MAPS applications: X-ray and bio imaging

Maciej Kachel

PICSEL group

Université de Strasbourg, **IPHC**, CNRS - Strasbourg, France
maciej.kachel@iphc.cnrs.fr

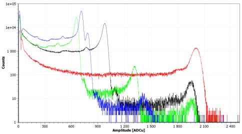
Front-End Electronics May 23, 2018

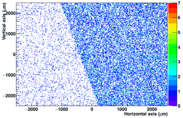
Introduction - Non-HEP applications of MAPS at IPHC

MAPS have been there for some time already, but

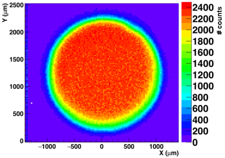
- Applications mainly in HEP thanks to:
  - Low material budget
  - Small pixel size
  - High signal/noise
- Depletion needed for some applications was not available until recently

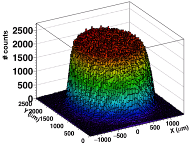
X-ray applications



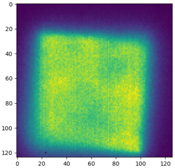


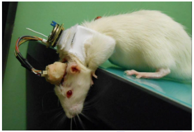
Proton beam profile
CYRCé - IPHC





Bio-imaging





Bio-imaging: MAPSSIC project

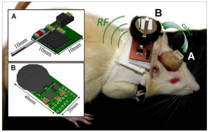
Molecular Neuroimaging on freely Moving Rats a project by IMNC (Orsay), CPPM (Marseille), CERMEP (Lyon), NeuroPSI (Orsay)

Project goals:

- Study molecular processes and behaviour at the same time on freely-moving rats
- Anaesthesia affects neural and vascular response and has effects on multiple physiological processes
- Imaging with radiotracers ^{18}F, ^{11}C

Previous approach - PIXSIC

- 10 passive pixels on silicon (200 x 500 μm^2)
- Connected to readout chip (PICPUS) (long $\sim$ 15 mm lines)
- μC transmits the data by wireless communication



Proof of concept, but drawbacks:

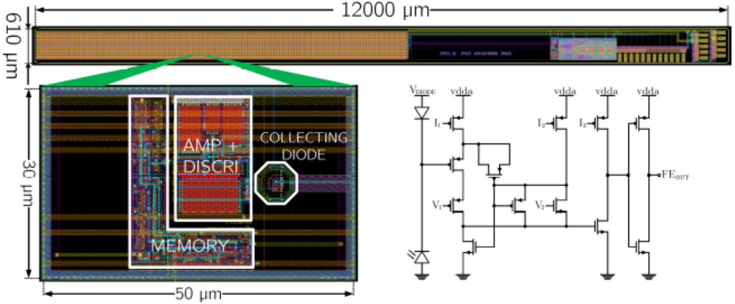
- Low signal to noise ratio
- Sensitive to annihilation gammas $\Rightarrow$ detector 200μm thick

Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

Bio-imaging: IMIC sensor

New sensor - IMIC (Imageur Moléculaire Intra-Cérébral)

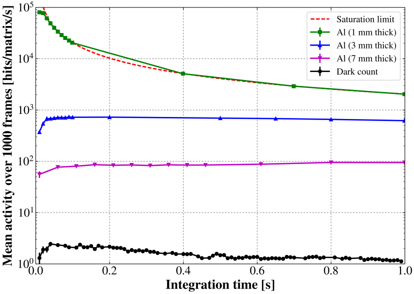
- Designed in 180 nm CMOS Image Sensor technology
- Size : 610 x 12800 μm^2
- Matrix of 16 x 128 pixels
- Pitch: 30 x 50 μm^2
- Fabricated on a high resistivity 18 μm thick epitaxial layer $\Rightarrow$ low efficiency of gamma collection (annihilation photons)
- Pixel design based on ALPIDE front-end with 1bit memory at the output
- Rolling shutter readout, and 16$\rightarrow$1 serialization
- Low power requirement



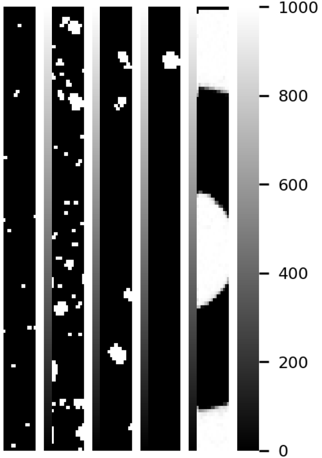
IMIC lab characterization

IMIC controlled by the μC

- **Power dissipated: 161 μW**
- Irradiated with different sources
- Integration time studies performed



