# Radiation effects on silicon photonic modulators of the COTTONTAIL chip

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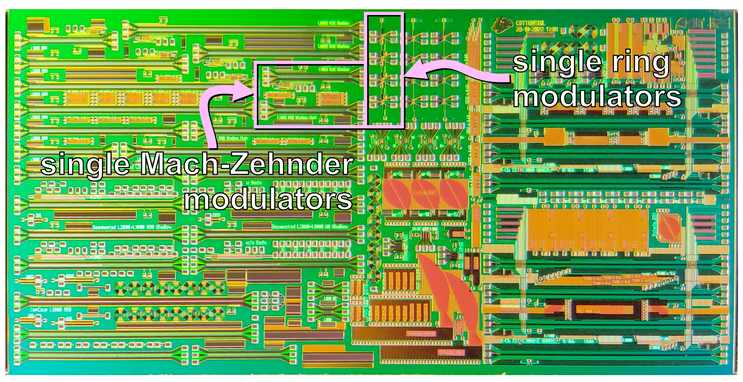
- Silicon photonic modulators are key elements for next generation optical data transmission
- Radiation tolerance important for particle detectors

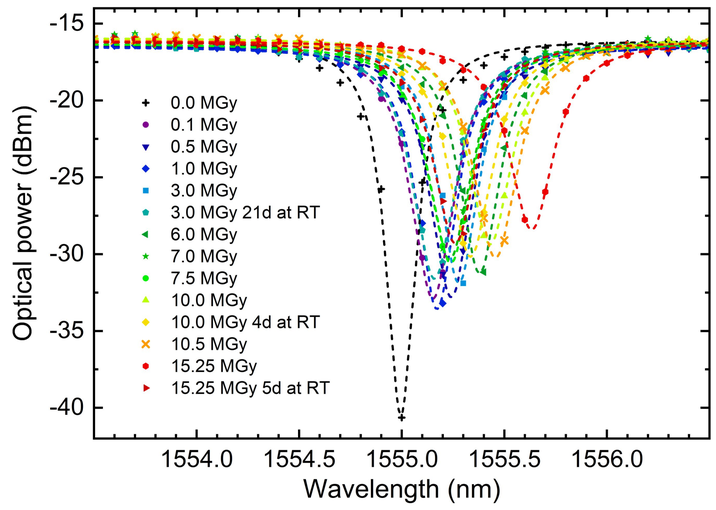



COTTONTAIL chip: silicon photonic chip with many different modulators and modulator systems, fabricated by IMEC.

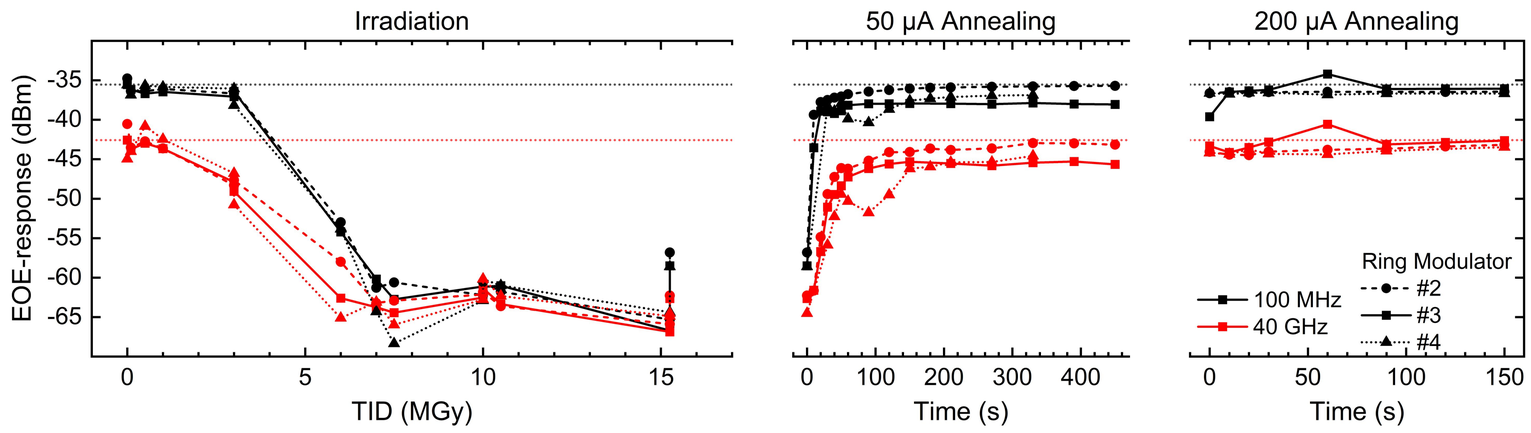
Irradiation experiment: 3 adjacent ring modulators were irradiated with increasing doses.
After irradiation the samples were annealed with 50 µA forward current, which restores most of the modulation efficiency.
Further annelaling with 200 µA forward current has a further slightly positive effect.

