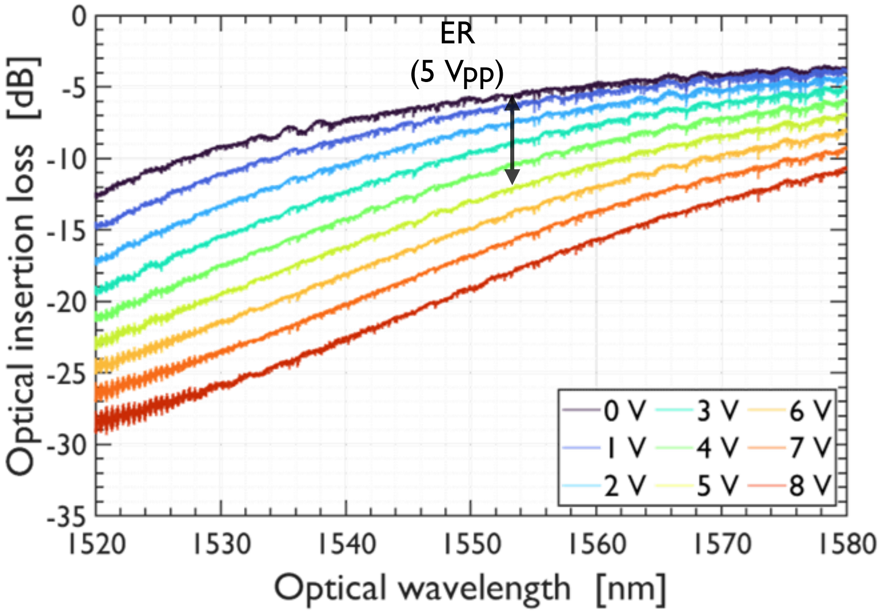
30 Gb/s

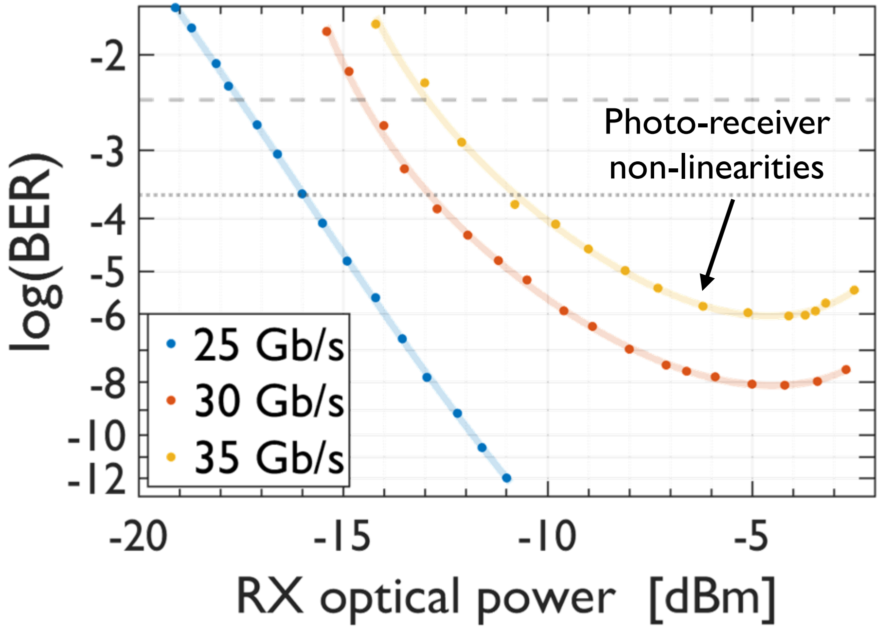


35 Gb/s



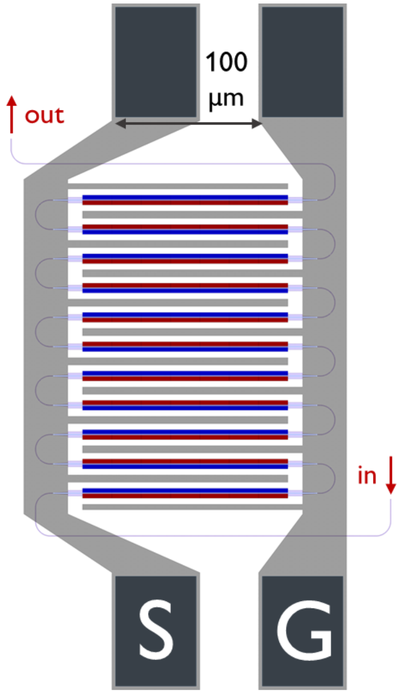


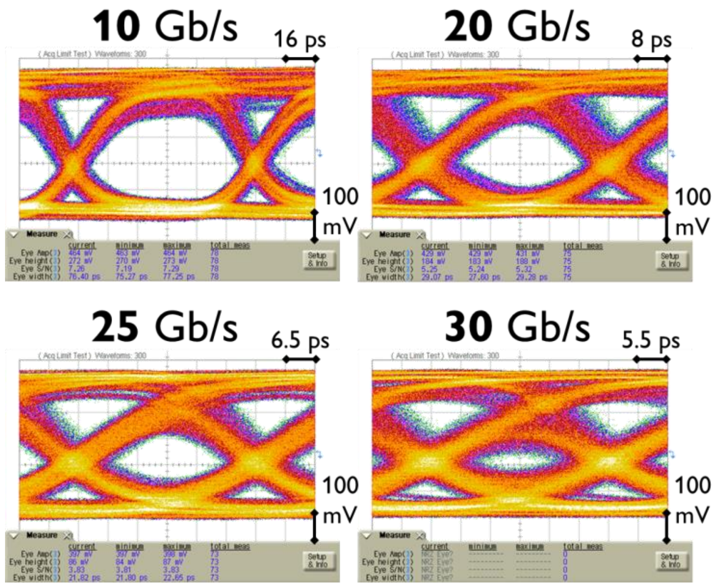


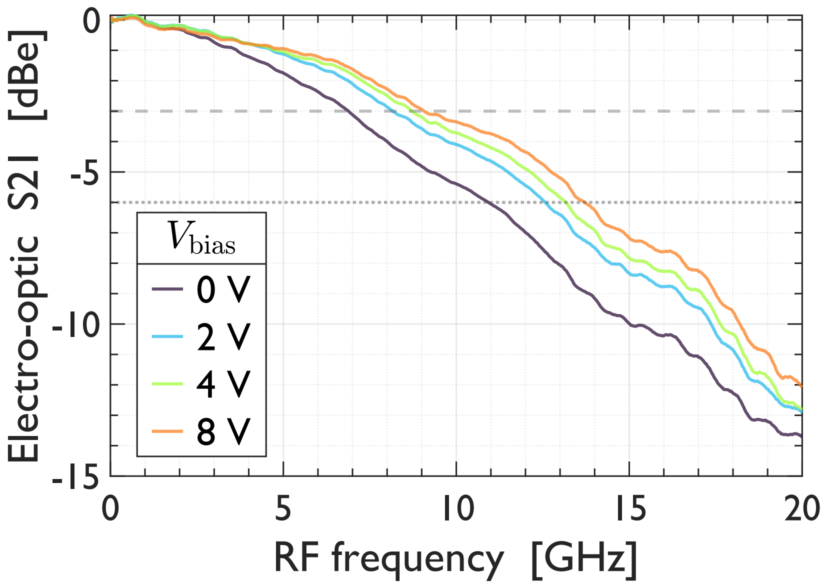


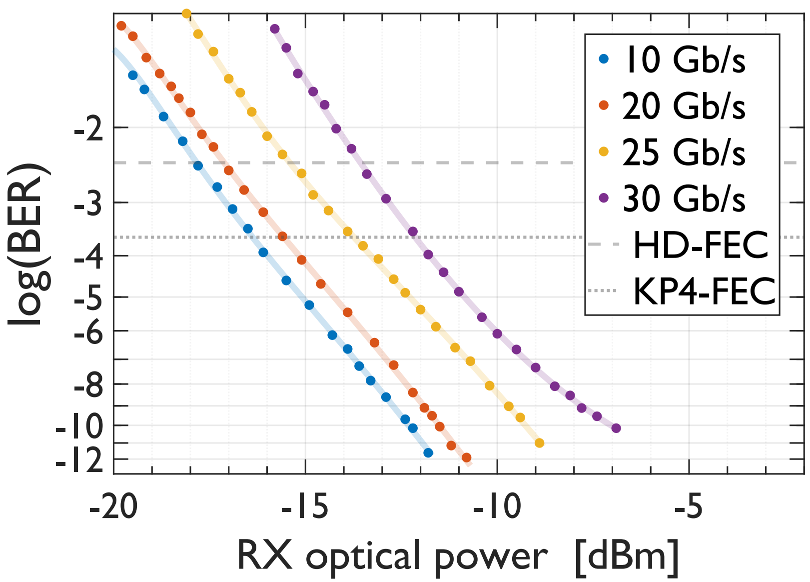
Folded MZM – FMZM1

- Lumped-element MZM: meandered deep-etch low-doped phase shifter layout
- $V_\pi L_\pi$ = 2.1 V·cm and per-unit-length optical attenuation = 9.6 dB/cm for a 4 V bias
- High-speed tests with RF probes shown NRZ transmission till 30 Gb/s with BER < $1 \cdot 10^{-10}$ and 13.2 GHz -6-dB electro-optic bandwidth (single-arm driving)
- Work submitted to IEEE Photonics Conference (IPC 2022)



