CMOS Pixel Sensors for High Precision Beam Telescopes and Vertex Detectors

Rita De Masi
IPHC-Strasbourg
on behalf of the IPHC-IRFU collaboration

• Principle of operation
• Achievements and applications
• Developments
• Summary and conclusions
CMOS sensor principle

• Signal collection
  • Charges generated in epitaxial layer $\rightarrow$ $\sim 1000$ e$^-$ for MIP
  • Charge carriers propagate thermally
  • In-pixel charge to signal conversion

• Advantages
  • High granularity
  • Thickness ($\sim O(50\mu m)$)
  • Integrated signal processing

• Issues
  • Undepleted volume limitations
    • radiation tolerance
    • intrinsic speed
  • Small signal $O(100e^-)/$pixel
  • In-pixel $\mu$-circuits with NMOS transistors only
Basic performances

• more than 30 different sensors designed, fabricated and tested (lab & beam)
• extensive use of AMS 0.35\(\mu\)m OPTO process
• room temperature operation
• noise \(\sim 10^{-15}\)e\(^-\)
• S/N \(\sim 15-30\)
• detection efficiency \(\sim 100\%\)
• fake hit rate \(\sim 10^{-4} - 10^{-5}\)
• Radiation tol. > 1MRad and \(10^{13}\)\(n_{eq}/cm^2\) with 10\(\mu\)m pitch (\(2\times10^{12}\)\(n_{eq}/cm^2\) with 20\(\mu\)m pitch)
• spatial resolution 1-5 \(\mu\)m (pitch and charge-encoding dependent)
Mimosa 26

Fast full scale sensors: 10kFrame/s
column parallel architecture + integrated zero-suppression

Pixel array: 576 x 1152, pitch: 18.4 \( \mu \text{m} \)
Active area: \( \sim 10.6 \times 21.2 \text{ mm}^2 \)

- binary output
  (3.5-4 \( \mu \text{m} \) spatial resolution)
- in-pixel CDS + preamp.
- column level discrimination
- power dissipated \( \sim 150 \text{ mW/cm}^2 \)
  (rolling shutter)
- integration time \( \sim 100 \mu \text{s} \)
- validated in lab

Characterisation @ CERN-SPS this summer
Mimosa 26 applications

- Reference planes of EUDET Beam Telescope
  - Supported by EU FP6
  - Infrastructure to support the ILC detector R&D
  - Commissioning @ CERN summer 2009

- STAR @ RHIC Heavy Flavour Tracker
  - 1152 x 1024 pixels; 200μs integration time
  - Submission end 2009
  - First data 2011/2012

- CBM @ FAIR Micro Vertex Detector
  - Double sided readout (40→20μs integration time)
  - Prototyping until 2012
A VTX detector for the International Linear Collider

Physics requirements

• single point resolution \( \sim 3 \mu m \)
• material budget \( \sim 0.2\% X_0/\text{layer} \)
• integration time \( 25 \text{ – } 100 \mu s \)
• radiation tolerance \( \sim 0.3\text{MRad}, \text{few } 10^{11} \text{n}_{eq}/\text{cm}^2 \)

\[
\sigma_{IP} = a \oplus b/\sin^{3/2}\theta
\]

\[a = 5 \mu m, \ b = 10 \mu m \text{ GeV}\]

\[\text{(LHC } a = 12 \mu m, \ b = 70 \mu m \text{ GeV})\]

A modified Mimosa 26

• Double sided readout
• 0.18 \( \mu m \) technology
• Integration issue \( \rightarrow \) PLUME project: double sided ladder equipped with 2x6 M26 (TDR 2012)
  
  first prototype to be tested in SPS beam next November

\( \sim 0.2 - 0.3\% X_0 \)
Further developments: Mimosa 25

- High resistivity epitaxial layer \( \Omega \cdot \text{cm} \) from XLAB 0.6\( \mu \text{m} \) process

- \( 20 \mu \text{m} \) pixel pitch, 160 \( \mu \text{s} \) readout, \( \sim 1 \text{ mm}^2 \) sensitive area
- Cluster size \( \sim 2 \times 2 \) pixels (3\( \times \)3 for low resistivity epi-layer)
- S/N \( \sim 50 \) for seed (20-25 for low resistivity epi-layer)
- S/N \( \sim 35 \) @ \( 10^{13} \text{n}_{\text{eq}}/\text{cm}^2 \)
- Improved tolerance to non-ionizing radiation (1-2 OM)
- Full characterization @ CERN-SPS this summer
- New: VDSM technology under study in coll. with CERN for sLHC
Further developments: 3D

Benefits:
• Increase integrated processing
• 100% sensitive area
• Select best process per layer task

To be assessed:
• Material budget?
• Power dissipation?

Example
• Tier1: charge collection
• Tier2: analog signal processing
• Tier3: digital signal processing
• Tier4: data transfer

FNAL + IN2P3 + INFN + … consortium
First run (2 Tiers) submitted to Chartered-Tezzaron
Summary and conclusions

• Current CMOS sensors
  • Mature technology for real scale applications
  • High resolution, very low material budget
  • Application under way
    • EUDET-BT, STAR-HFT, CBM-MVD (R&D)
    • ILC-VTX (Option)

• New perspectives
  • Depleted sensitive volume (Non ionizing rad. tol. improved by >1 OM → sLHC)
  • 3D integration technology

More information on
http://www.iphc.cnrs.fr/-CMOS-ILC-.html