X-ray irradiation campaigns of the Monopix2 depleted monolithic active pixel sensors

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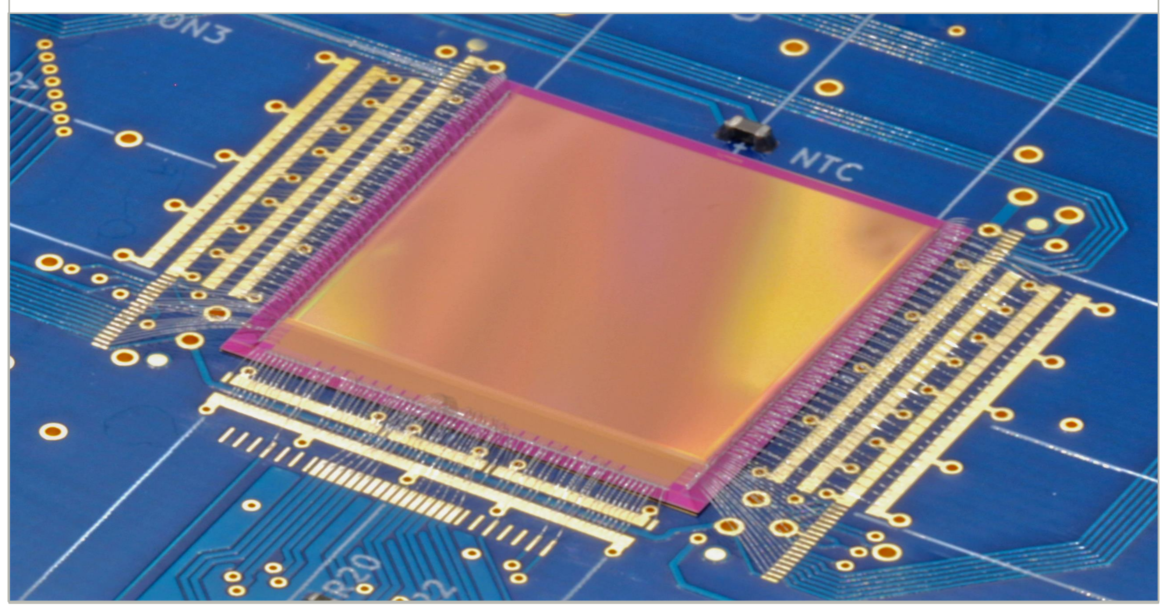
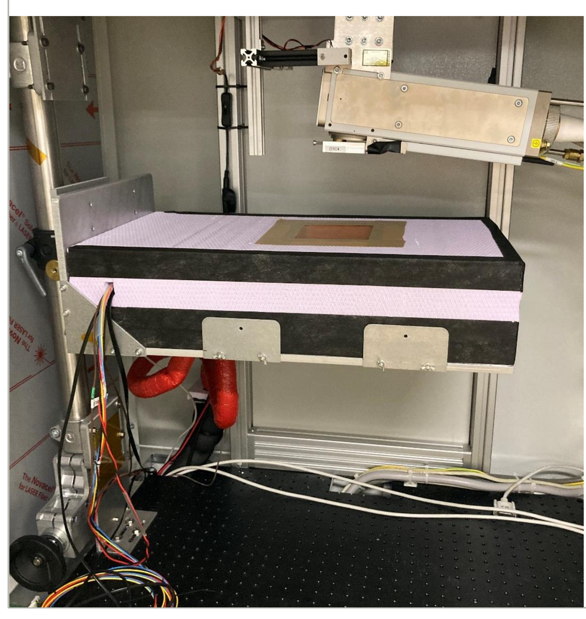
TJ-Monopix2

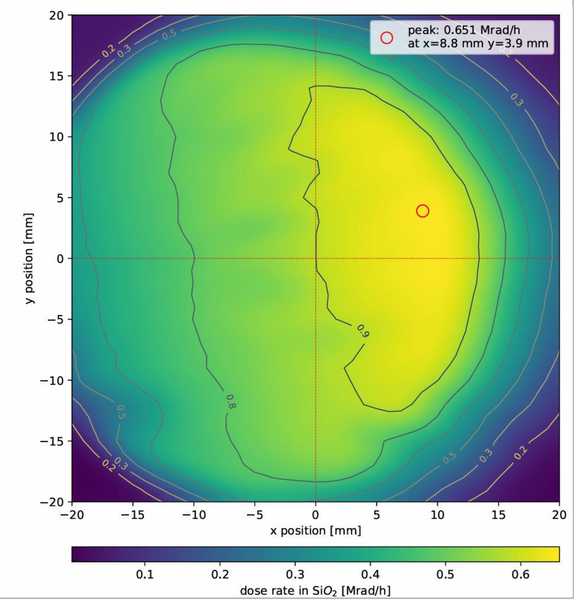
- 180 nm TowerSemiconductor technology
- 2 x 2 cm² chip with 33 x 33 µm² pixel pitch
- Small collection electrode relative to pixel pitch
  - Small sensor capacitance, long drift distances
- 7-bit ToT information and 3-bit in-pixel threshold DAC
- Triggerless column-drain readout architecture



