A quick review on different Semiconductor Detector Technologies used in High Energy Physics Experiments

Shyam Kumar
INFN Bari, Italy
shyam.kumar@ba.infn.it

1st International Workshop on a 2nd Detector for the Electron-Ion Collider, Temple University, May 17-19, 2023

- **Material:** Silicon (E_g = 1.12 eV) and Diamond (E_g = 5.5 eV)

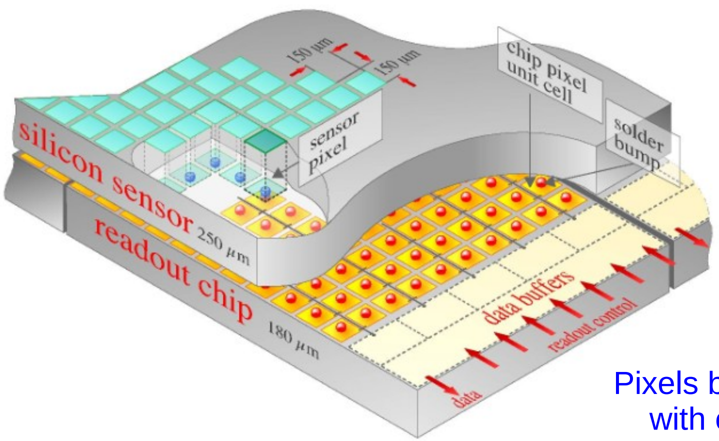
- **Silicon:**
  - Widely used semiconductor material, need to create p-n junction, thin sensors (~50 µm) allows fast charge collection, low multiple scattering, and bending of sensors

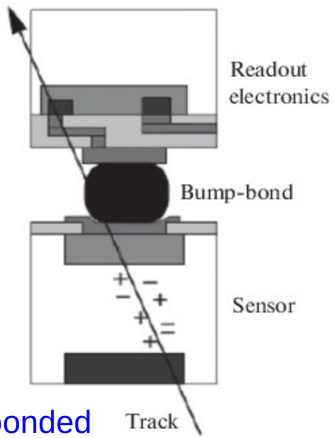
- **Lab Grown Diamond (Microwave Plasma Chemical Vapor Deposition (MPCVD) Process):**

  arXiv:1308.5419

  - Highly resistive, therefore p-n junction not required, radiation hard material (no surface damage and bulk damage is also small w.r.t. Si), single crystal diamond can give a good charge collection efficiency (costly), smaller size (typically ~1cm^2), issue of reproducibility of high-quality diamond
  - Applications as a Beam condition Monitor in ATLAS experiment, Detection of slow and fast neutrons, and **detection of neutrons, at very high temperature at 300⁰C (ITER experiment)**

