MIMOSA-22SX - A Monolithic Active Pixel Sensor for Low Energy X-Ray Counting Applications

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Motivation
Mimosa 22 SX design details
Charge collection studies
Mimosa 22SX results
Conclusions and future steps
Motivation:
Low energy X-Rays counting with MAPS

CCD
- Detector
- Readout & Processing Cell
  - Few interconnections
  - Slow data transmission
  - Small pixel pitch
  - Wide energy range
  - No single photon image
  - Limited counting rate

Monolithic Sensor MAPS
- Sensitive Volume
  - NO interconnections
  - Single photon counting
  - Low energy detection
  - Low cost
  - Small pixel pitch
  - Moderate counting rate (per pixel)

Hybrid Pixel Sensor
- Pixel detector
  - Bump bonding
  - High counting rate
  - Single photon counting
  - Limited low E detection
  - High cost
    - Bonding
    - Detector

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Mimosa 22SX design (I)

Specifications
- Designed by PICSEL + µElec – IPHC, Detector - Soleil
- Tower Jazz 180 nm CIS
- 128 x 256 pixels with **22 µm pixel** pitch (16 mm² active)
- Two versions of pixels with **AC coupled collecting diode**
- Discriminator with 2 thresholds -> **energy window**
- 8 columns with analog outputs (characterization)
- Submitted in 30\(^{th}\) November 2015 on two substrates:
  - 18 µm epitaxial layer, resist. > 1 k Ohm.cm
  - Czochralski, resist. > 0.6 kOhm.cm
- Lab tests started in June 2016

Targeted Performance
- X-Ray Energy Range  [few hundreds eV – 5 keV]
- ENC < 20 e\(^{-}\) rms
- Counting Dynamic: from 1 to **10\(^4\)** (not discussed) ph/pix/s
Collecting diode:
- Front-side bias
- AC coupled
- Circular shape

Amplifier:
- Self biased
- Switched power

Output stage:
- Correlated Double Sampling
- Rolling shutter

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Mimosa 22SX design (II)

Energy window

- Discriminator at the end of each column
- Two thresholds provide an energy window
  - Value of the thresholds controlled by the internal DACs (1 step = 0.25 mV ~ 10 e⁻ rms)
Photon detection efficiency: Depletion studies

Studies performed with a Pipper2 circuit
- Tower Jazz 180 nm CIS
- ‘3T’ pixel + analog readout study charge collection
- Identical collecting diode as Mimosa 22SX
- 360 eV - Mn Kα FWHM (10°C) for EPI18

- EPI 18 - TCAD simulation: Depleting max ~ 15µm
- CZ - compare number of entries from Mn Kα with EPI 18

Note: with 30 µm of depletion, 80% of 5keV photons are absorbed
MIMOSA 22SX: Detection efficiency with Energy window

- NIR laser emulates a space-correlated continuous energy spectrum
  - Short laser pulses (100ns) sent at the beginning of every recorded frame
  - Unfocused laser spot $\rightarrow$ center $\sim 6000$ eV, outer ring $\sim 500$ eV

**Reconstructed (energy window scan) laser spot profile**

*Stable number of pulses detected throughout range of thresholds* $\Rightarrow$ *suggest constant detection efficiency from 800 to 6000 eV*
MIMOSA 22SX: Energy window (II)

- $^{55}$Fe spectrum reconstruction
  - Energy window scan -> window width $\sim 250$ eV

![Graphs showing raw analog data and digital reconstructed data with FWHM values.](image-url)
Conclusions

- **PIPPER 2** - Charge collection studies with analog output
  - Front-side bias (30 V) depletes at least 30 µm with 22 µm pitch.
  - Maximum depletion thickness still under investigation

- **MIMOSA 22SX** — a prototype of MAPS counting X-rays
  - Pixel size 22x22 µm²
  - Energy windowing operational
  - Sensitivity (of q-collection & readout) to energy equivalent of 800 eV confirmed.

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Next Steps

Chip processing for back side illumination
- Thinning to depleted depth
- Entrance window for low X-ray energies

Design
- Optimization of amplifier
  - Lower noise
  - Higher speed
- Full scale circuit with 1cm$^2$ active area
Mimosa 22 SX: Fake Rate

- Measurements performed without the source
- Scanning with energy window (~60 eV) from 800eV to 2keV

Above 1 keV, for 1M pixels 1 ‘dark count‘ per frame

Fake Hit Rate @ room Temperature

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Mimosa 22 SX:
Analogue response

• Measurement with $^{55}$Fe at 40V

- Peak at the same position in seed and cluster plots -> single pixel events
- Noise base line $\sim 11$ DAC $\Rightarrow 24$ e$^-$, Peak sigma $\sim 135$ e$^-$ (500 eV)

Amplifier has higher noise than expected, but for first tests with monochromatic X-rays of few keV should be sufficient