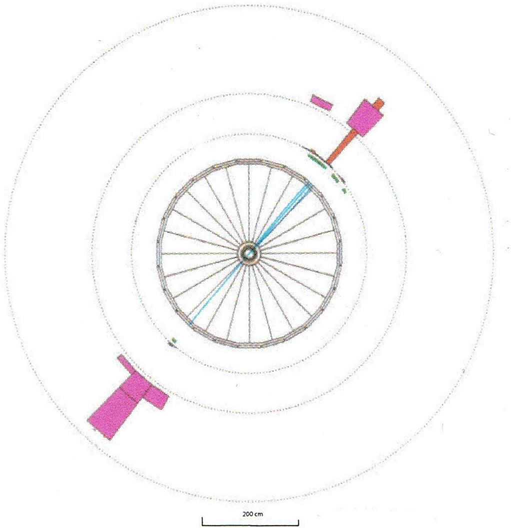
Hybrid Silicon Pixel Detectors

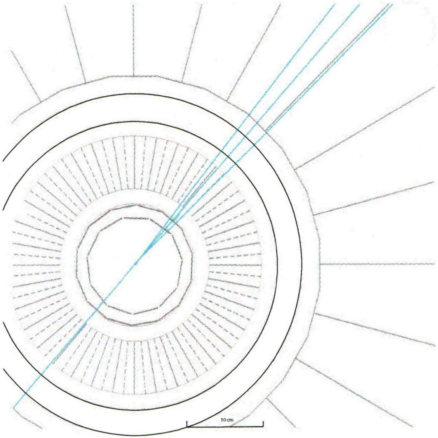
Richard Kaiser

08.12.2017

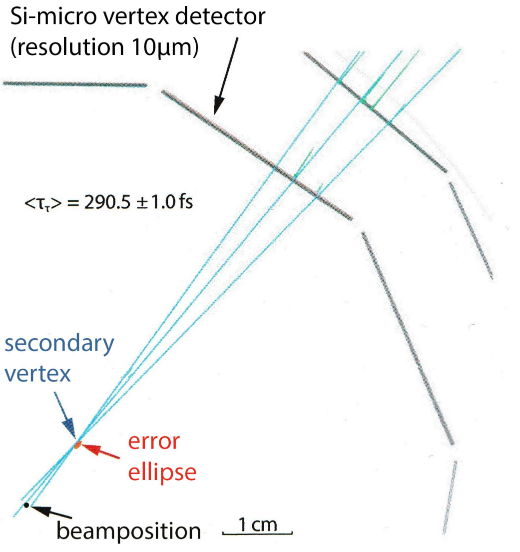
Motivation



Motivation



Motivation



Si-micro vertex detector
(resolution 10µm)
<τ_τ> = 290.5 ±1.0 fs
secondary
vertex
error
ellipse
beamposition
1 cm

Table of Contents

Contents

Semiconductor

- electric conductivity between conductor and insulator
- no free electrons
- valence and conduction band separated through band gap
- band gap small (Si $\approx 1.1eV$)
- electron- hole pairs
- n- and p- doped semiconductors

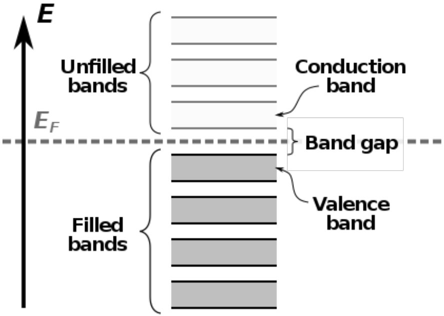
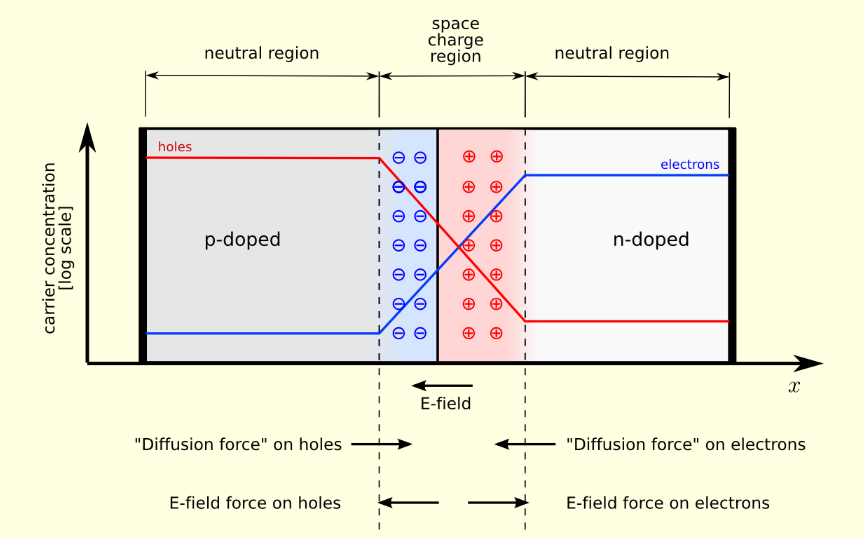


