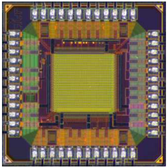
Characterization of APTS

An analog MAPS test structure fabricated in 65 nm CMOS technology



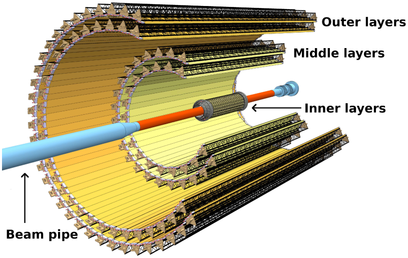
3. High-D Consortium Meeting

David Schledewitz

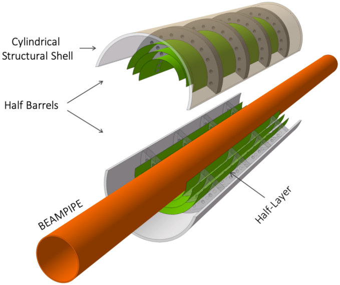
09/02/2023

ALICE ITS Upgrade

- New ALICE **I**nner **T**racking **S**ystem (ITS2) installed and running
- Consists of 7 layers of ALPIDE **M**onolithic **A**ctive **P**ixel **S**ensors (MAPS)
- ITS3 Upgrade: Three innermost layers will be replaced with new ultra-light, truly cylindrical layers
  - Improvement of vertexing performance and efficiency at low p_T
  - Improving pointing resolution by factor 2
  - Reduction of material budget



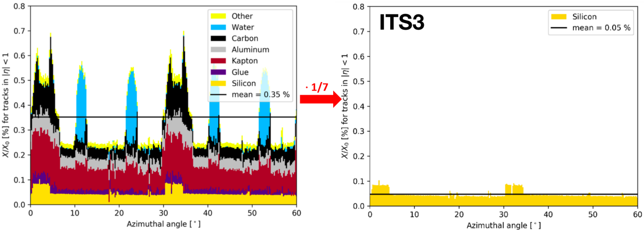
ALICE ITS2



ITS3 Inner Barrel

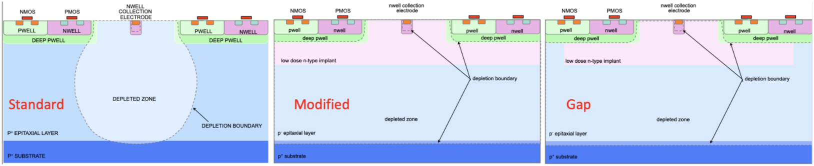
ALICE ITS Upgrade

- Thinned down sensors to 20-40 µm to bent silicon to target radii
  - Bent sensors held in place by carbon foam
  - Closer distance to interaction point (from 23 to 18 mm)
- Reducing material budget from 0.35% to 0.05% X/X_0
  - Negligible systematic error from material distribution due to homogeneity
- Stitched, wafer-size sensors
  - ALPIDE is 30x15 mm, ITS3 target is up to 280x94 mm
- **Requires new dedicated sensor design**



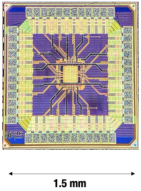
Sensor Design

- First submission fabricated in 65 nm CMOS technology (designed within CERN EP R&D)
- Smaller feature (transistor) size:
  - Possibility to create smaller pixels with same amount of in-pixel logic
  - Larger commercially available wafer sizes (required for ITS3 design)
- Several variants of sensors:
  - Different implant geometries (standard, modified, modified with gap)
  - Different pixel pitches (10 - 25 μm)
  - Different doping concentrations



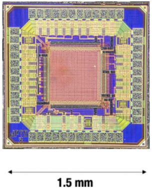
Pixel Test Structures

APTS Analogue Pixel Test Structure



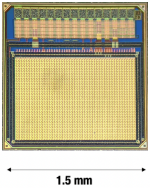
Matrix: 6x6
Readout: direct analogue readout of central 4x4
Pitch: 10,15,20,25 µm
Process: all 3 variants

DPTS Digital Pixel Test Structure



Matrix: 32x32
Readout: async. digital with ToT
Pitch: 15 µm
Process: 1 variant (modified with gap process)