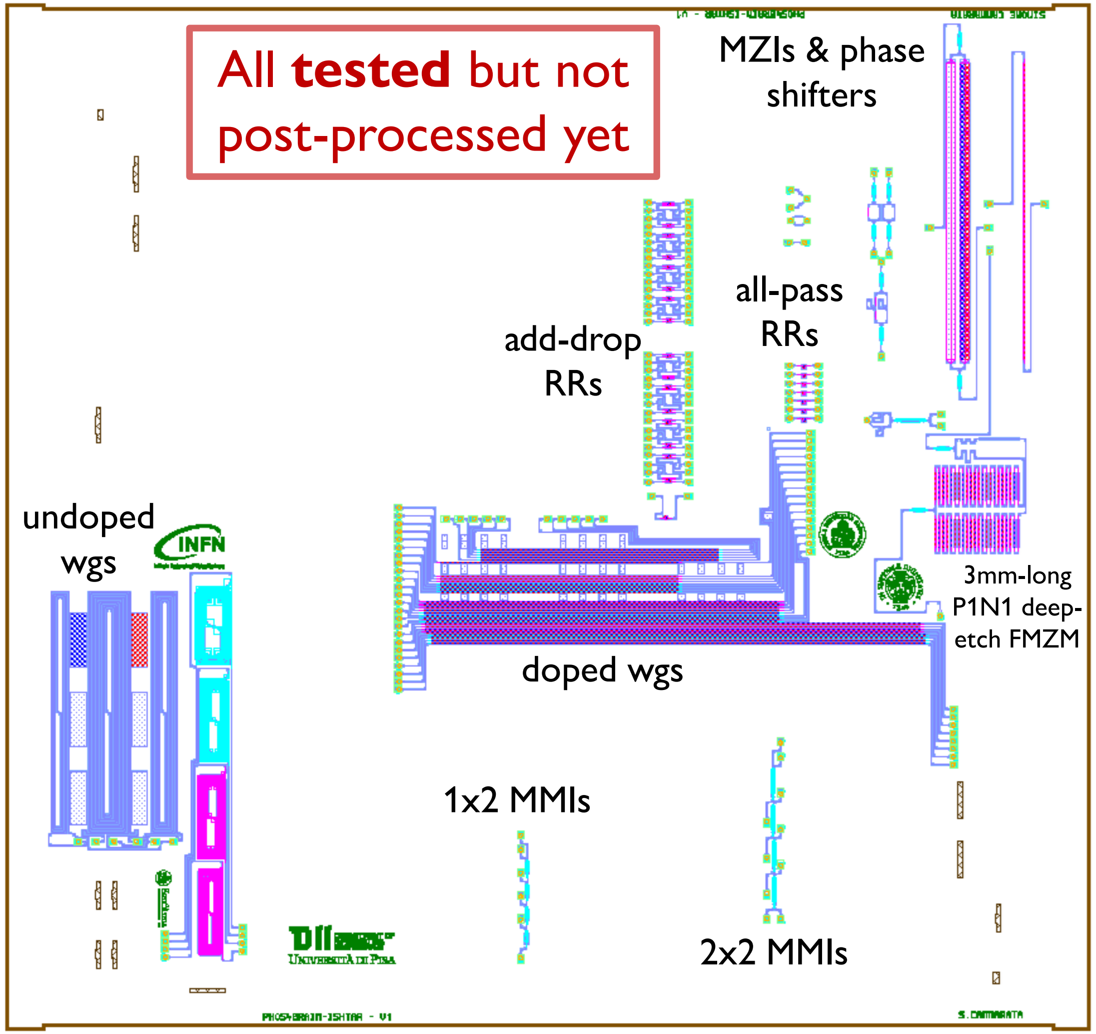






Imec PIC – Test stuctures – Overview

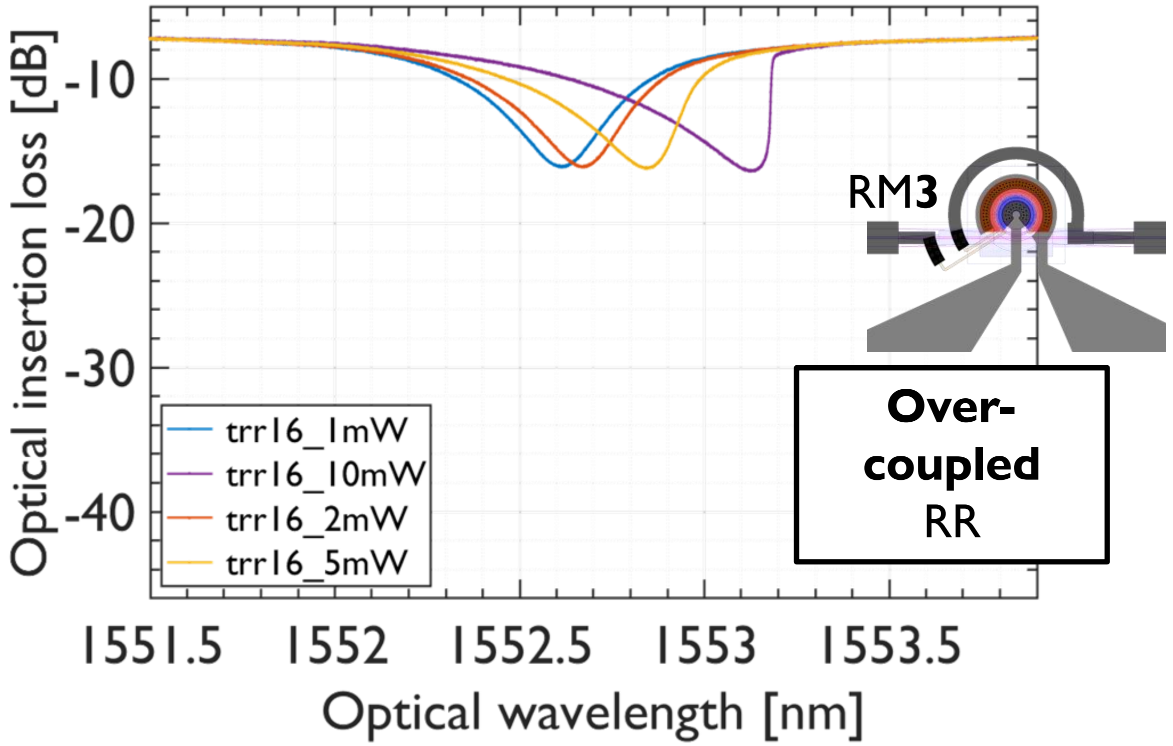
- Ring resonators
  - Doped add-drop RRs (10x 5 μm-radius, 6x 7.5 μm-radius)
  - Doped all-pass RRs (4x 5 μm-radius, 3x 7.5 μm-radius)
- MZIs and phase shifters
  - 1x 1.5mm P1N1-doped deep-etch phase shifter
  - 1x 1.5mm deep-etch MZI with one arm PN-doped, the other left undoped
- Doped waveguides
  - Cutback with lenghts 2.5mm, 1.8mm, 1.2mm for all doping configurations in shallow and deep-etch configs
  - 5x 1.2mm shallow-etch P+PN-doped waveguides varying P+ offset
- Undoped waveguides
  - 3x full-etch spirals (1 cm, 2.5 cm, 5 cm lengths)
  - 2x deep-etch spirals, 2x shallow-etch spirals
- MMIs
  - 1x2 and 2x2 4-element chains