Figure: schematic of particle detection

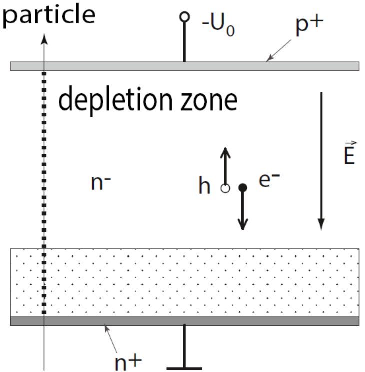
PN-Junction



space charge region
neutral region
neutral region
carrier concentration [log scale]
holes
electrons
p-doped
n-doped
x
E-field
"Diffusion force" on holes
"Diffusion force" on electrons
E-field force on holes
E-field force on electrons

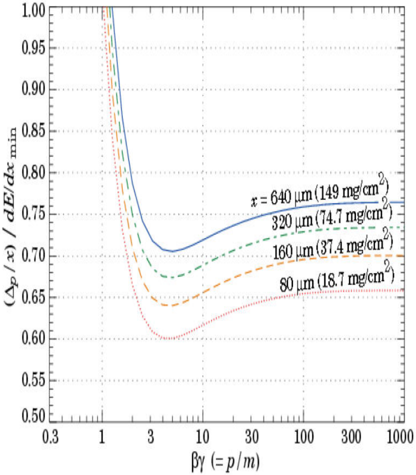
Detection

- only charged particles
- particles traverse the depletion zone
- pn transistor is at maximum depletion
- particle traversing generates electron hole pairs(which do not recombine)
- number of pairs
  $Q = \text{mean MIP ionization} \cdot \text{thickness}$
- $Q = 80e\mu m^{-1} \cdot 300\mu m = 24000e$



Ionisation

- Bethe-Bloch formula
- $-\frac{dE}{dx} = 4\pi\alpha^2 \frac{(\hbar c)^2}{mc^2} n_0 \frac{z^2}{\beta^2} (ln(\frac{2mc^2\beta^2}{(1-\beta^2)I}) - \beta^2)$
- $\alpha \approx \frac{1}{137}$
- $\beta = \frac{v}{c}$
- mean excitation potential $I = 10eV \cdot Z$



How fast?

- driftspeed $v_D = \mu E$
- mobility $\mu = \frac{q\tau}{m_{eff}}$
- relaxationtime τ
- effective mass m_{eff}

Example:

- thickness d$=$ 300μm
- driftspeed in silicon $v_D = 50\mu m/ns$
- $t = \frac{d}{v_D} = \frac{d}{\mu E} \approx 6ns$
- loss of energy $\approx 117keV$

Types of Silicon Pixel Detector

- pad detector

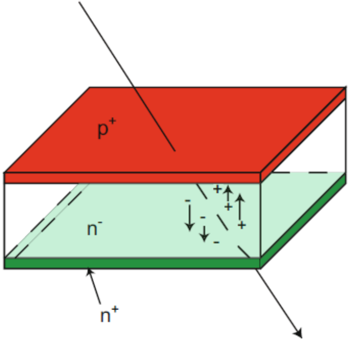


Figure: Pad detector

Types of Silicon Pixel Detector

- pad detector
- pad detector with guard ring

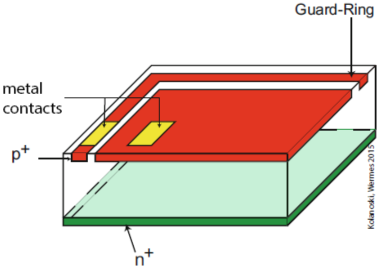


Figure: pad detector with guard ring

Types of Silicon Pixel Detector

- pad detector
- pad detector with guard ring
- pixel detector

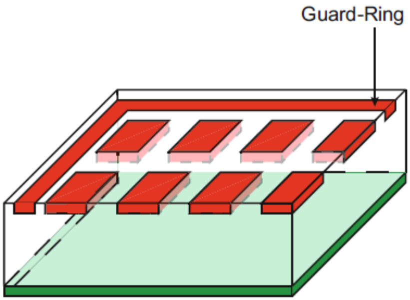


Figure: pixel detector

Types of Silicon Pixel Detector

- pad detector
- pad detector with guard ring
- pixel detector
- strip detector

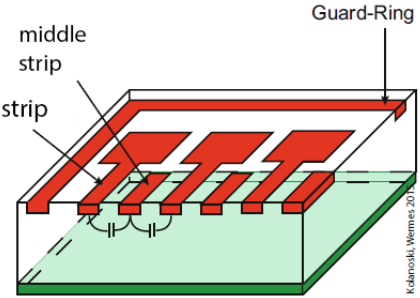


Figure: strip detector

Types of Silicon Pixel Detector

- pad detector
- pad detector with guard ring
- pixel detector
- strip detector
- monolithic pixel detector