Activity range: ≈10 - 60000 hits/matrix/s (for t_{int}=10 ms)

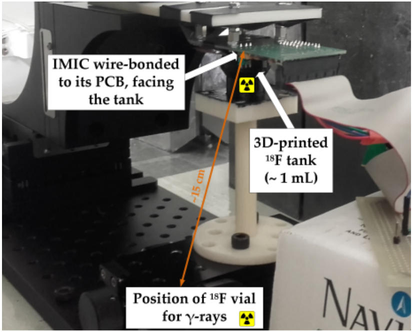


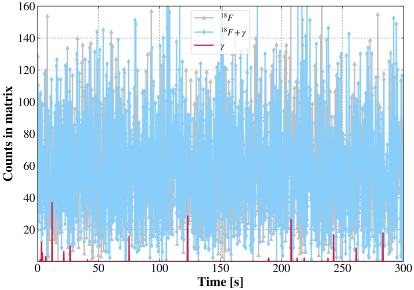
(a) 55Fe (b) 90Sr (c) 18F (d) γ (e) 55Fe*

IMIC sensitivity measurements with ^{18}F

^{18}F source: positron emitter + annihilation photons of 511 keV

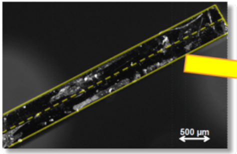
- Produced at CYRCÉ cyclotron (IPHC)
- T1/2=109.7 min
- Tank with low activity close to the sensor: positron emitter
- Vial with high activity (100 MBq) 15 cm away from sensor: annihilation photons emitter

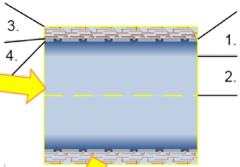


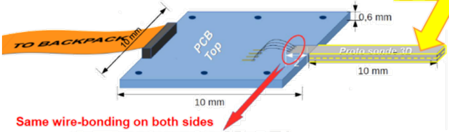


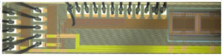
Experiment illustrates the small sensitivity of IMIC to γ-rays with respect to $\beta+$

IMIC Module development



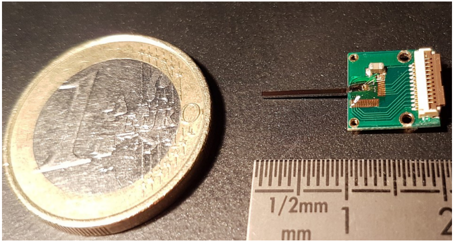






1. Epi-layer (18 µm)
2. P-type Substrate
3. Metallization (~ 10 µm)
4. Process

1.+2.+3. ~ 250 µm



MAPS for low energy X-ray applications

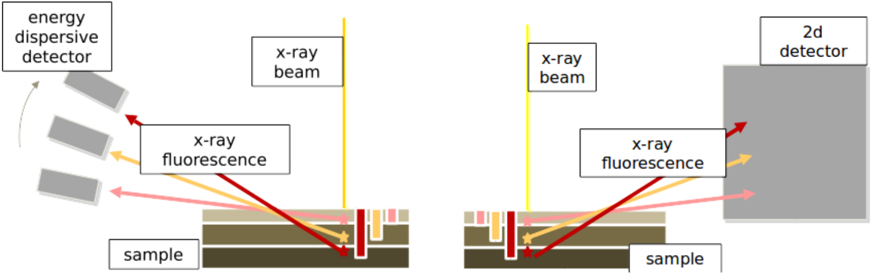
	CCDs	MAPS	SOI	Hybrids
Counting single photons	No	Yes	Yes	Yes
Energy Range	Wide	Limited	Wide	Detector
Noise	Lowest(cooling)	Low	Low	Medium
Cost	High	Low	?	High
Counting Rate	Limited	Moderate	?	High

The PICSEL group has two main application goals in the low energy X-ray domain:

- X-ray imaging at the synchrotron source
- Fluorescence measurements (SF-GEXRF, EDXRF)

Scan Free Grazing Emission X-ray Fluorescence

We have started to work with "Berlin Laboratory for innovative X-ray Technologies" (BLIX) to provide an X-ray sensor for their applications.



