Semiconductor detectors

An introduction to
semiconductor detector physics
as applied to particle physics

Contents

4 lectures – can’t cover much of a huge field

- Introduction
- Fundamentals of operation
- The micro-strip detector
- Radiation hardness issues

Lecture 3 – Microstrip detector

- Description of device
- Carrier diffusion
  - Why is it (sometimes) good
- Charge sharing
  - Cap coupling
  - Floating strips
- Off line analysis
- Performance in magnetic field
- Details
  - AC coupling
  - Bias resistors
  - Double sides devices

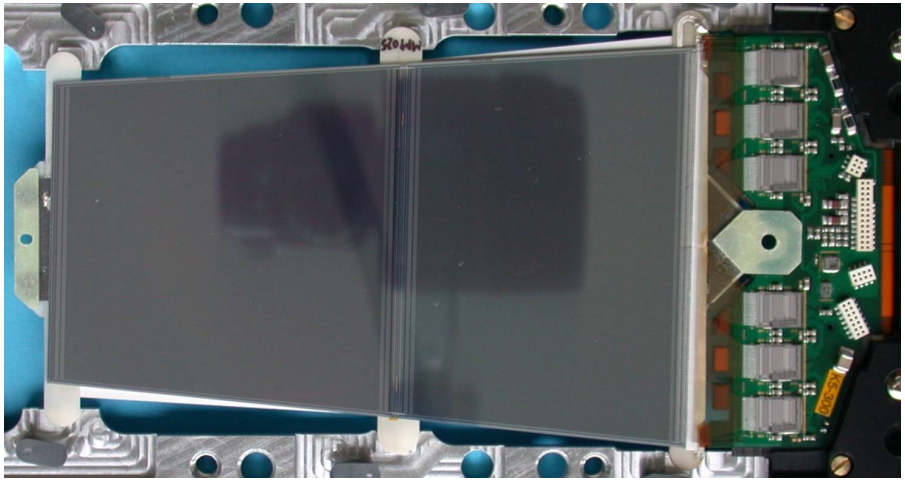
What is a microstrip detector?

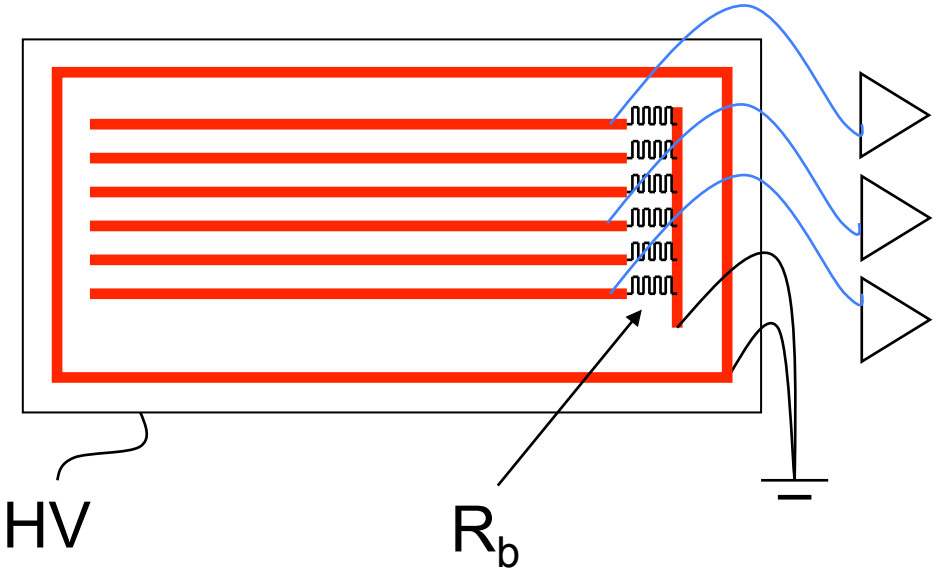
- p-i-n diode
- Patterned implants as strips
  - One or both sides
- Connect readout electronics to strips
- Radiation induced signal on a strip due to passage under/close to strip
- Determine position from strip hit info

What does it look like?