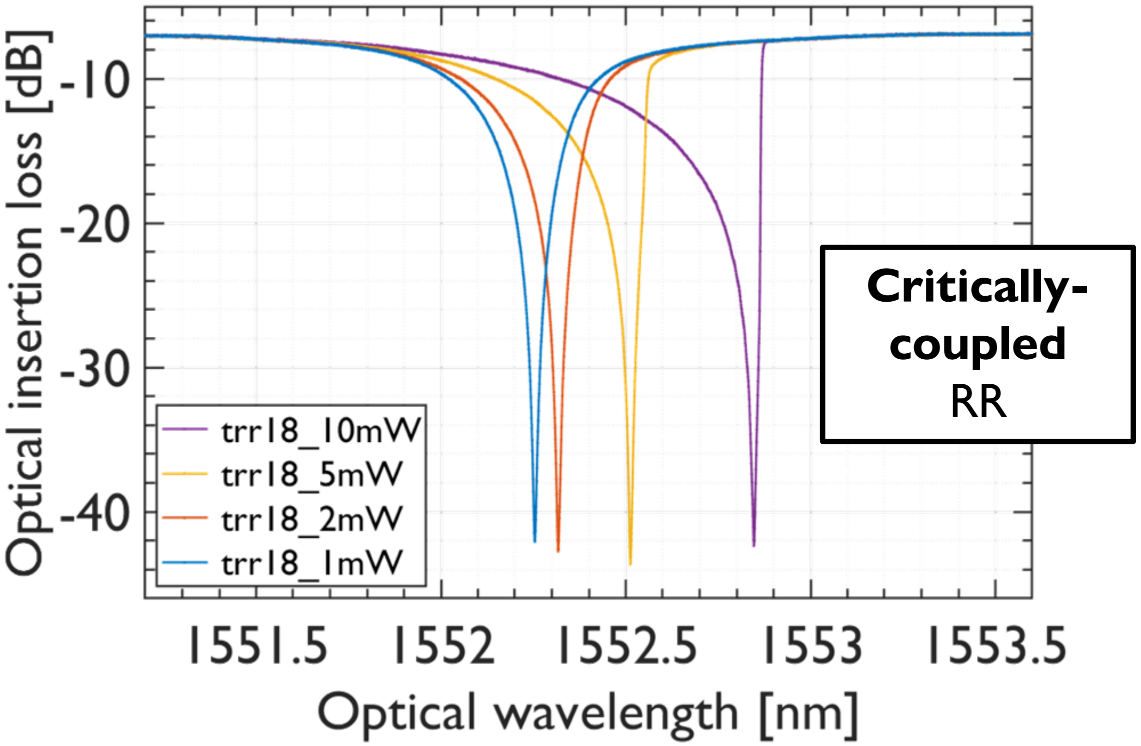
Test Structures – All-pass RRs Coupling

- Test ring resonators (TRRs) reveal that custom RMs are overcoupled (like TRR #16 on left)
- For each TRRs self-heating is also investigated

