

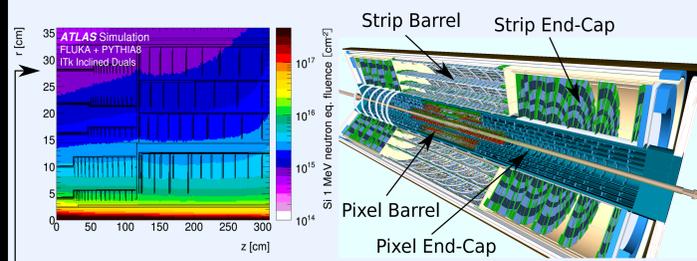
Update on the TowerJazz CMOS DMAPS development for the ATLAS ITk

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Glossary:

CMOS: Complementary Metal Oxide Semiconductor
DMAPS: Depleted Monolithic Active Pixel Sensor
ITk: Inner Tracker (of the ATLAS experiment)

ATLAS ITk Pixel Detector



5th layer of pixel tracker:

Challenges:

- Occupancy: 1MHz/mm²
- Expected NIEL: 10¹⁵ N_{eq}/cm²
- TID : 50 Mrad
- Active area of 5th layer: 3 m²

Upgrades and Changes:

- η coverage increased to 4.0
- 5 barrels, 10 pixel rings
- All silicon designs to cope with occupancy and pile up in HL-LHC

Radiation Resistant CMOS Sensors

Two variants:

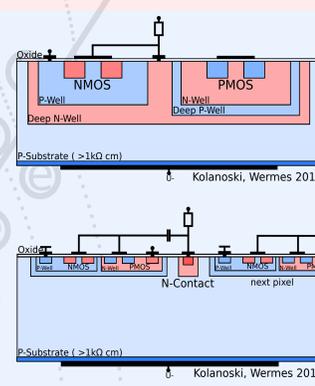
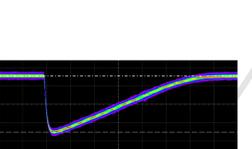
- CMOS circuitry inside collection diode
- CMOS circuitry in separate deep p-well

Advantages:

- Complex electronics in active area of pixel matrix
- Very thin at around 100μm
- Cheaper by a factor~3 (no front end no bump bonding)
- Production in large quantities much easier (layer 5 of ITk is largest!)

Signal Generation:

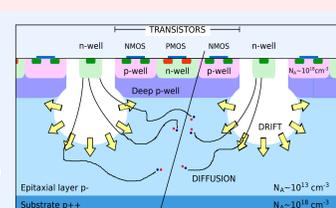
- Voltage on collection diode drops when charge from an incident particle is collected and is "slowly" recovered via diode reset
- Initial diode signal is amplified by the in-pixel circuitry and then read out



TJ180nm CMOS Process Modification

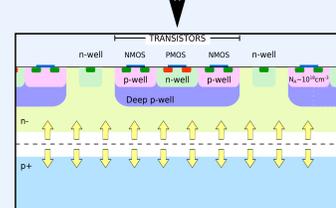
Standard Process:

- Depletion only around collection diode
- Charge collection **partially via diffusion** (far from electrode) and **via drift** (close to electrode)



Modified Process:

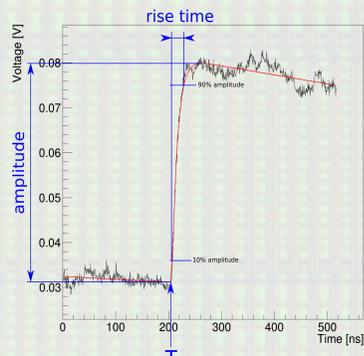
- Interstitial n-implant ensures homogeneous depletion across whole bulk
- Charge collection **only via drift** thus faster and more radiation tolerant



TowerJazz Investigator

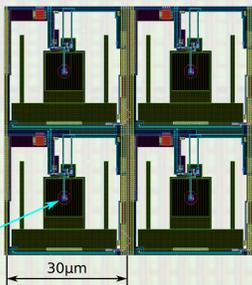
Features:

- 134 "mini-matrices" with a great variety of pixel designs
- pixel pitches range from 20μm to 50μm
- variable deep p-well coverage
- variable shape of collection diode
- analogue output of signal waveform for detailed analysis
- 3T (3 transistor) readout
- dedicated reset
- single pixel readout