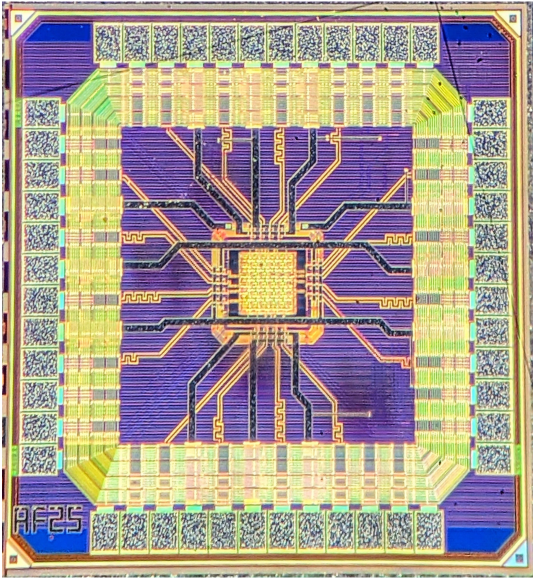
CE-65



Matrix: 48x32
Readout: rolling shutter analog
Pitch: 15, 25 µm
Process: 1 variant (modified with gap process)

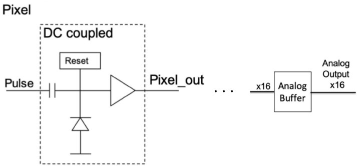
- Intensive campaign of characterization performed in the laboratory and in beam tests
- Verification of the technology in terms of charge collection efficiency, detection efficiency and radiation hardness

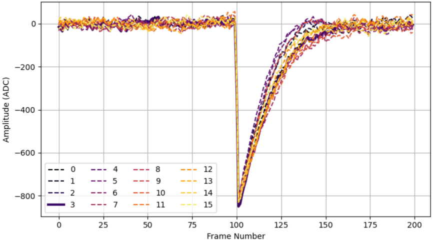
The Analog Pixel Test Structure (APTS)



APTS: Pulsing

- Many variants. Here: DC source follower (amplifier type), modified process with gap, 15 µm pixel pitch
- Goal: Characterization of charge collection properties and radiation hardness
- Generate analog pulse by traversing ionizing particles or **charge injection**
  - Collected charge leads to voltage drop
  - Driven back to baseline by reset current proportional to I_{reset}
- Extracting full waveform to analyze characteristics

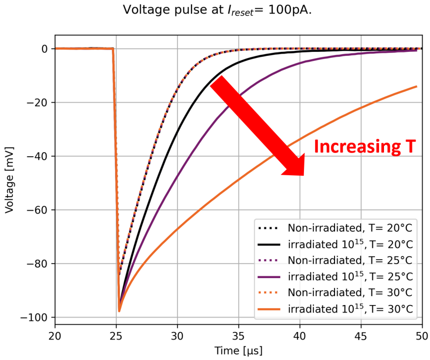




Frame = 0.25µs

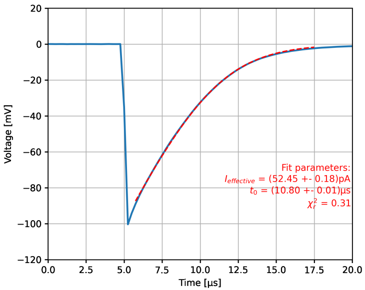
APTS: Temperature Dependence

- Inject pulse 1000 times and take the average (for one pixel)
- Investigating temperature dependence.
  - No significant dependence for non-irradiated sensor
  - For irradiated sensor significantly extended recovery time to baseline for increasing temperatures
  - Fails to operate at even higher temperatures without adjustment of parameters
- Possible reason: Increasing leakage current