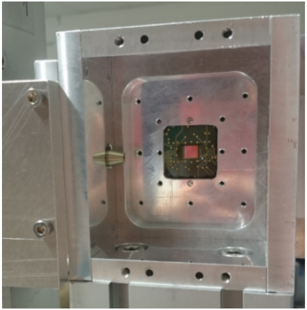
*figures from V.Szwedowski, BLIX

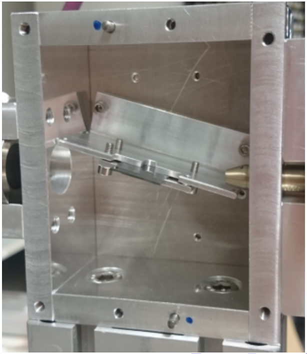
Scan Free Grazing Emission X-ray Fluorescence - first tests

Measurement set-up

The SF-GEXRF set-up was simplified:

- No vacuum
- Short sample-detector distance
- Flat irradiation angles possible
- Since the large detection surface was needed (low X-ray flux), we have use one of the old sensors Mimosa 18 with an active area ≈ 1 cm^2.

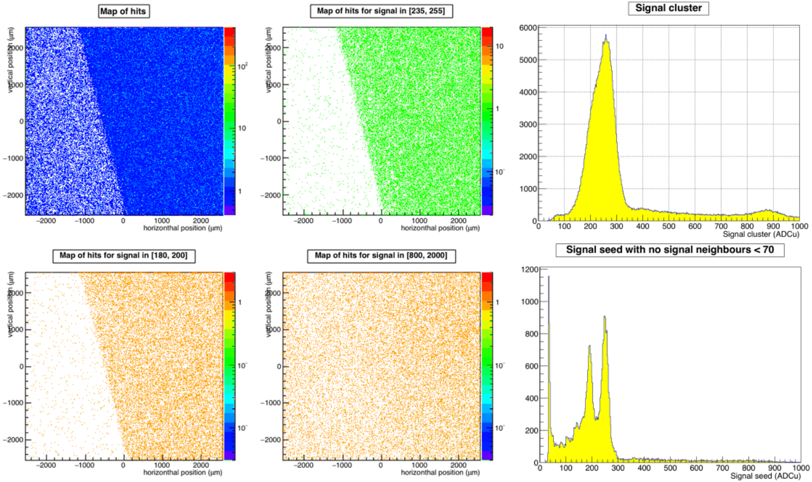




Scan Free Grazing Emission X-ray Fluorescence - first results

Measurements with Mimosa 18

- **Although the sensor is "undepleted", we can still see the good results but only for a fraction of the pixels**
- Sample Cr-Sc multilayer at an angle of 14°

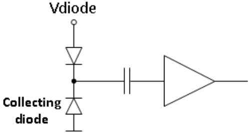


IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

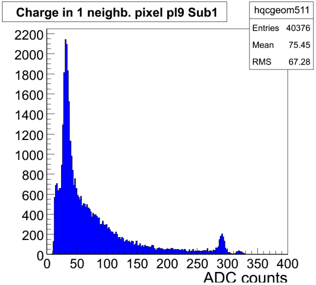
Low energy X-ray fluorescence with depleted MAPS

Obtaining 'full' depletion throughout the sensor

- Fabricate sensor on high-resistivity wafer (Cz, FZ)
- Thinning to $\approx 50\ \mu m$
- Back side processing: Ion implantation and laser activation $\Rightarrow$ entrance window
- Biasing the collecting diode from the front side

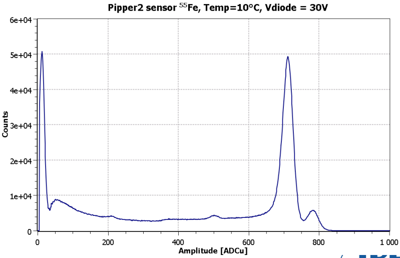


Undepleted Mimosa18

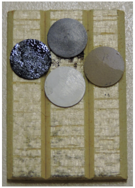


$\Rightarrow$

Depleted Pipper2

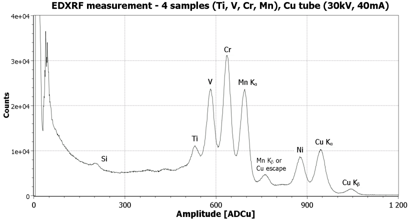


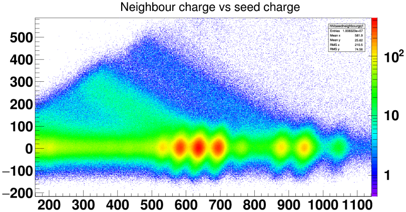
Low energy X-ray fluorescence with depleted MAPS



EDXRF Measurements with 4 samples of Ti, V, Cr, Mn

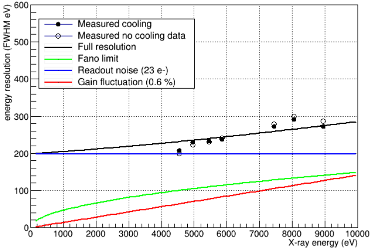
- X-ray lamp with Cu target
- Nickel used for shielding
- Si line seen → internal fluorescence peak

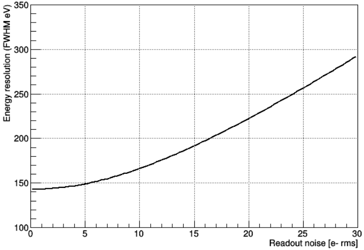




- Energy resolution for fluorescence peaks < 250 eV
- Most of the clusters are single pixels

Energy resolution - Where does it come from?