Test RR #16 – gap 180 nm

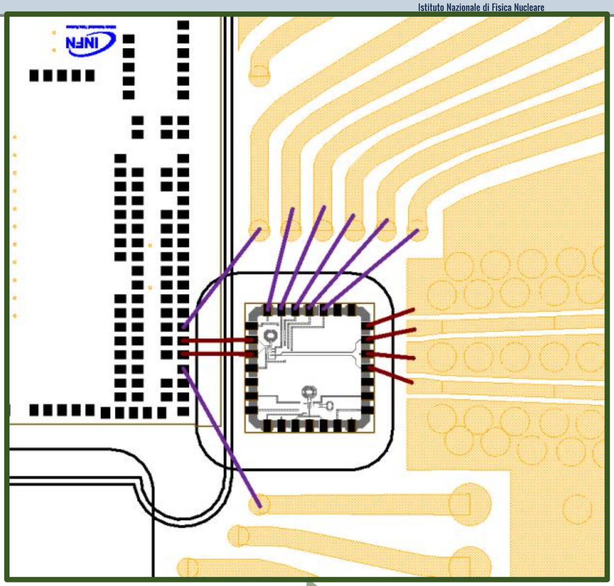


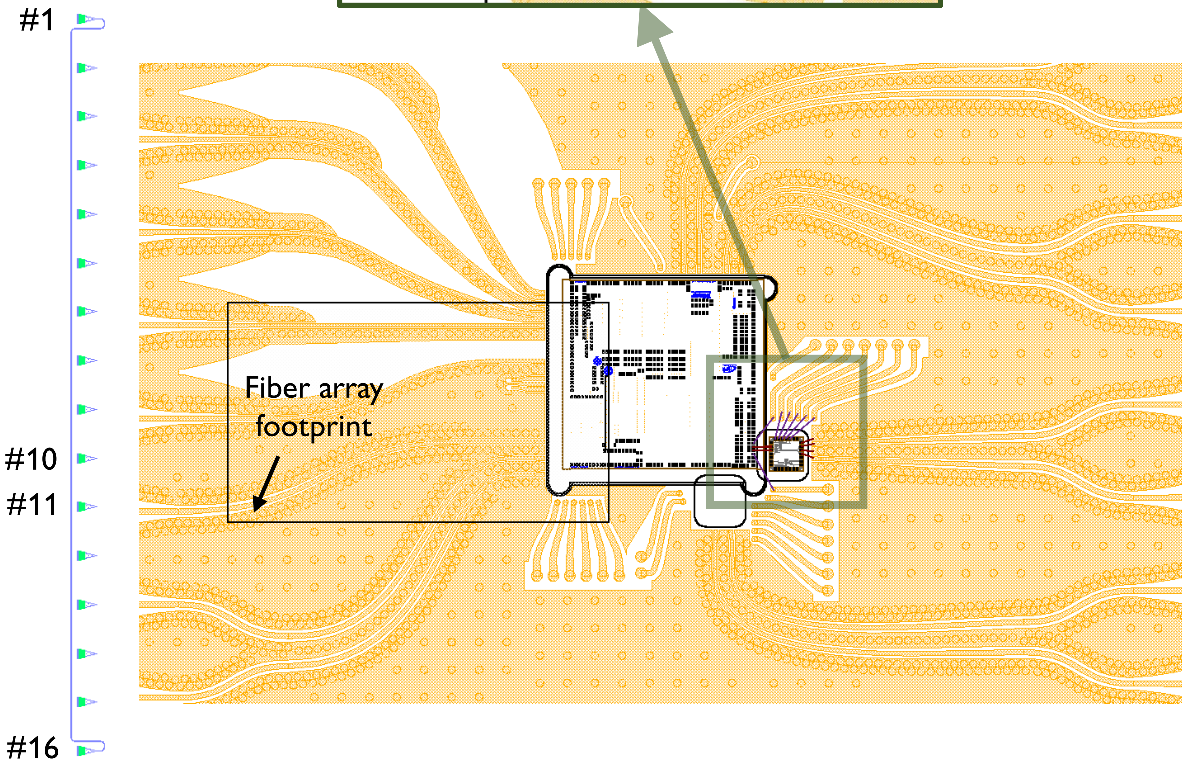
Test RR #18 – gap 230 nm



PIC-EIC Integration - CamGraphic

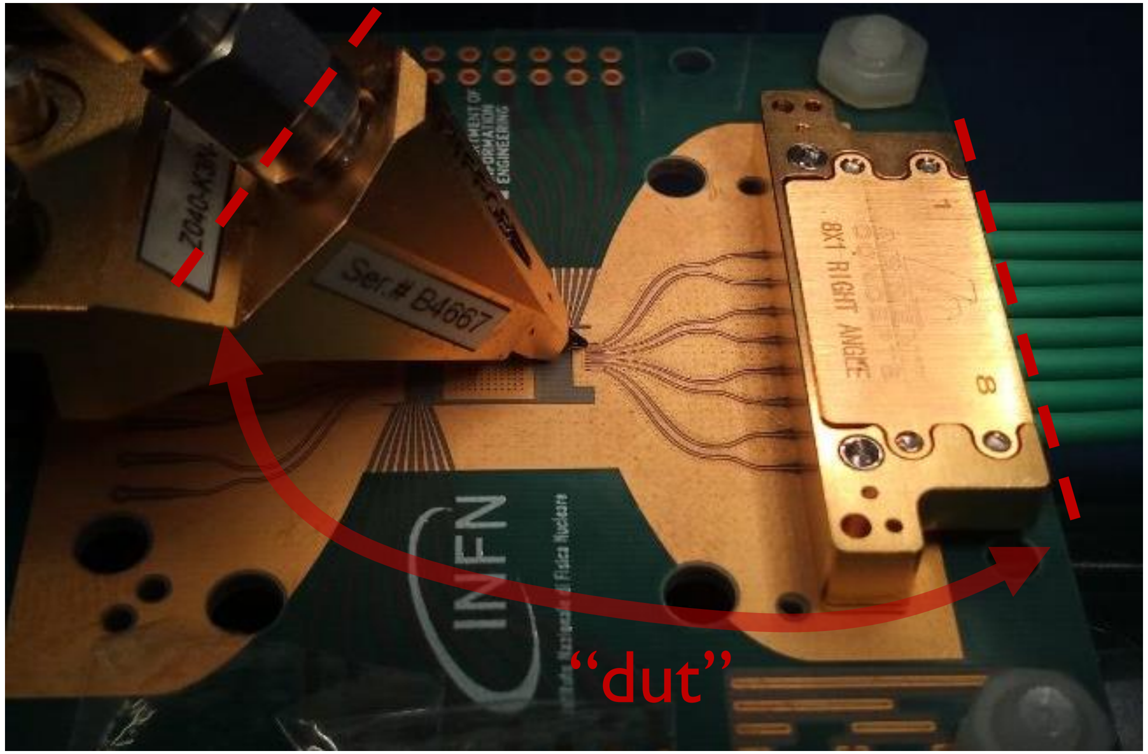
- Materials: 1x PCB, 1x PIC, 1x EIC, 1x fiber array
- **PIC** and **EIC attach** with heat-conductive glue (H70) inside cavities.
- **RF bonds** should be as short as possible. Use the largest wire available (25 µm-diameter Au)
- **Fiber array attach**
  - Put additional epoxy on the PCB top surface to make the assembly more robust
  - Optical loop for active aligment integrated on the outer grating couplers (**#1** and **#16** channels of the fiber array)
- 2 assemblies requested (end of June 2022 lead-time)
  - 28 nm driver connected to RM**5** (imec)
  - 28 nm driver connected to RM**7** (custom)





