

DEPLETED MONOLITHIC ACTIVE PIXEL SENSOR

Séminaires thématiques

GT08 – DéTECTEURS ET INSTRUMENTATION ASSOCIÉE

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CPPM-CERN-Bonn University-CEA/IRFU-KIT-RD50 collaboration

Outline

- DeMAPS (Depleted Monolithic Active Pixel Sensor)
- DeMAPS for HEP experiments
- DeMAPS for futures experiments
- Challenging prospects

DeMAPS

The LHC upgrades (Run4->) and other future colliders (FCC, CePC...) will lead to a significant **increase in luminosity**.

These future tracker detectors require enhanced granularity, reduced material budget and radiation hardness to all components.

The DeMAPS technology proposes alternative solution as thinner module with less material, finer pixel granularity, lower price on any used technology and much simpler production model.

In addition, enough **radiation hardness**.

DeMAPS

DeMAPS combines the compactness of CMOS sensor with the performance of hybrid planar silicon sensors by :

- using **high-voltage** compliant CMOS processes/design rules. (Electronics shielded from bias voltage)
- using an **isolated deep well** that collects charge **and** includes both analogue and digital circuits -> **monolithic pixel**

Those latter allow large signal and fast charge collection,

Sensors can be thinned **to 50 µm without signal loss.**

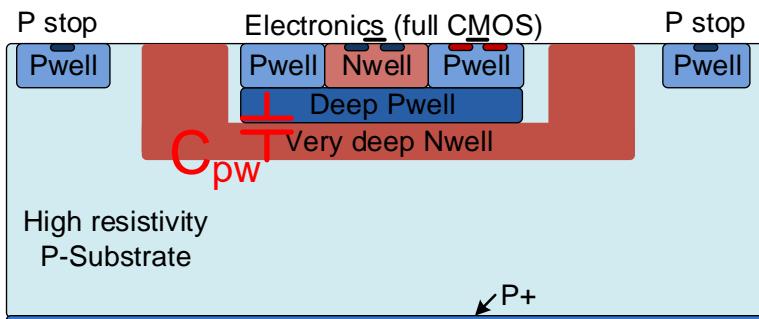
Sensors can operate in a high rate environment (< 25 ns)

And demonstrated radiation tolerance to 100Mrad and 1.5×10^{15} 1Mev neq /cm⁻² in at least 3 technologies (TJ180, LF150, TSi180).

Sensor concepts

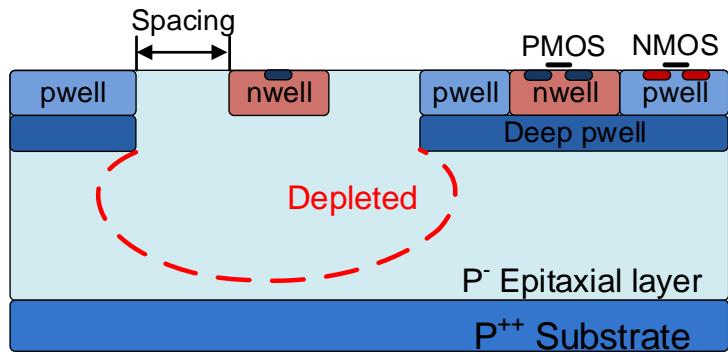
High-rad. envir. => fast charge collection => **depleted** sensitive layer => $d \sim \sqrt{\rho \cdot V}$

Large fill factor (ex. LF-Monopix)



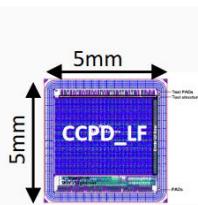
- Rad. hard**
 - uniform field, short drift distance
- Large sensor capacitance (200 - 400fF)**
 - non-negligible C_{pw}
 - noise & speed (power) penalties
 - x-talk: dedicated pixel design needed

Small fill factor (ex. TJ-Monopix)



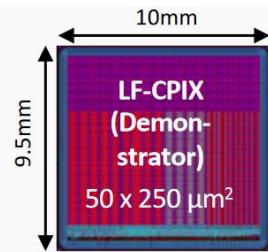
- Very small sensor capacitance (< 10fF)**
 - low noise & power
- Limited depletion, long sig. travel path**
 - dedicated efforts and price to enhance depletion