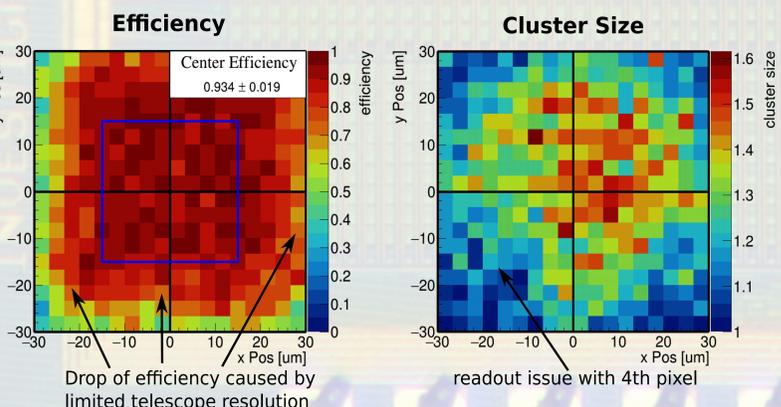
Minimatrix 106:

- Mini-matrix 106 was measured extensively
- 30μm x 30μm pixel pitch
- 3μm collection diode
- large deep p-well extends close to collection diode
- is close to the design of the pixels for the first full sized digital chip "MALTA"



Results:

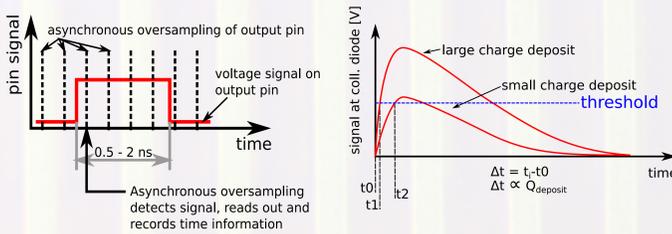
- software threshold of 110e⁻
- high efficiency maintained after irradiation of 10¹⁵ N_{eq}/cm²
- efficiency is maintained at pixel borders and edges (see center of efficiency plot)
- cluster size clearly indicates charge sharing even further away from pixel borders



MALTA

General Information:

- full sized digital chip
- 25μm epil layer, fully depleted
- 512 x 512 pixels with a 36.4 x 36.4 μm² pitch
- 8 sectors of 64 columns with different pixel flavours
- fully asynchronous operation
- readout via asynchronous oversampling

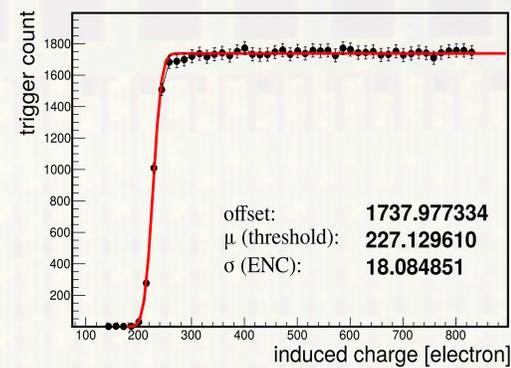


Special Features:

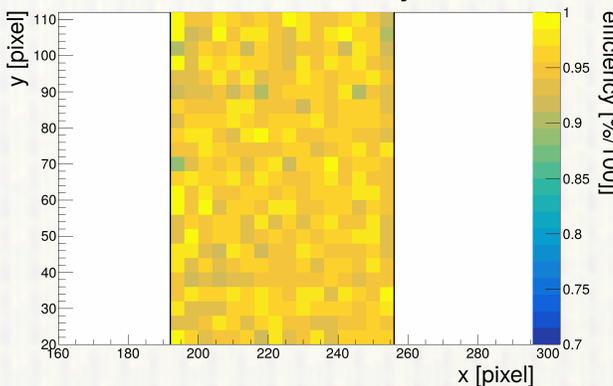
- very small collection diode with low capacitance of <5pF
- low capacitance greatly reduces noise
- low noise allows for operation at very low thresholds
- ENC of only ~15-20e⁻ possible!
- low thresholds are needed for thin epi layers of 25μm thickness which can be fully depleted
- full depletion of epi layer means charge is only collected via drift
- chip is faster and more tolerant to radiation damages
- charge deposition is inferred from time walk of signal
- 500nA/pixel or <70mW/cm²

S0	S1	S2	S3	S4	S5	S6	S7
diode reset	diode reset	diode reset	diode reset	PMOS reset	PMOS reset	PMOS reset	PMOS reset
2 μm el. size	2 μm el. size	3 μm el. size	3 μm el. size	3 μm el. size	3 μm el. size	2 μm el. size	2 μm el. size
4 μm spacing	4 μm spacing	3.5 μm spacing	3.5 μm spacing	3.5 μm spacing	3.5 μm spacing	4 μm spacing	4 μm spacing
med. deep p-well	max. deep p-well	max. deep p-well	med. deep p-well	med. deep p-well	max. deep p-well	max. deep p-well	med. deep p-well

Threshold scan



MALTA Efficiency



Time walk for Sr⁹⁰, unirradiated, Q_{TH} = 210e⁻