- **Sensors Structure:** Hybrid pixel sensors

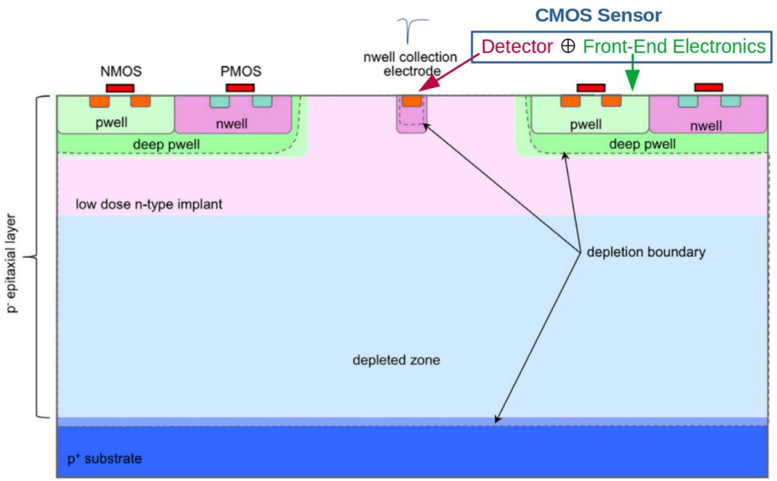




Pixels bump bonded with electronics

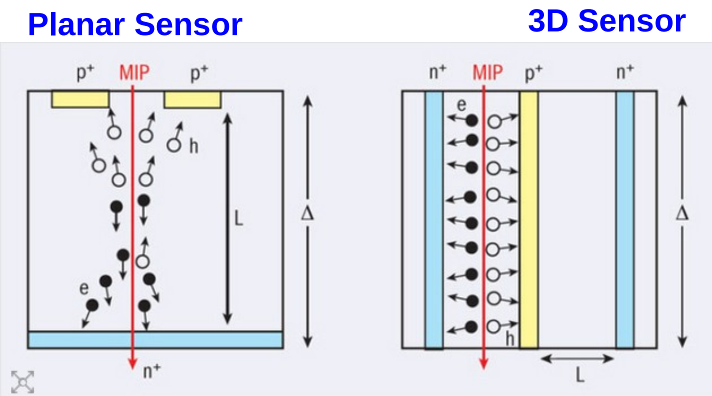
Pixels and electronics on same wafer

Monolithic Active Pixel Sensors: Fully depleted



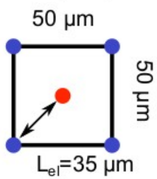
Hybrid Pixel Sensors (Planar and 3D Sensor)

ITk Pixels 3D Sensors (ATLAS)



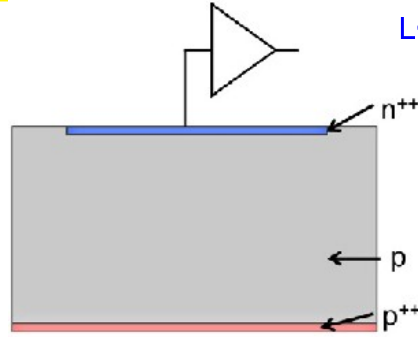
Thickness = Δ

50×50 µm², 1E

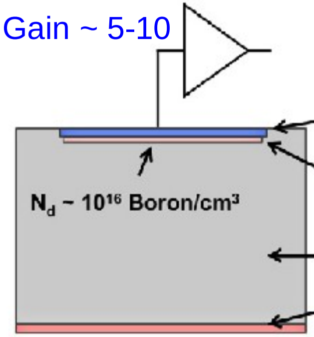


3D Sensor: small pixel, good signal, fast timing, low occupancy, etc.

LGAD Sensor: Gain ~ 5-10



Traditional silicon detector

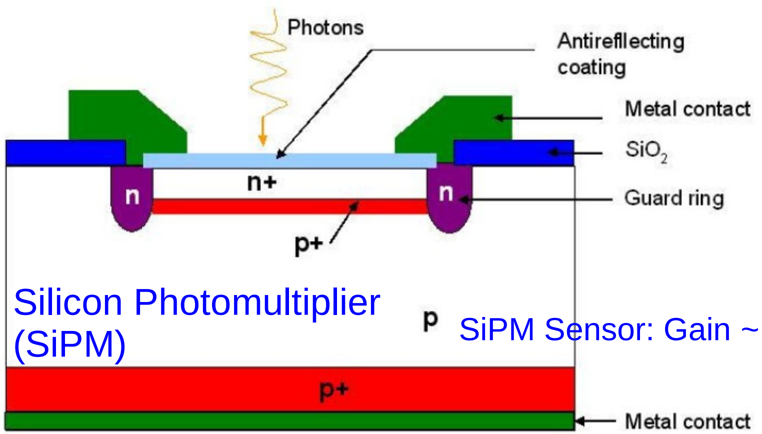


Low gain avalanche detectors

LGAD can provide time resolution of 10s of ps but spatial resolution is poor, End Cap Timing Layer (ETL) (CMS), and High Granularity Timing detector (HGTD) (ATLAS)

