Silicon detectors

Intrinsic silicon

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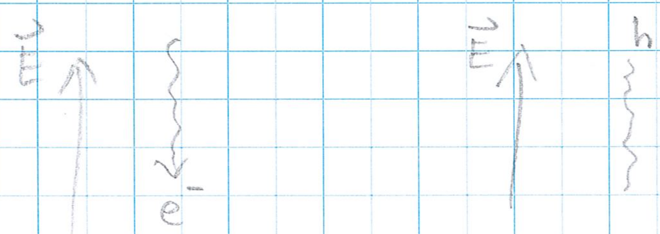
A free electron will migrate through the lattice.

$$\vec{J} = nq\vec{v} = \sigma \vec{E}$$

Likewise, a hole will migrate in the opposite direction.



Mobility, μ : $\vec{v}_e = -\mu_e \vec{E}$

$\vec{v}_h = \mu_h \vec{E}$

At 300 K $\mu_e \approx 145 \ \mu m^2 / V \cdot ns$

$\mu_h \approx 45 \ \mu m^2 / V \cdot ns$

Example : $d = 320 \ \mu m$
$V = 100 \ V$

$$|E| = 0.313 \ V/\mu m$$

Carrier speed : $v_e = 45 \ \mu m/ns$

$v_h = 14 \ \mu m/ns$

Drift time : $T_e = d/v_e = 7$ ns

$T_h = d/v_h = 23$ ns

Doped silicon:

Conductivity of intrinsic silicon, $n_e = n_h = n_i$

$$\vec{J} = e n_i (\mu_h + \mu_e) \vec{E} = \sigma_i \vec{E}$$

Intrinsic conductivity is very low:

$\sigma_i \sim 10^{10}$ cm^{-3} at 300K.

Number density of Si atoms:

$$n_{Si} = \frac{\rho}{m} N_A = 5 \times 10^{22} \text{ cm}^{-3}.$$

Doped silicon:

A small number of donor or acceptor atoms will completely determine the conductivity.

$$n_{Si} \gg n_D \gg n_i$$

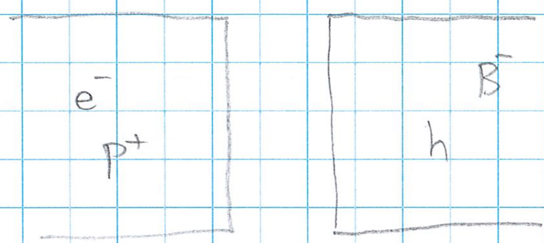
Phosphorus donates electrons n-type

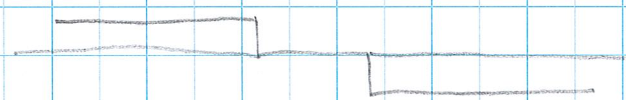
Boron makes a hole : p-type

$$\sigma_n = e n_D \mu_e$$

$$\sigma_p = e n_D \mu_h$$

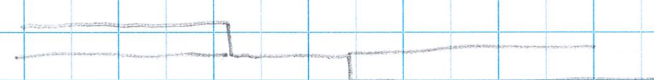
P-N junction



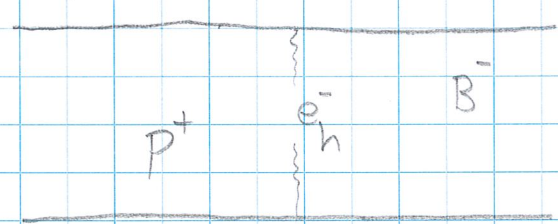


n-type dopant concentration

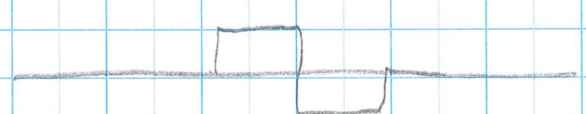
charge density



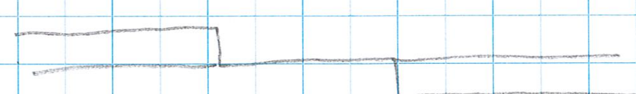
carrier density



n-type dopant concentration



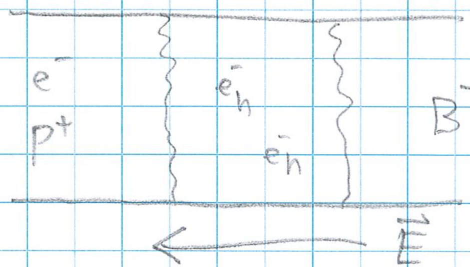
Charge density



carrier density

depletion region

An electric field forces more electrons and holes into the depletion region:

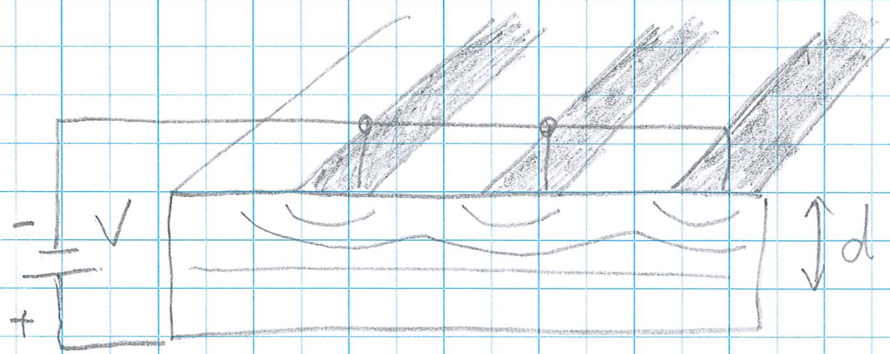


Carrier density

Charge carriers can still exist in the depletion region. Created by

- Thermal excitation
- Ionizing radiation

Silicon Strip detectors



depth of depletion region:

$$d = \sqrt{2 \varepsilon \rho \mu V}$$

Parallel plate capacitor

$$C = \frac{\varepsilon A}{d}$$

$$\frac{1}{C^2} \propto V$$

Mean energy loss of a MIP in 320 um thick sensor

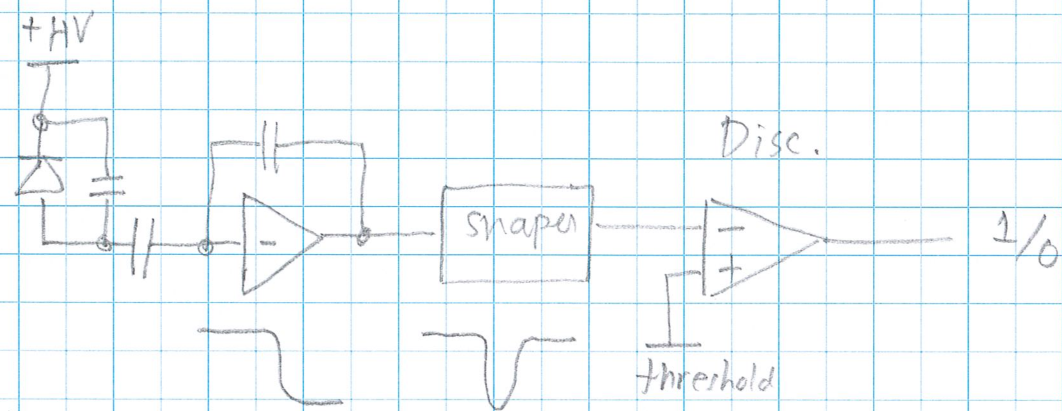
$$\langle \Delta \rangle = (377 \text{ eV}/\mu m)(320 \mu m) = 120 \text{ keV}$$

Energy needed to produce one $e^- h$ pair:

3.6 eV

A MIP produces 33,000 $e^- h$ pairs.

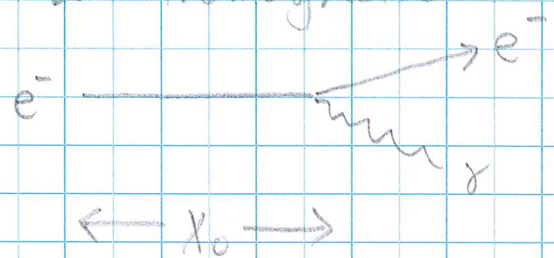
Motion of e^- and h in the electric field induces a current on the implanted strips (image charge).