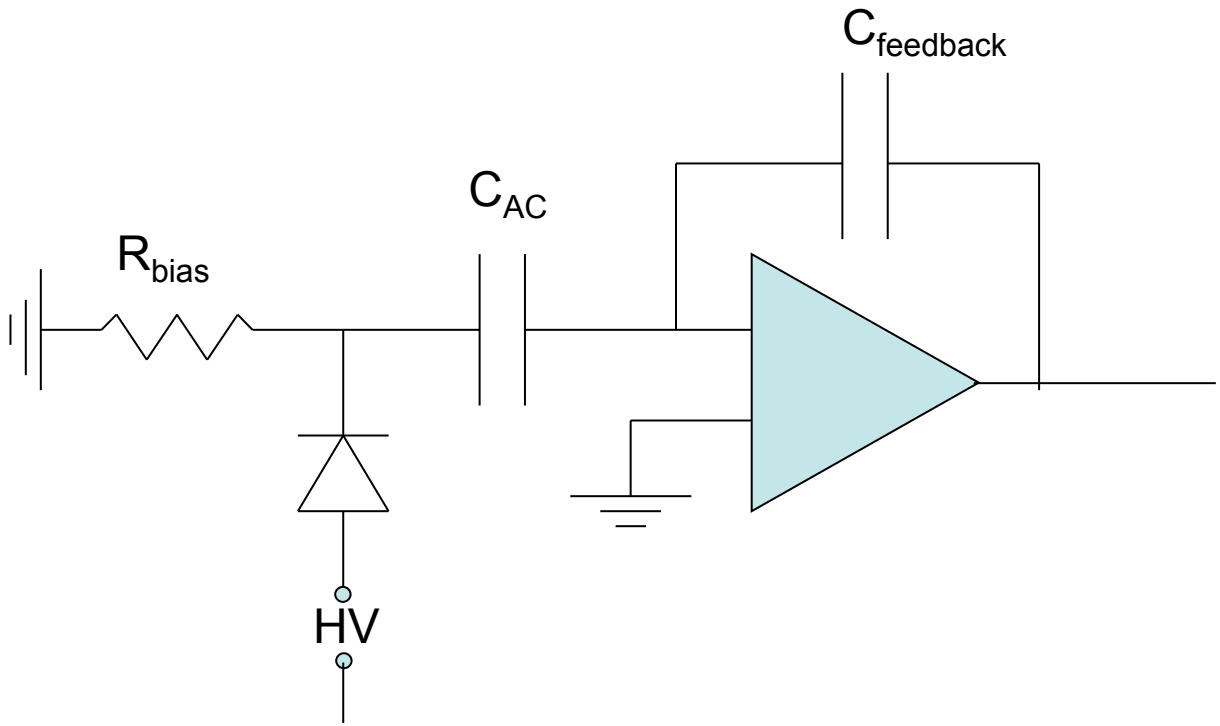
- P+ contact on front of n- bulk
- Implants covered with thin thermal oxide (100nm)
  - Forms capacitor ~ 10pF/cm
- Al strip on oxide overlapping implant
  - Wirebond to amplifier

- Strips surrounded by a continuous p+ ring
  - The guard ring
  - Connected to ground
  - Shields against surface currents
- Implants DC connected to bias rail
  - Use polysilicon resistors MΩ
  - Bias rail DC to ground