Lfoundry and TowerJazz DeMAPS prototyping line



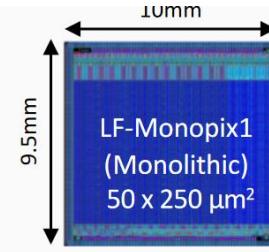
CCPD_LF

- Subm. Sep. 2014
- Fast R/O coupled to FE-I4



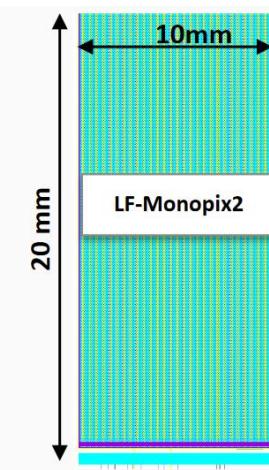
LF-CPIX (DEMO)

- Subm. Mar. 2016
- Fast R/O coupled to FE-I4



LF-Monopix1

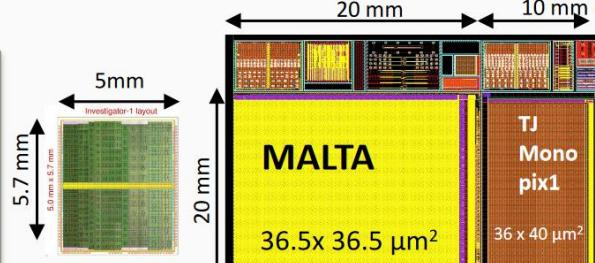
- Subm. Aug. 2016
- Fast column drain R/O



LF-Monopix2

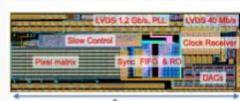
Estimated subm. **spring 2020**

- $50 \times 150 \mu\text{m}^2$ pixels
- Full height matrix
- Fast column drain R/O



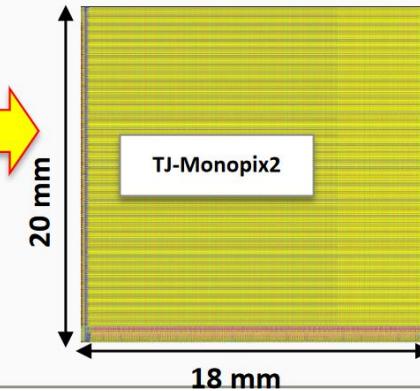
INVESTIGATOR

- 2016
- 8 x 8 pixel submatrices
- MALTA (asynchronous) & TJ-Monopix1 (column drain)
- subm. 2018
- large matrices



miniMALTA

- subm. 2018
- measures for rad. hardness

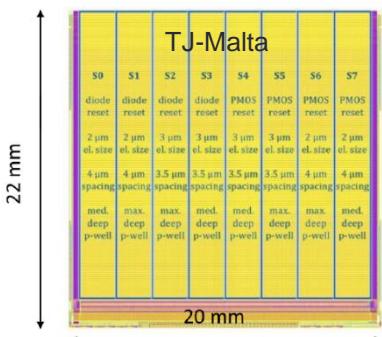


TJ-Monopix2

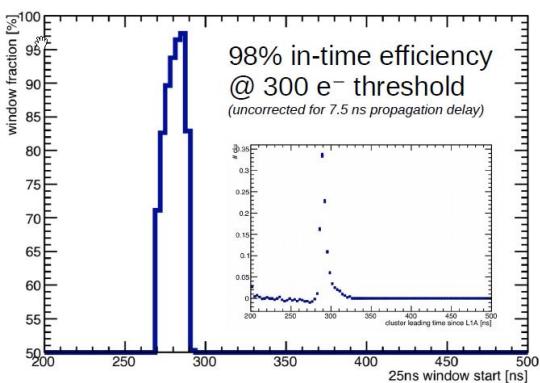
Estimated subm. **spring 2020**

- $33 \times 33 \mu\text{m}^2$ pixels
- Full height matrix
- Fast column drain R/O