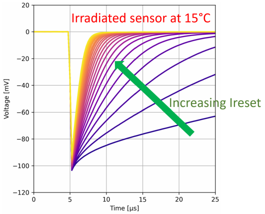
APTS: Leakage Current Investigation

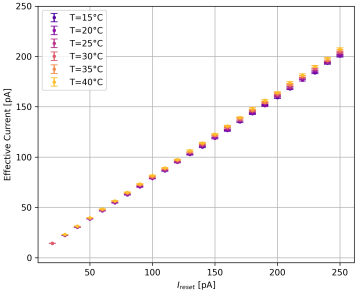
- Determine Leakage Current
  - Assumption: $\mathrm{I_{effective}} = \mathrm{m} \cdot \mathrm{I_{reset}} - \mathrm{I_{leakage}}$
  - Find physically motivated fit function with $\mathrm{I_{effective}}$ as fit parameter, describing the pulse
- Signal dependent current through reset transistor
  - $\mathrm{I(t)} = \mathrm{I_{eff}} \cdot \left(1 - \exp\left(\frac{-\mathrm{V(t)}}{\mathrm{V_{th}}}\right)\right)$
  - $\mathrm{V_{th}} = \mathrm{n\,k_B T/q}$
- Solving for $\mathrm{dV} = \mathrm{I/C\,dt}$:
  - $\mathrm{V(t)} = -\mathrm{V_{th}} \cdot \ln\left(\exp\left(-\frac{\mathbf{I_{eff}} \cdot (\mathrm{t} - \mathbf{t_0})}{\mathrm{V_{th}} \cdot \mathrm{C}}\right) + 1\right)$



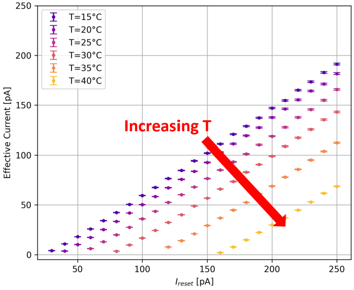
APTS: Reset Current Variation

- Find dependence of $\mathrm{I}_{\mathrm{effective}}$ to $\mathrm{I}_{\mathrm{reset}}$ by varying parameter
- Determine leakage current by linear fit
  - $\mathrm{I}_{\mathrm{effective}} = \mathrm{m} \cdot \mathrm{I}_{\mathrm{reset}} + \mathrm{b}$
  - $\mathrm{I}_{\mathrm{leakage}} = -\mathrm{b}$



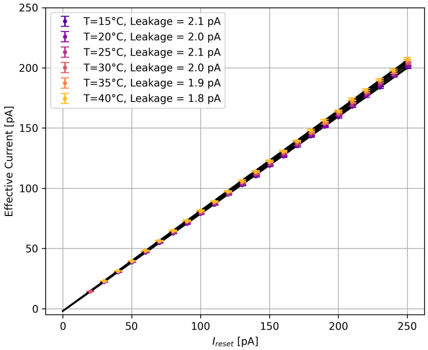


Non-irradiated sensor

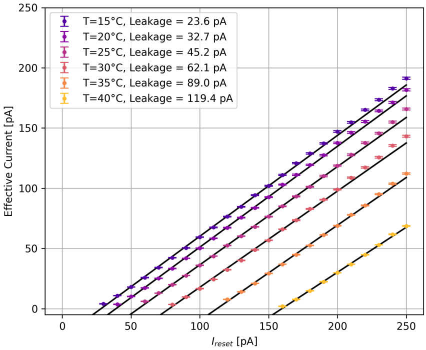


Irradiated sensor

APTS: Leakage Current Results



Non-irradiated sensor



Irradiated sensor

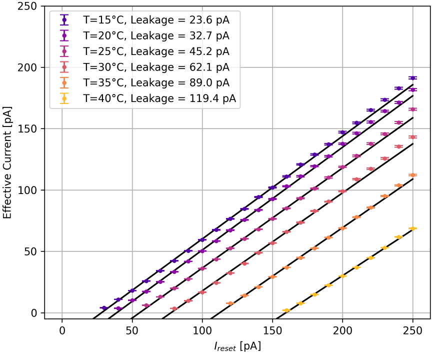
Summary and Outlook

Summary:

- Developed method for leakage current determination
  - $\rightarrow$ Useful tool to study the performance of irradiated sensors

Outlook:

- Leakage Current Measurements for different irradiation levels and parameters



Thank you for your attention :)

Backup: APTS Current dependence on different parameters