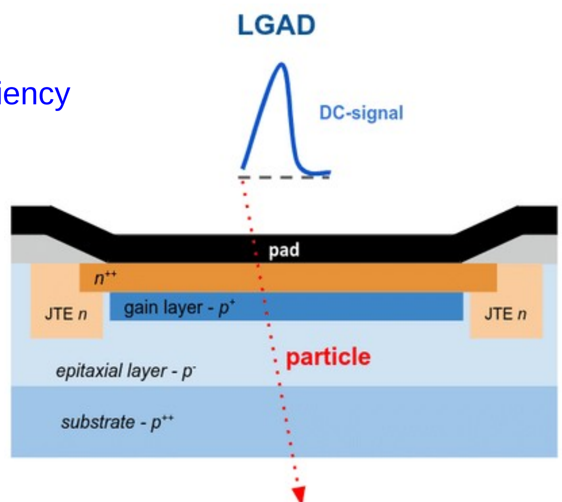
AC-LGAD can provide time resolution of 10s of ps together with a good spatial because of charge sharing

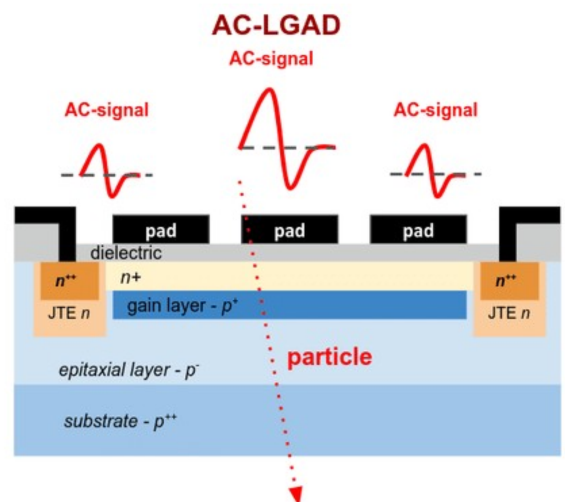
Detection of Single Photon with fast response and good efficiency



Silicon Photomultiplier (SiPM)