X-ray irradiation setup

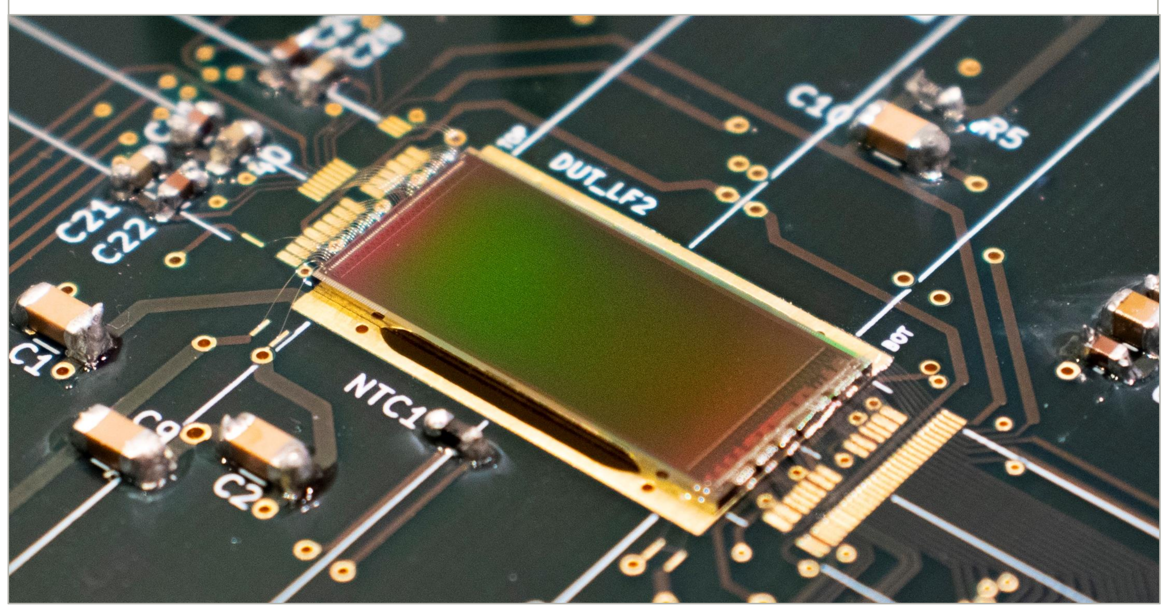
- Irradiation up to 100 Mrad including 16 measurement steps in between
- DUTs cooled to 0 °C during irradiation and measurement
- Operate X-ray tube around 0.58 Mrad/h mean intensity
  - Chip placement such that dose rate is as homogenous as possible





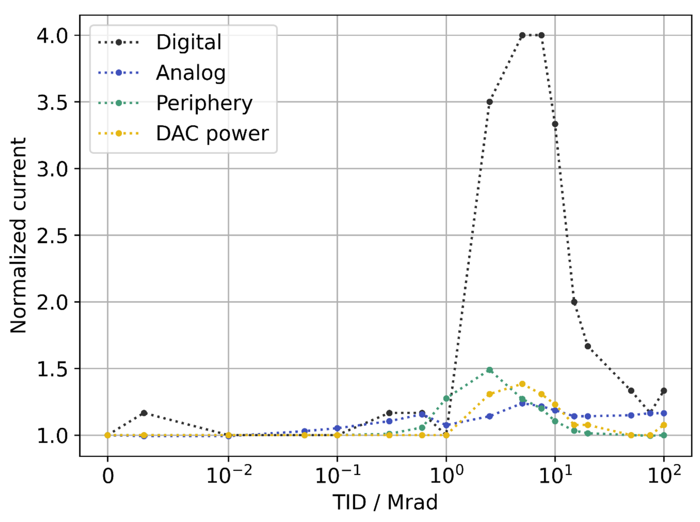
LF-Monopix2

- 150 nm LFoundry technology
- 1 x 2 cm² chip with 150 x 50 µm² pixel pitch
- Large collection electrode relative to pixel pitch
  - Short drift distances, large sensor capacitance
- 6-bit ToT information and 4-bit in-pixel threshold DAC
- Triggerless column-drain readout architecture