TJ MALTA and TJ MONOPIX1 : results

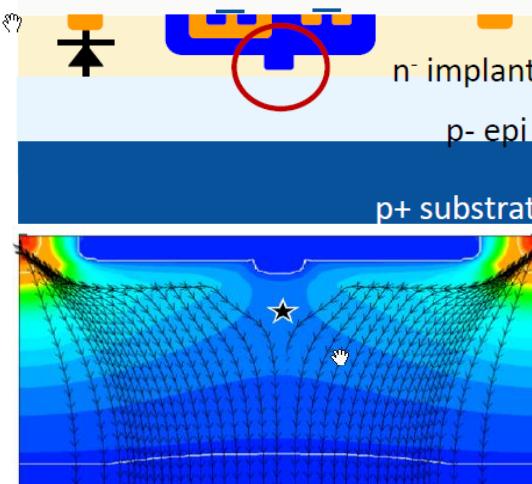


E.J. Schioppa, digital measurement in test beam

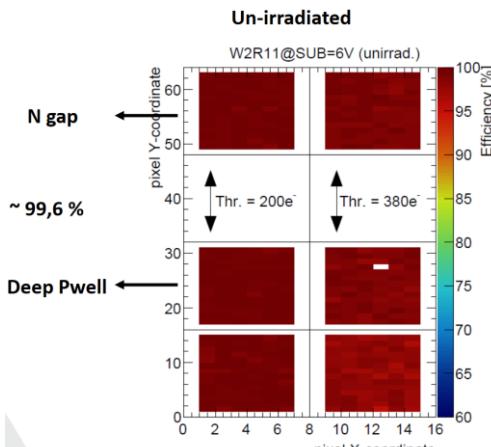


- Weakness understood: weak E field under electronics.
- Modification with (reactive!) founder
→ summer 2018 submission

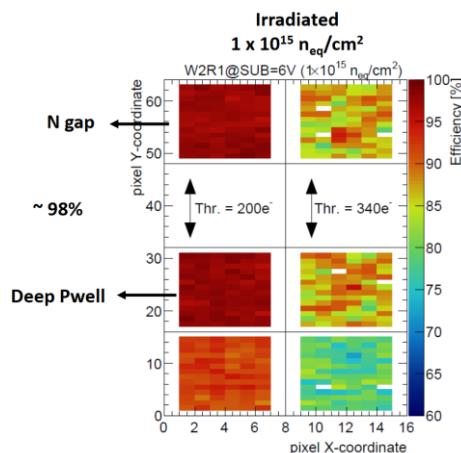
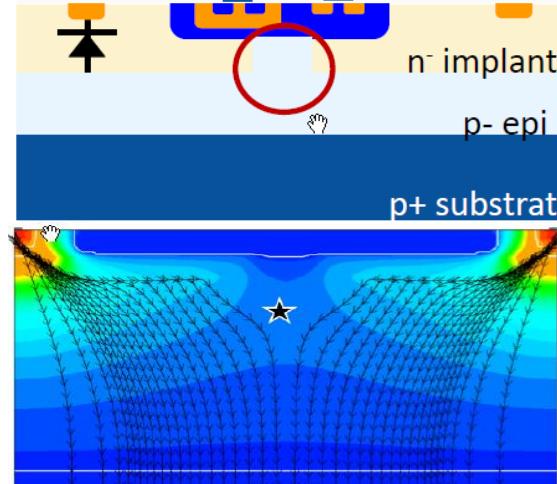
Modification1: Additional PWELL



3D TCAD by M. Munker, CERN



Modification2: Gap in n-implant



LF-MONOPIX1 results

Un-irradiated : Breakdown @ **-280 V** => up to $\sim 300 \mu\text{m}$ depletion

TID tolerance (Proton irradiation)

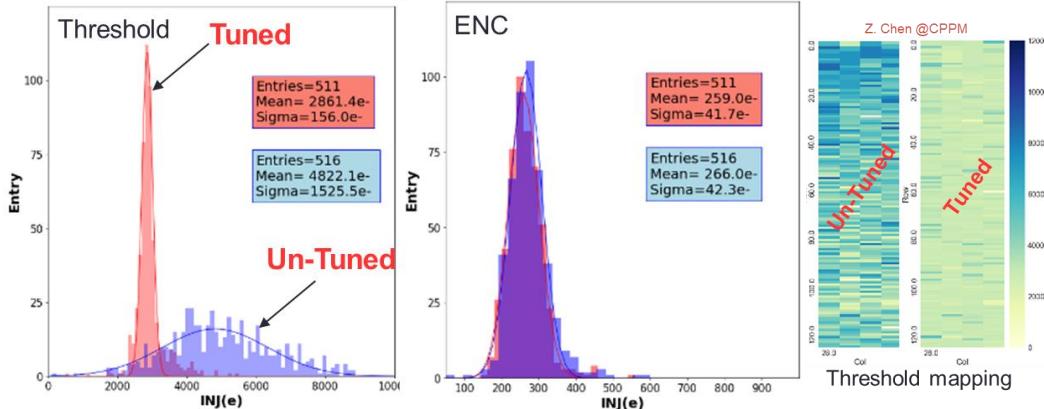
Chip irradiated to **160 Mrad**, 80 days room temperature annealing