SiPM Sensor: Gain ~ 10^6

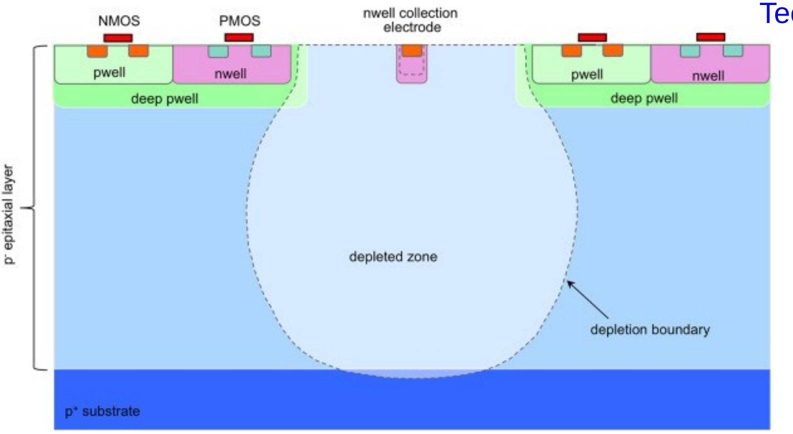




Internal gain in the sensor is very helpful

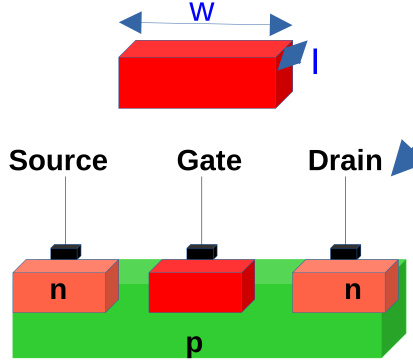
MAPS Sensors

ALICE Run3: CMOS (Complementary Metal Oxide Semiconductor) Sensor



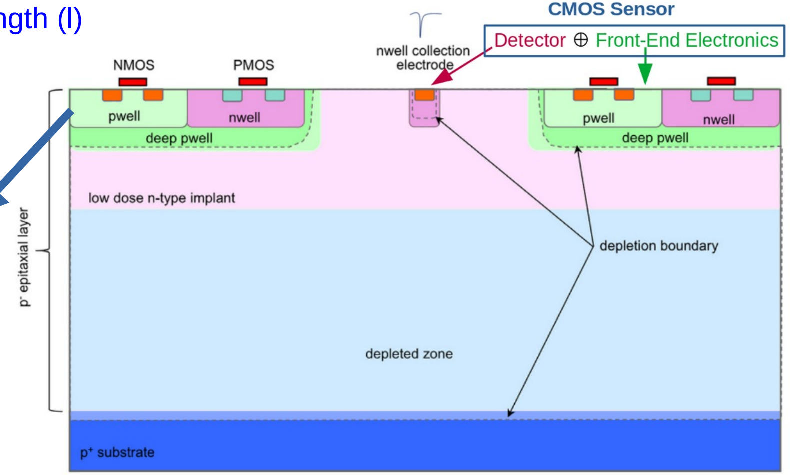
ALICE Run3: Bell Shape depletion region, small charge collection efficiency, and slow if particle deposits charge outside depletion zone (diffusion and then drift)

Technology Node 65 nm = Gate length (l)



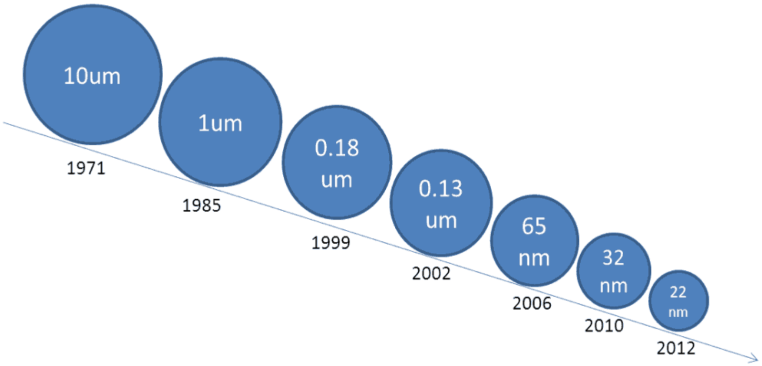
MOSFET: Metal Oxide Semiconductor Field Effect Transistor

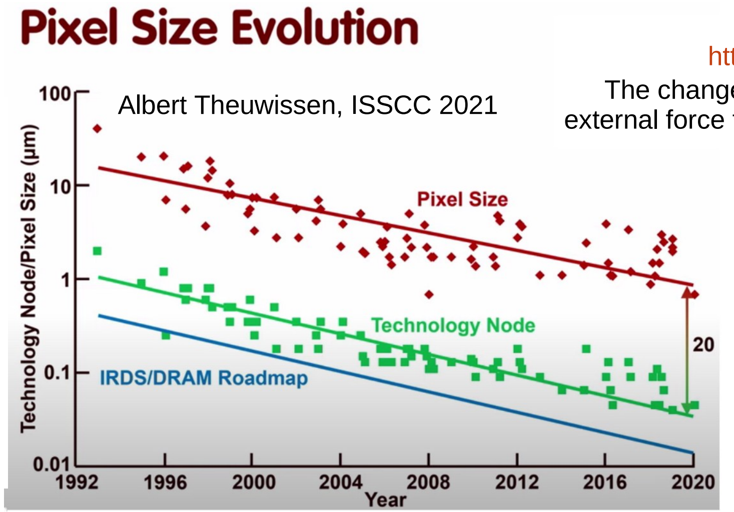
ALICE3: CMOS (Complementary Metal Oxide Semiconductor) Sensor