**Setup 1:**

- Silicon photonic chip: COTTONTAIL
- Procedure:
  - Chip irradiated in X-ray chamber to certain dose (3 kW X-ray tube @ 1.8 kW (60 kV, 30 mA) resulting in 33 Gy/s at sample position)
  - Transfer to optical measurement setup for characterization
  - Electro-optical characterization of three single ring modulators (stock modulators from IMECs PDK)
  - Transfer to X-ray chamber for next dose

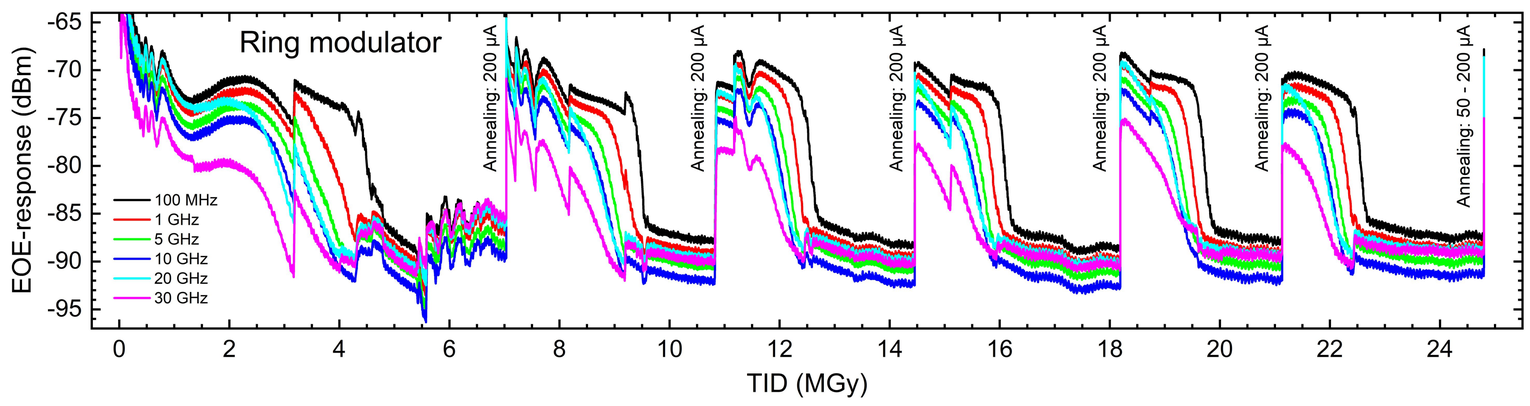



Shift of resonance notch with increasing dose.