Measured at -12 °C, HV = -40 V

NMOS pre-amplifier + Discriminator V2

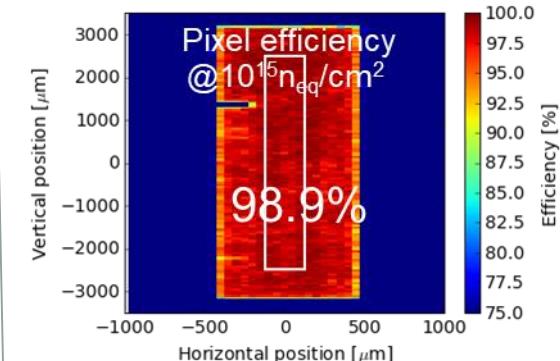
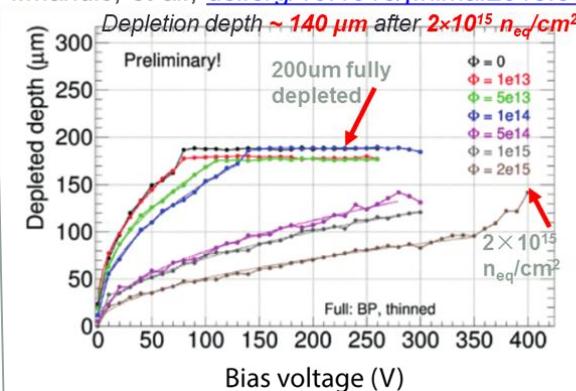
Noise $\sim 250 \text{ e-}$

The threshold dispersion can be tuned to $\sim 150\text{e-}$



Neutron irradiation

I.Mandić, et al., doi.org/10.1016/j.nima.2018.06.062



DeMAPS for futures experiments

- BELLE II upgrade (2026) (see J.Baudot talk)
 - 100mW/cm² et 0,1% à 0,3-0,5% X0 (*material budget consideration*)
 - Pixel size 30-40 µm
 - Time 25ns-100ns
- Beyond 2030-2035
- HL-LHC (ATLAS Post-ITK) : **Hybrid Pixels** or **DeMAPS**
 - 700mW/cm²
 - Actual sensor thickness 200µm (material budget 1% X0) (*prospect lower thickness*)
 - Actual pixel size 50 x 50 µm² (*prospect lower size*)
 - 25ns time resolution
 - TID 500 Mrad, NIEL : 1^E16 neq/cm² (*very challenging*)
- FCC-ee/CEPC-ee (estimation) : **DeMAPS**
 - 20mW/cm² (*prospect lower power consumption*)
 - sensor thickness 50µm (material budget 0,15 - 0,2% X0) (*prospect lower thickness*)
 - Pixel size 25 x 25 µm² or less (*prospect lower size*)
 - 5ns time resolution or less (*prospect timing resolution*)
 - TID 10-100 Mrad, NIEL : 1^E12-1^E13 neq/cm²

Challenging prospects

- Futures colliders (and experiments) request new sensor for tracker detectors
 - Enhanced granularity (small pixel size)
 - Reduced material budget (Thin sensor)
 - Radiation hardness to all components (small node electronic)
- Strong interest in the community to start novel R&T and qualify the candidate
 - Actual DeMAPS qualified technologies are LF 150nm, TJ 180nm, TSI 180nm
 - Next generation should target 65nm or lower technologies
(to reach pixel size lower than 25 μ m x 25 μ m)
 - Lower than 65nm to add new digital functions and read out solution (Gbit serializer)
- Exploration of 4D tracking solutions
 - DeMAPS with enhanced sensor and timing resolution
 - Fast Front-End electronic
 - Low power budget
- Extensive TCAD simulation and prototypes need to be realized
- Extensive test campaigns (under radiation, E-TCT, functionalities..)