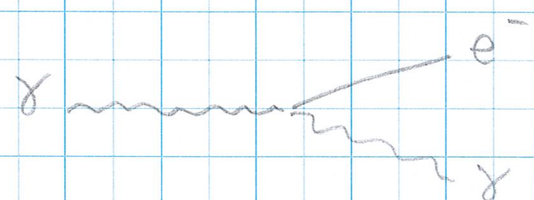


This circuit must be implemented on each and every strip (or pixel)

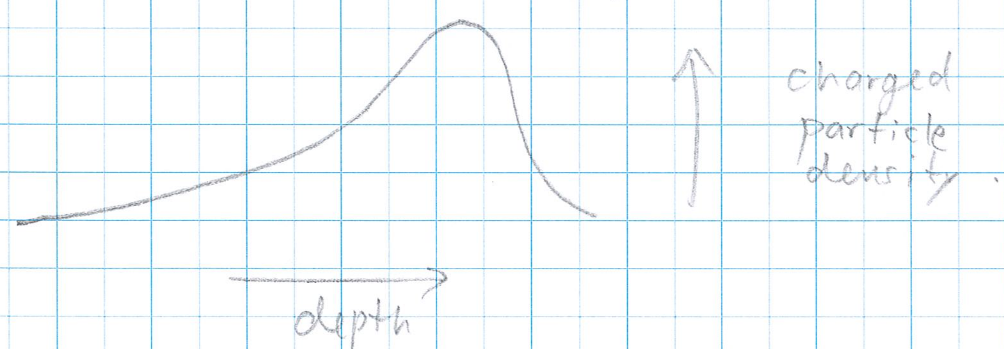
Sampling Calorimeters.

Electromagnetic





The number of secondary particles approximately doubles each X_0 of depth.



The charged component will ionize the detector material.

Sampling calorimeter:

Alternating layers of sensitive elements and radiator material.

Longitudinal shower development

$$\frac{dE}{dt} \propto t^{\alpha} e^{-t} \qquad t \text{ is in } X_0$$

Shower max at $t_{max} = \log \frac{E}{E_c} \cdot \frac{1}{\log 2}$

95% containment $t_{95\%} \approx t_{max} + 0.08Z + 9.6$
(In X_0)

Lateral shower profile

Molière radius

$$\rho_m = \frac{21\ \text{MeV}}{E_c} X_0 \approx 7 \frac{A}{Z} \left(g/cm^2 \right)$$

About 90% of the energy is contained within a cylinder of radius ρ_m.
95% within $R < 2\rho_m$.

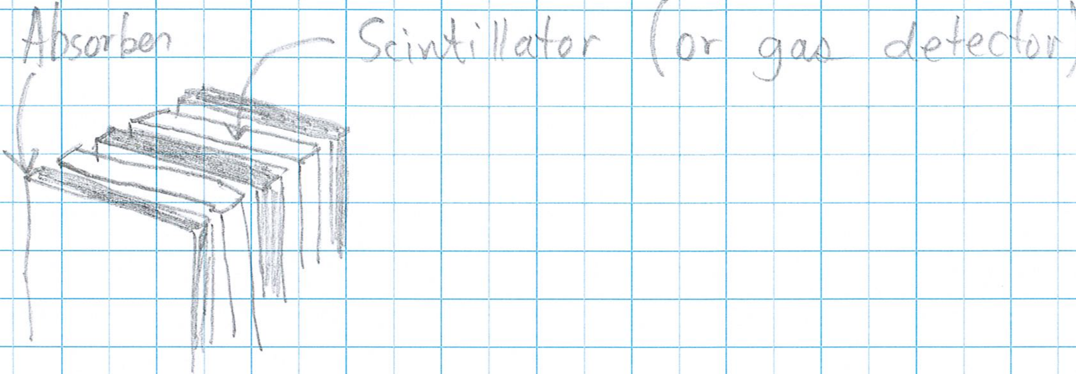
$E_c = 19$ MeV for Cu, Zn,

$E_c = 21$ MeV for Fe

$E_c = 42$ MeV for Al

http://pdg.lbl.gov/2017/AtomicNuclearProperties/

Sampling calorimeters



Energy resolution:

$$\Delta E \propto \sqrt{N} \quad \text{(Poisson statistics)}$$

$$N \propto E$$

$$\frac{\Delta E}{E} = \frac{\alpha}{\sqrt{E}} \oplus \beta \oplus \frac{\gamma}{E}$$

α = stochastic term
β = constant term
γ = noise

Homogeneous calorimeters

Absorb the entire shower in sensitive material.

eg, Dense scintillating crystals.

BGO
CsI
$PbWO_4$