ALICE3: Fully depleted sensors (Still ongoing R&D)

Transistor technology nodes





Bending of Sensors

https://doi.org/10.1063/1.4906034

The change in electrical resistance due to applied external force to a semiconductor: **Piezoresistive effect**

Further ongoing R&D with MAPS to improve timing performances

References

- A. Kumar and A. Topkar, "A Study of the Fast Neutron Response of a Single-Crystal Diamond Detector at High Temperatures," in IEEE Transactions on Nuclear Science, vol. 65, no. 1, pp. 630-635, Jan. 2018, doi: 10.1109/TNS.2017.2783919.
- Amit Kumar, Arvind Kumar, Anita Topkar, D. Das,Prototyping and performance study of a single crystal diamond detector for operation at high temperatures, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 858, 12-17, 2017.
- T. Rohe, Sensor Concepts for Pixel Detectors in HEP, Pixel 2002. https://www.slac.stanford.edu/econf/C020909/trslide.pdf
- Dalkarov, O.D., Nechaeva, P.Y. & Negodaev, M.A. Silicon Detector Quality Control Demonstrator at LPI Moscow: Status and Perspectives. Phys. Part. Nuclei 52, 766–771 (2021).
- W. Snoeys et al., A process modification for CMOS monolithic active pixel sensors for enhanced depletion, timing performance and radiation tolerance, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 871, 90-96, 2017.
- W. Snoeys, RAPID2021, October 27th, 2021. https://indico.cern.ch/event/1068553/contributions/4538098/attachments/2335049/3979955/RAPID_pixel_W_Snoeys.pdf
- L. Gonella on behalf of the ATLAS collaboration, The ATLAS ITk Detector System for the Phase-II LHC Upgrade, 15th Pisa Meeting on Advanced Detectors, 2022.
- H. Sun et al.,Characterization of the CMS Endcap Timing Layer readout chip prototype with charge injection, JINST 16, 06, P06038 (2021)
- M.P. Casado, A High-Granularity Timing Detector for the ATLAS Phase-II upgrade, Nuclear Instruments and Methods in Physics Research Section A, 1032 (2022)
- Silicon sensors go 3D, 31 May 2012. https://cerncourier.com/a/silicon-sensors-go-3d/
- M. Ferrero et al.,Radiation resistant LGAD design, Nucl.Instrum.Meth.A 919, 16-26 (2019)
- G. D'Amen et al., Signal formation and sharing in AC-LGADs using the ALTIROC 0 front-end chip, JINST 17, 11, P11028 (2022).
- Joëlle Barral, Promotion X2001, Ecole Polytechnique, France, Study of Silicon Photomultipliers, 13th April-2nd July 2004. https://www.physi.uni-heidelberg.de/~dwiedner/DetektorenBeschleunigerWS1112/Study%20of%20Silicon%20Photomultipliers.pdf
- Technology Node, https://anysilicon.com/semipedia/technology-node/.
- C. Neubüser, T. Corradino, G.-F. Dalla Betta, L. Pancheri, ARCADIA FD-MAPS: Simulation, characterization and perspectives for high resolution timing applications, Nuclear Instruments and Methods in Physics Research Section A, 1048, 2023.
- A. Gorišek, V. Cindro, I. Dolenc, H. Frais-Kölbl, E. Griesmayer, H. Kagan, S. Korpar, G. Kramberger, I. Mandić, M. Meyer, M. Mikuž, H. Pernegger, S. Smith, W. Trischuk, P. Weilhammer, M. Zavrtanik, ATLAS diamond Beam Condition Monitor, Nuclear Instruments and Methods in Physics Research Section A, 572, 67-69, 2007.