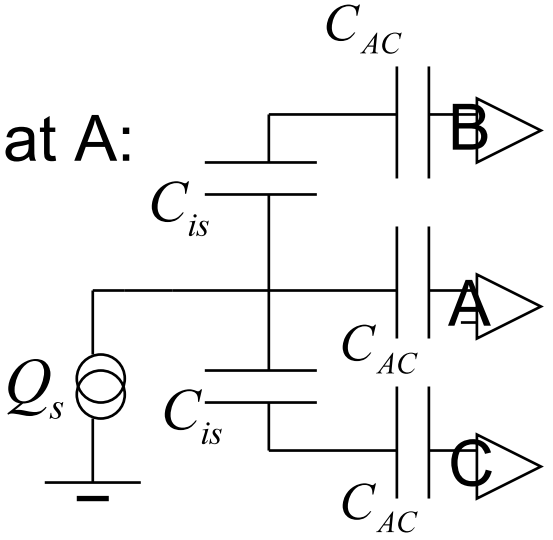


AC coupled strip detector



Capacitive coupling

- Strip detector is a RC network
- $C_{\text{strip to blackplace}} = 0.1 \times C_{\text{interstrip}}$
- $C_{sb} \parallel C_{is} \Rightarrow$ ignore C_{sb}
- Fraction of charge on B due to track at A:



$$K = \frac{Q_B}{Q_A + Q_B + Q_C} = \frac{C_B}{C_A + C_B + C_C}$$

$$C_B = \frac{C_{is} C_{AC}}{C_{is} + C_{AC}} = C_{eff} \qquad \Rightarrow C_{eff} = C_{is}$$

$$K = \frac{C_{eff}}{2C_{eff} + C_{AC}} \qquad as \quad C_{AC} >> C_{is} \qquad \Rightarrow K = \frac{C_{is}}{C_{AC}}$$

$$\Rightarrow K \; is \; small$$

Resolution

- Delta electrons
  - See lecture 2
- Diffusion
- Strip pitch
  - Capacitive coupling
  - Read all strips
  - Floating strips
- Incident Angle
- Lorentz force

Carrier collection

- Carriers created around track $\Phi \approx 1\mu m$
- Drift under E-field
  - p^+ strips on n^- bulk
  - p^+ -ve bias
  - Holes to p^+ strips, electrons to n+ back-plane
- Typical bias conditions
  - 100V, W=300μm E=3.3kVcm^{-1}
  - Drift velocity: e= 4.45x10^{6}cms^{-1} & h=1.6x10^{6}cm^{-1}
  - Collection time: e=7ns, h=19ns

Carrier diffusion

- Diffuse due to conc. gradient dN/dx
  - Gaussian $$\frac{dN}{N} = \frac{1}{\sqrt{4\pi Dt}} \exp\left(-\frac{x^2}{4Dt}\right) dx$$
- Diffusion coefficient: $$D = \frac{kT}{q}\mu$$
- RMS of the distribution: $$\sigma = \sqrt{2Dt_{coll}}$$
- Since D $\propto$ μ & $t_{coll} \propto 1/\mu$
  - Width of distribution is the same for e & h
- As charge created through depth of substrate
  - Superposition of Gaussian distribution

Diffusion

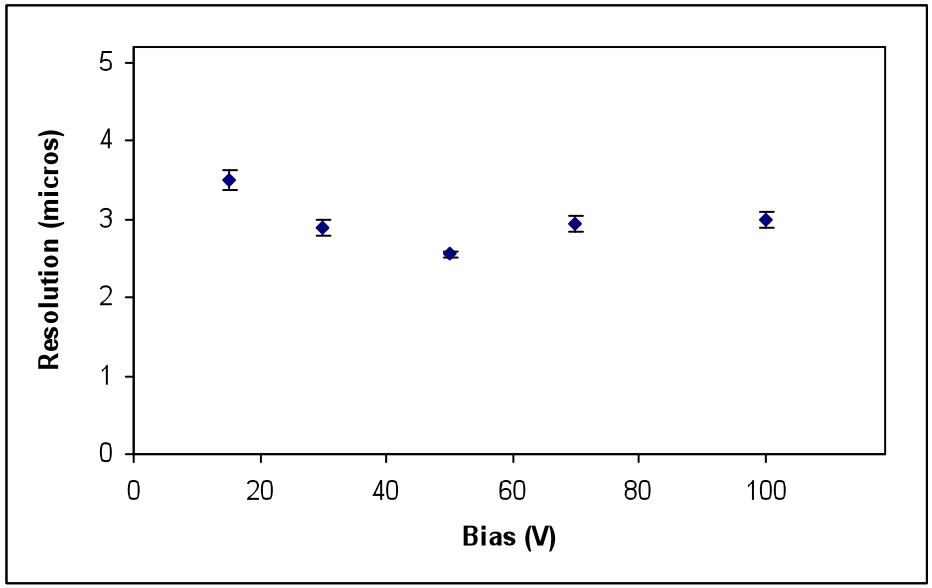
- Example for electrons:
  - tcoll = 7ns; T=20^{o}C
  - ➢ σ = 7μm
- Lower bias $\Rightarrow$ wider distribution
- For given readout pitch
  - wider distribution $\Rightarrow$ more events over >1 strip
  - Find centre of gravity of hits $\Rightarrow$ better position resolution
- Want to fully deplete detector at low bias