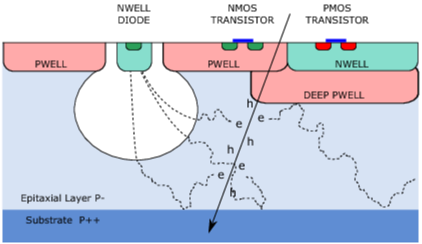
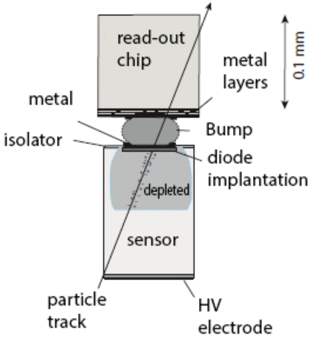


Figure: Monolithic pixel detector

Types of Silicon Pixel Detector

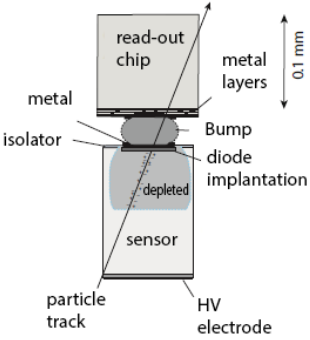
- pad detector
- pad detector with guard ring
- pixel detector
- strip detector
- monolithic pixel detector
- hybrid silicon pixel detectors



(a) hybrid pixel cell

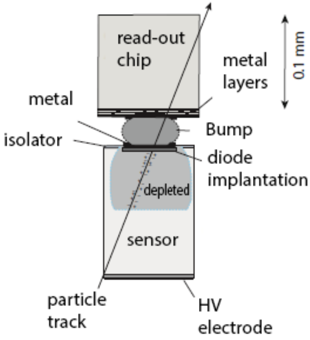
Hybrid Silicon Pixel Detectors

- sensor and chip
- connected via bump
- independent parts this increases yield
- low noise level due to low capacity
- production yield critical
- expensive technology

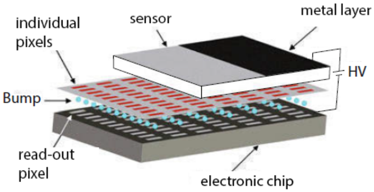


(a) hybrid pixel cell

Concept



(a) hybrid pixel cell



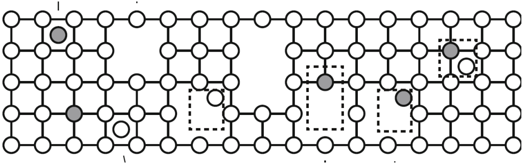
(b) pixel matrix

Problems

- no amplifier at sender side
- high voltages near electronics
- complexity (hard to build this kind of detector)

Irradiation Damage

- radiation causes imperfections
- leakage current
- typeinversion
- trapping

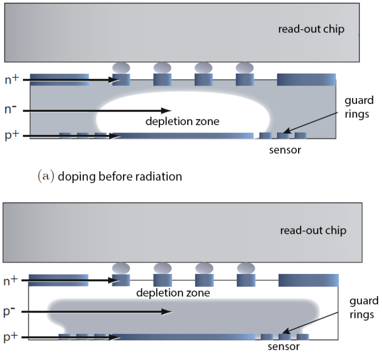


Trapping

- due to irradiation damage defects appear in the silicon
- electrons and holes can be trapped by defects
- higher recombination chance
- signal loss
- holes more affected than electrons

Type Inversion

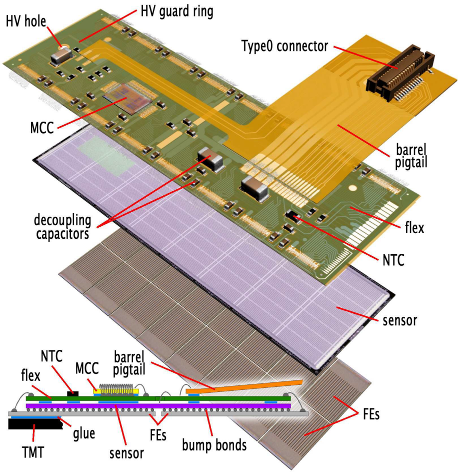
- changes from n to p
- steady voltage increse and decrease of depletion zone
- readout at one point not possible anymore
- due to high radiation near the beam and long useage of the detectors
- solution: use $n^+ n^- p^+$ sensors change to $n^+ p^- p^+$