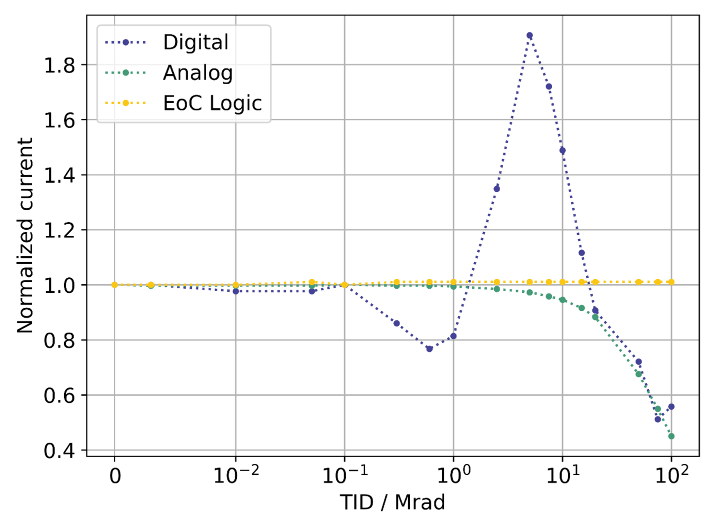
Power consumption TJ-Monopix2

- Measure power consumption of different low voltage power domains for default settings
- Peak between 1 – 10 Mrad for all power domains
  - Positive oxide charges in STI oxide decrease threshold voltage of NMOS transistors
  - Negative charge states of interface traps in silicon substrate compensate the effect for higher doses
  - Largest relative increase for digital power domain
  - Largest absolute contribution from periphery (clock distribution)
- Close to initial power consumption after 100 Mrad



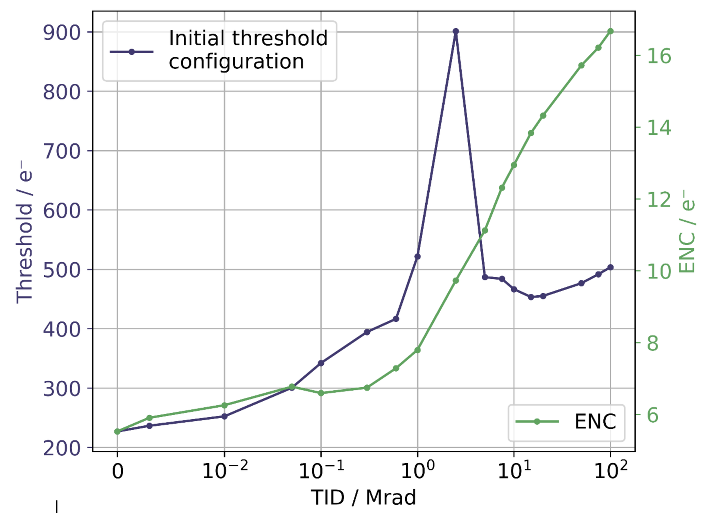
Power consumption LF-Monopix2

- Measure power consumption of different low voltage power domains for default settings
- Digital power domain:
  - Characteristic peak between 1 – 10 Mrad
- Analog and digital power consumption:
  - Start decreasing from 5 Mrad onward
- No significant change for power of EoC logic
- Behavior in agreement with observations of predecessor LF-Monopix1



Threshold and noise performance TJ-Monopix2

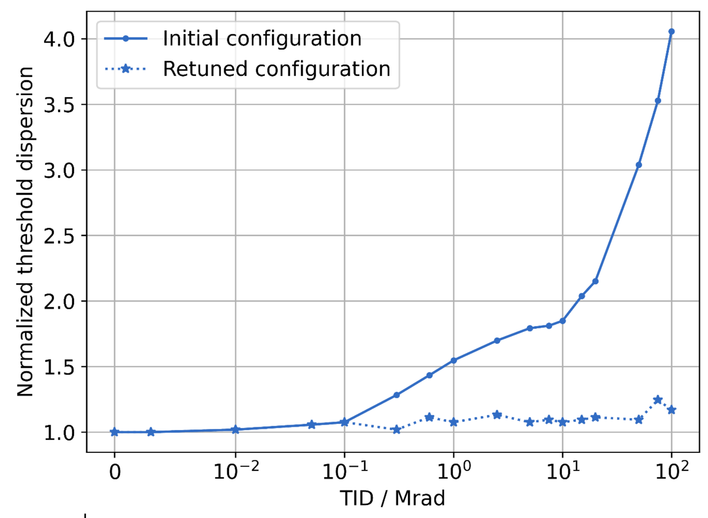
- Measure initial threshold and noise configuration
- Impact of irradiation on initial tuning configuration most severe between 1 – 10 Mrad
- ENC increases by almost 300 % after 100 Mrad
  - Annealing reduces ENC to 13 e⁻
- Typical operational threshold still achievable after 100 Mrad and annealing