  $\Rightarrow$High Resistivity silicon required

$$W = \sqrt{\frac{2\varepsilon V}{q}\left(\frac{1}{N_{eff}}\right)}$$

Resolution as a f(V)

Spatial resolution as a function of bias



V_{fd} = 50V

- V<50V
  - charge created in undeleted region lost, higher noise
- V>50V
  - reduced drift time and diffusion width less charge sharing more single strips

Resolution due to detector design

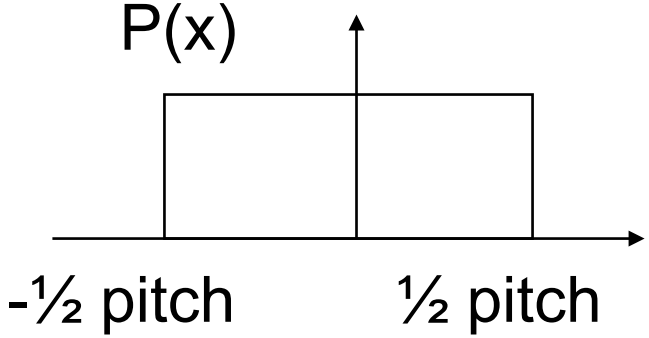
- Strip pitch
  - Very dense
  - Share charge over many strips
  - Reconstruct shape of charge and find CofG
  - Signal over too many strips $\Rightarrow$ lost signal (low S/N)
- BUT
  - FWHM ~ 10μm
  - Technology $\Rightarrow$ limited to strip pitch $\geq$20μm
- Signal on 1 or 2 strips only for normal incident, no B-field

Two strip events

- Track between strips
  - Find position from signal on 2 strips
  - Use centre of gravity or
  - Algorithm that takes into account shape of charge cloud (eta, η)
- Track midway between strip Q on both strips
  - best accuracy
- Close to one strip
  - Small signal on far strip
    - Apply S/N cut to remove noise hits
    - Signal lost in noise

Off line analysis

- Binary readout
  - No information on the signal size
  - Large pitch and high noise
    - Get a signal on one strip only



<x> = 0

$$\sigma_x^2 = \int_{-1/2}^{1/2} \left(x - \langle x \rangle\right)^2 P(x)dx$$

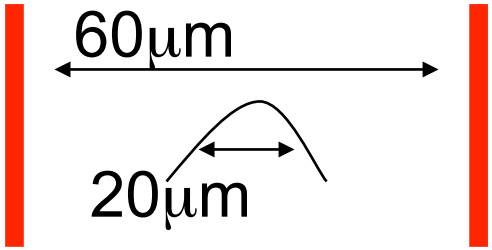
$$= \int_{-1/2}^{1/2} x^2 P(x)dx$$

$$\sigma = \frac{1}{\sqrt{12}} = \frac{Pitch}{\sqrt{12}}$$

Floating strips

- Assume 20μm strip pitch ⇒ σ = 2.2μm

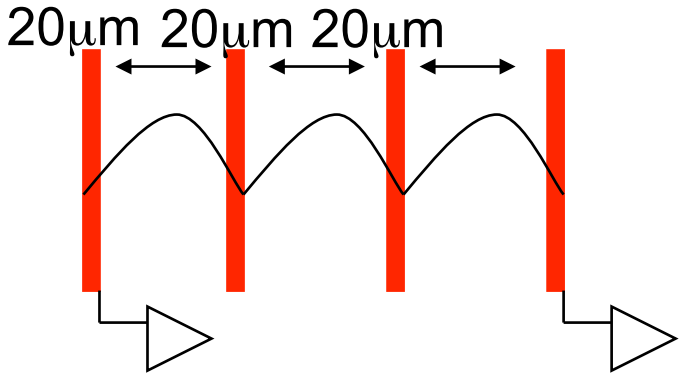
- Large Pitch (60μm)