(a) doping before radiation

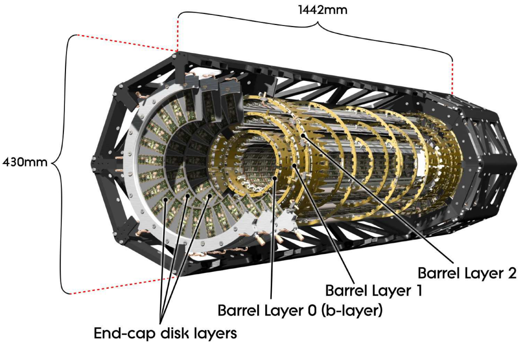
(b) doping after radiation

Atlas schematic



Numbers of Atlas

- pixelsize $50\mu m \cdot 400\mu m$
- barrel layers with
  13,23 and 31 mio Channels
  for layer 1,2 and 3
- 2 endcaps with 3 disks
- each with 2.2 mio channels
- in total 80 mio channels
- active area $1.7 m^2$

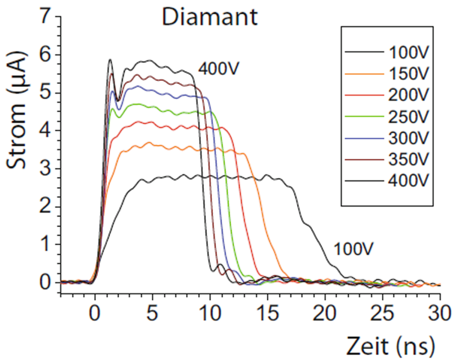


Upgrade Possibilities

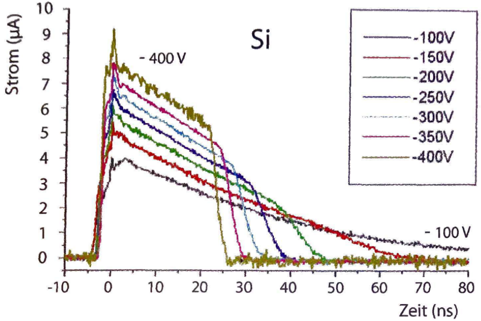
- smaller pixel size
- problem small yield
- other material
- diamond is expensive and new
- new structure
- 3D detectors

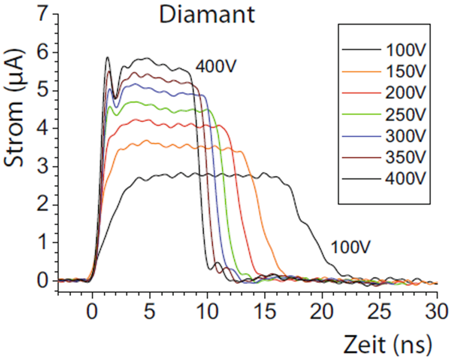
Diamond Detectors

- band gap $\approx 5.5 eV$
- more radiation resistant
- faster electron/hole movement
- expensive to build
- expensive to research
- low efficiency
- usage as a beam monitor



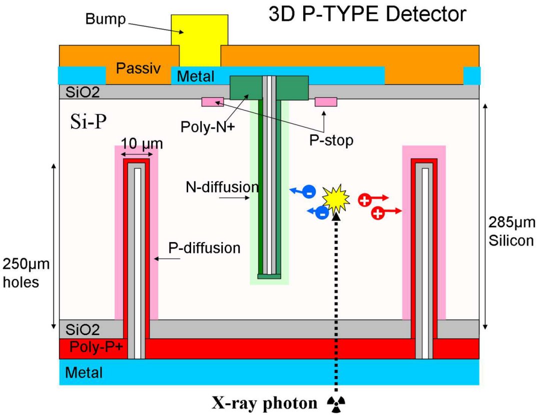
Diamond Detectors





3D-Detectors

- n and p layers reach into depletion zone
- more radiation resistant
- small driftdistance ($\approx 50\mu m$)
- complex structure
- fabrication in industry
- next step in silicon detectors



Conclusion

- wide use in tracking
- fast and low noise signals
- complex structure which is well understood
- limit not yet reached

Thank you for your Attention

Sources

- Book: Teilchendetektoren
- https://www.quantumdiaries.org/2008/07/25/how-a-pixel-detector-works/
- http://aliceinfo.cern.ch/Public/Objects/Chapter2/detectorComponents/silicon_pixel_detector.htm
- http://portal.uni-freiburg.de/jakobs/dateien/vorlesungsdateien/particledetectors/kap_06b.pdf
- http://meroli.web.cern.ch/meroli/lecture_hybrid_pixel_detector.html