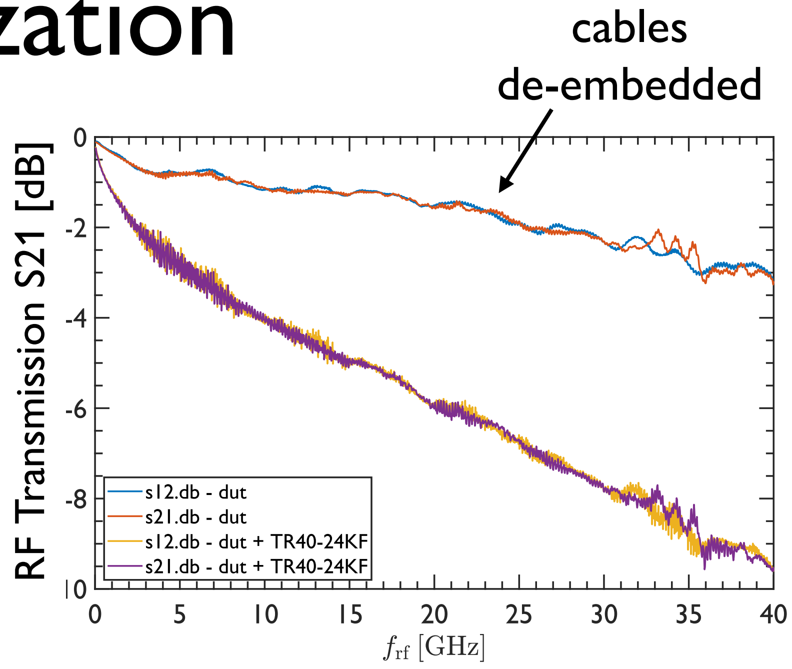
SOMACIS – Test PCB #A Characterization

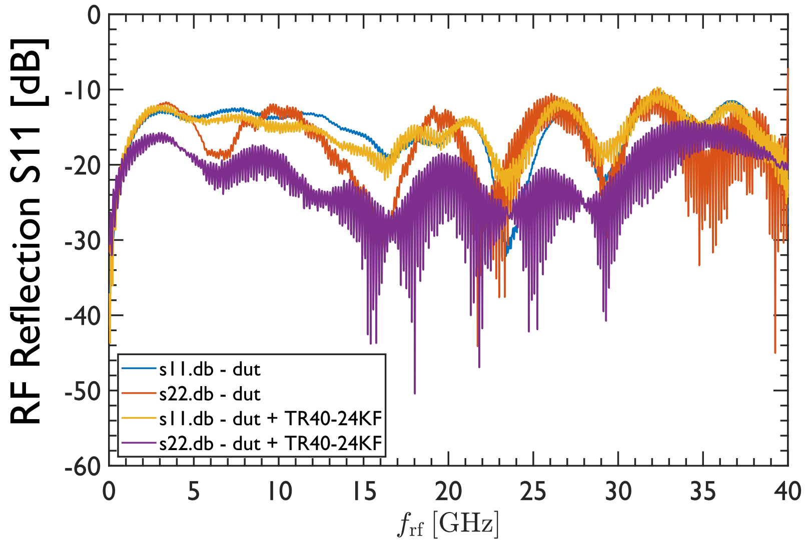
- Hybrid RF probe-coaxial connector small-signal test
- 24''-long coaxial cables of the multi-lane connector are the major source of RF insertion loss



"dut" includes:

1. RF probe
2. PCB trace
3. Connector launch & IP





Thanks for the attention

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Pisa, 06 June 2022