1/3 tracks on both strips
Assume σ = 2.2μm
2/3 on single strips
σ = 40/√12 = 11.5μm
Overall:

$$\sigma = 1/3 \times 2.2 + 2/3 \times 11.5$$
$$= 8.4\mu m$$

- Intermediate strip

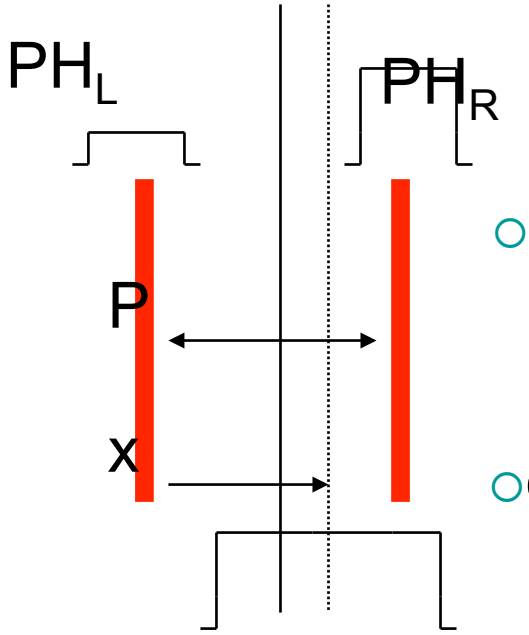


Capacitive charge coupling
2/3 tracks on both strips
NO noise losses due to cap coupling
1/3 tracks on single strips
σ = 2/3 x 2.2 + 1/3 x 20/√12
= 3.4μm

Centre of Gravity

- Have signal on each strip
- Assume linear charge sharing between strips

$$X = \frac{\sum_{i=strips} PH_i \times x_i}{\sum_{i=strips} PH_i}$$



- Q on 2 strips & x = 0 at left strip

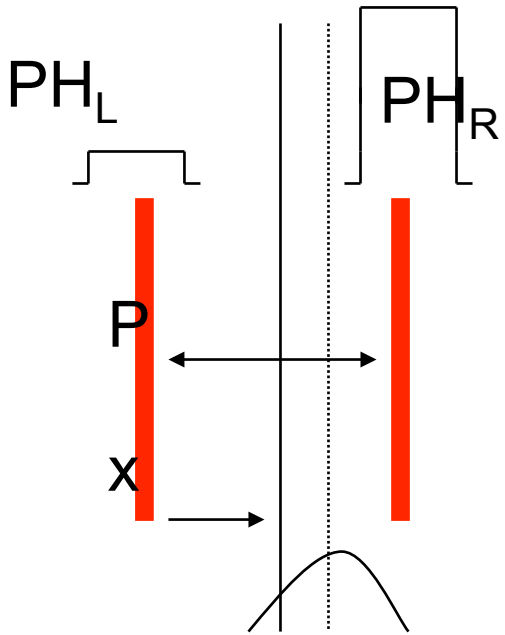
$$X = \frac{PH_R \times P}{PH_L + PH_R}$$