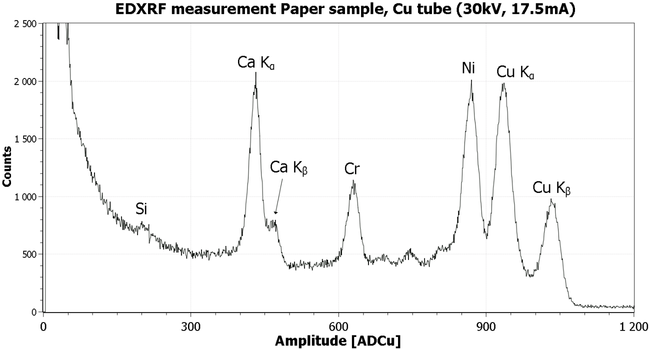


- Readout noise due to a big collecting diode (6 μm diameter), to go below 200 eV $\Rightarrow$ RO noise < 17 e$^-$ rms
- Gain fluctuation of 0.6% at 5.9 keV $\Rightarrow$ FWHM 228 eV $\rightarrow$ 242 eV
- Aiming for room temperature applicatons

Low energy X-ray fluorescence with depleted MAPS

"Unknown" paper sample

- NDT of paper quality - Application idea from *B. Norlin et al. "Precision scan-imaging for paperboard quality inspection utilizing X-ray fluorescence", 2018 JINST 13 C01021*
- Same X-ray setup as before
- Cr from the ink



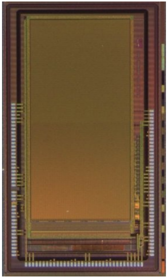
Low energy X-ray imaging at the synchrotron source

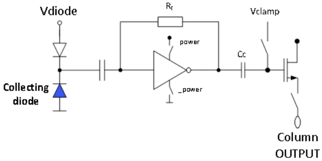
Requirements

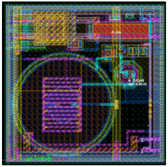
- X-Ray Energy Range [few 100 eV – 5 keV] with 100% QE
- Counting Dynamic [1-10^7] ph/pix/s
- High Spatial Resolution (pixel pitch $\approx$ 20 μm)

First prototype M22SX

- Designed in image sensor 0.18 μm tech.
- 128 x 256 pixels with 22 μm pitch
- Collecting diode AC coupled to the amplifier
- Discriminator with 2 thresholds $\rightarrow$ energy window
- Counting photons outside of the matrix



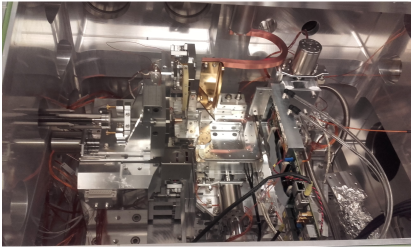


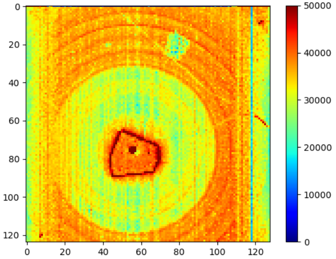


Low energy X-ray imaging at the synchrotron source II

Measurements of M22SX at SOLEIL with Detectors group

- Hermes beam line, Scanning Transmission X-ray Microscope station
- Setup put under vacuum.
- Post processed Mimosa22SX, back side illuminated, vdiode = 40V





Airy pattern of the zone plate at 1.2 keV can be seen
Sensor was damaged with direct beam before this measurement

Conclusions

Different applications (apart from HEP) exist where MAPS may be attractive

- Bio imaging in-vivo
- Low energy X-ray domain: XRF, counting
- Proton beam monitoring

Benefits of MAPS

- Bio-imaging:
  - Thin sensitive layer ⇒ transparency to background
  - Low power dissipation
- X-ray related applications
  - Small pixels
  - Depletion ⇒ quantum efficiency
- General
  - High S/N
  - Low cost

Thank you for your attention