TID	Threshold	Thr. Disp.	ENC
0 Mrad	230 e⁻	5 e⁻	6 e⁻
100 Mrad	245 e⁻	5 e⁻	13 e⁻

Threshold performance LF-Monopix2

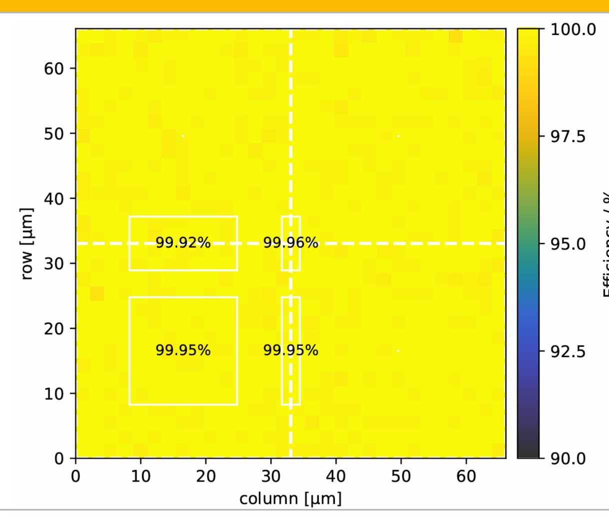
- Measure initial threshold configuration
  - Initial threshold dispersion increases by around 400 % after 100 Mrad
  - Adjustment of DACs and re-tuning limits threshold broadening
  - After 100 Mrad and annealing: typical operational configuration still achievable



TID	Threshold	Thr. Disp.	ENC
0 Mrad	2055 e⁻	91 e⁻	92 e⁻
100 Mrad	1983 e⁻	108 e⁻	122 e⁻

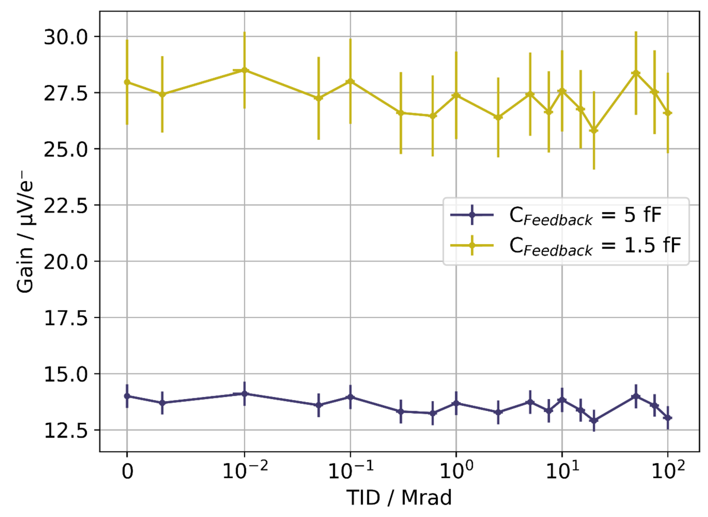
Beam tests after irradiation TJ-Monopix2

- Tested 100 Mrad X-ray irradiated sensor in electron beam at DESY
  - Measurements conducted at 0 °C
- No significant degradation in performance
  - Still > 99.8 % hit-detection efficiency across different front-end variations



DAC and front-end response LF-Monopix2

- DAC linearity measured via LEMO testing output
  - Linear behavior verified throughout full irradiation campaign
- Measured gain using un-biased threshold scans
  - Small feedback capacitance offers larger gain and faster timing response
  - Constant gain across all total ionizing dose



Summary

Both Sensors are fully functional after irradiation to 100 Mrad total ionizing dose. Characteristic spikes in the power consumption between 1 – 10 Mrad were measured for both DMAPS. The threshold performance of both chips after irradiation and annealing were recoverable by adjusting given chip parameters accordingly. A total increase of 117 % and 32 % in the ENC performance for TJ-Monopix2 and LF-Monopix2, respectively, was observed. TJ-Monopix2 proved excellent hit-detection efficiencies >99.8 % after X-ray irradiation. While beam test measurements of x-ray irradiated LF-Monopix2 are still pending, they are expected to show similar results. Furthermore, the next steps include x-ray irradiation until the end of life for both DMAPS is reached.

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