- e.g. $PH_L = 1/3 PH_R$

$$X = \frac{1/3 \times 0 + 3/4 \times P}{1/3 + 3/4} = \frac{3}{4} P$$

Eta function

– Non linear charge sharing due to Gaussian charge cloud shape

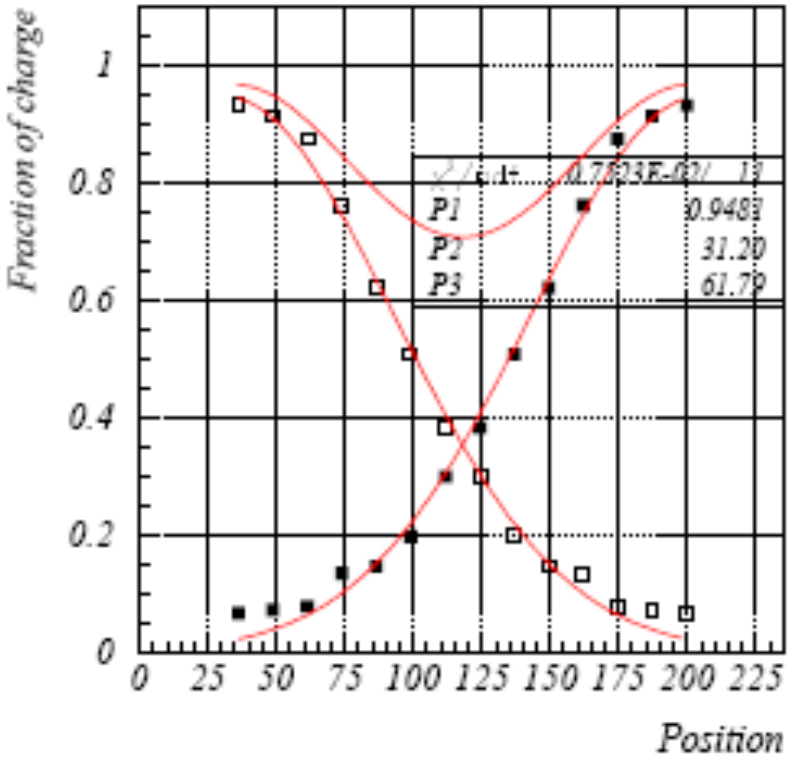


More signal on RH strip
than predicted with
uniform charge cloud shape

Non-linear function to determine
track position from relative pulse
heights on strips

Measure Eta function

- Testbeam with straight tracks
- Reconstruct tracks through detector under test
- Measure deposited charge as a function of incident particle track position

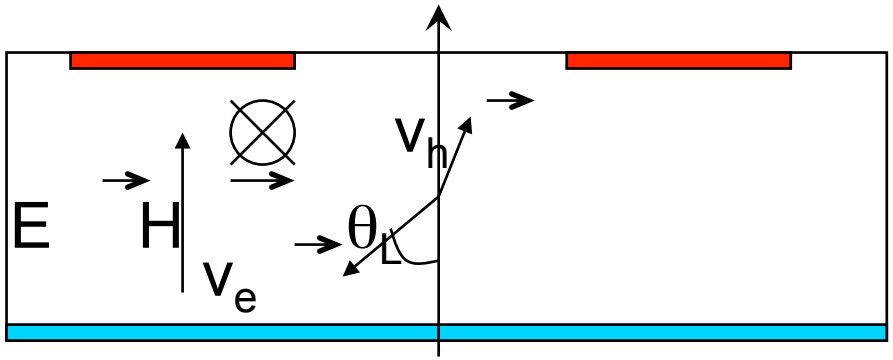


Lorentz force

- Force on carriers due to magnetic force

$$\vec{F} = q\left(\vec{E} + \frac{\vec{v}}{c} \times \vec{B}\right)$$

- Perturbation in drift direction
  - Charge cloud centre drifts from track position
  - Asymmetric charge cloud
  - No charge loss is observed
- Can correct for if thickness & B-field known



Details

- Modern detectors have integrated capacitors
  - Thin 100nm oxide on top of implant
  - Metallise over this
  - Readout via second layer
- Integrated resistors
  - Realise via polysilicon
    - Complex
  - Punch through biasing
    - Not radiation hard
    - Back to back diodes – depleted region has high R

Details

- Double sided detectors
  - Both p- and n-side pattern
- Surface charge build up on n-side
  - Trapped +ve charge in SiO
  - Attracts electrons in silicon near surface
  - Shorts strips together
  - p+ spray to increase inter-strip resistance