Evolution of the design of Ultra Fast Silicon Detector to cope with high irradiation fluences and fine segmentation

4D tracking motivation

Ultra fast silicon detectors (UFSDs) are suitable for 4D tracking in future experiments at HL-LHC:

- Time resolution of ~30ps
- Segmentable detectors;
- Performance maintained at fluxes > 10^{11}n/cm²

Low Gain Avalanche Diode (LGAD)

Principle:

Add to n-on-p Silicon sensor a locally enriched p-layer (~10^19 atoms/cm²) below the junction which increases the E-field so that charge multiplication with moderate gain of 10-50 occurs without breakdown.

High Doping Concentration equal High Field

Ultra Fast Silicon Detector (UFSD) is a thin LGAD (~50µm thick) optimized to achieve a time resolution of ~30ps

Radiation effects

Acceptor removal

Investigation of acceptor removal mechanism on different gain layer flavors

- Neutron irradiation
- Proton irradiation

LGD gain mechanism

- The position of the GL determines the field working point: the deeper it is, the lower the field is
- Different manufacturers have different gain layer strategies
- FKB: shallow implant
- HPK: deep implant

At high field the mean free path is saturated, so the "recovering power" of bias is much reduced. At lower field, bias is more effective

UFSD standard design

Trench Isolated LGADs

Trench isolation technology successfully used in FKB SiPMs

Resistive AC-Coupled Silicon Detectors (RSD)

Silicon particle detector with 100% fill factor

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Conclusion

- Ultra Fast Silicon Detectors are being realized in form of thin Low-gain Avalanche Diodes
- Radiation hardness improved by co-implantation of carbon into the gain layer
- The interplay of acceptor removal and the capability to recover the effect of fluence with bias will determine the more radiation resistance designs.
- 16-17µm is the minimum inter-pads distance measured in multi-pad sensors
- Trench isolated and Resistive AC-coupled detectors are the two technological solutions to improve the inactive inter-pads region in multi-pad sensors

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