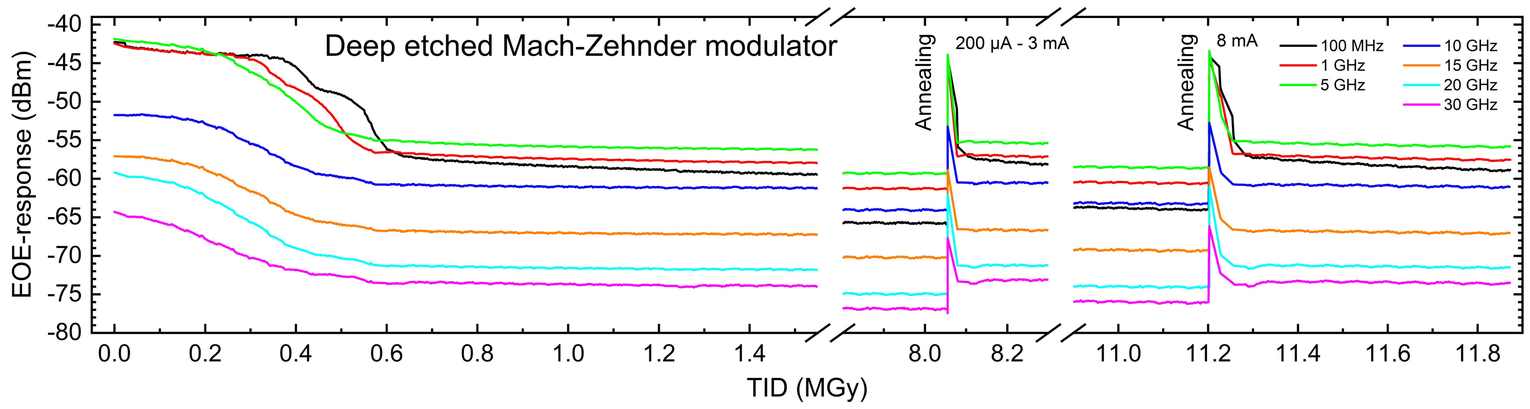



**Setup 2:**

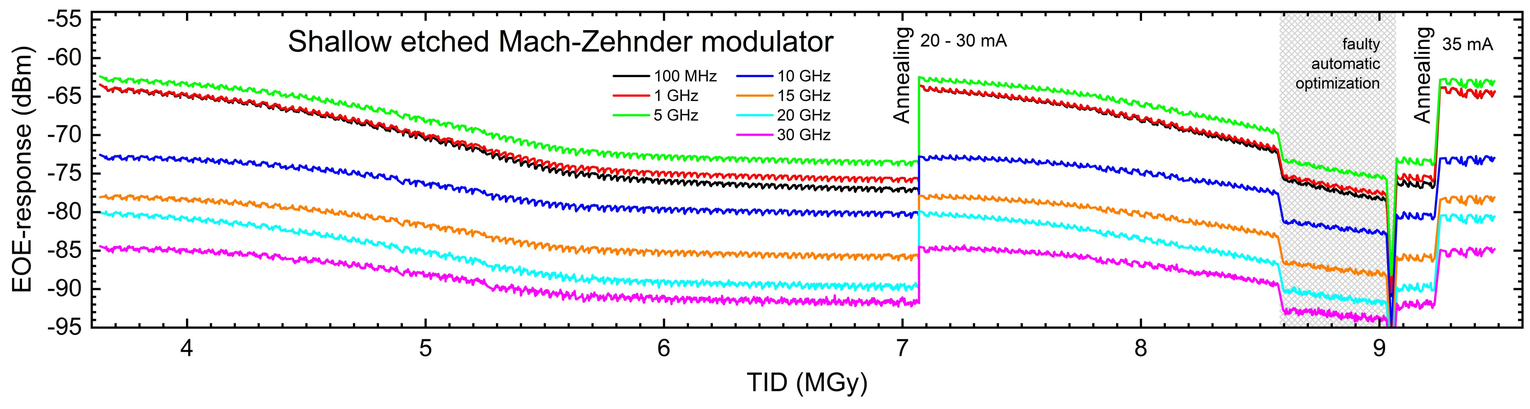
- Silicon photonic chip: diced COTTONTAIL with single chiplets of ring modulators (RM) and 1 mm long Mach-Zehnder modulators (deep (DE) and shallow etched (SE) MZM)
- Chiplets mounted to substrates with electrical breakout boards and glass fiber holders
- Angle polished single mode glass fibers for flat fiber-chip-coupling
- Setup placed in X-ray chamber with all cabling
- Procedure:
  - Irradiation with 43.6 Gy/s (RM), 48.5 Gy/s (DE-MZM), and 41.2 Gy/s (SE-MZM) at sample position while measuring optical DC-spectra and RF-modulation for several frequencies
  - Automated modulation wavelength optimization if required
  - Irradiation until break down of modulation
  - Annealing through forward biasing with 200 µA for ring modulators and up to 35 mA for Mach-Zehnder modulators
  - Repeat for next cycle



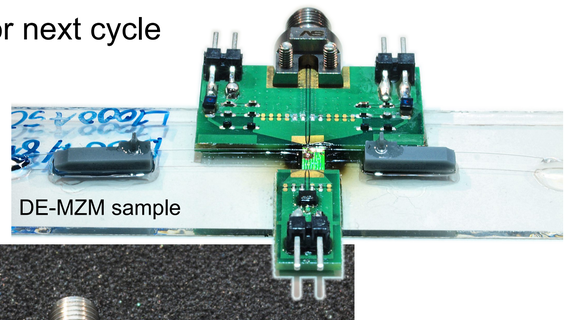

Modulation response of RM from IMECs PDK irradiated with increasing X-ray dose and 6 annealing cycles.

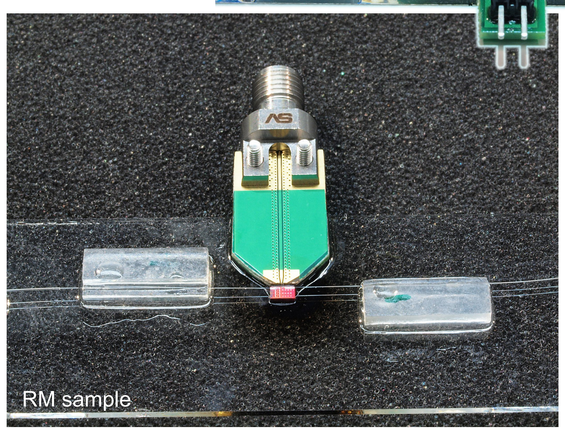



Modulation response of custom deep etched MZM irradiated with increasing X-ray dose and 2 annealing cycles.




Modulation response of custom shallow etched MZM irradiated with increasing X-ray dose and 2 annealing cycles.

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