Power Electronics Introduction

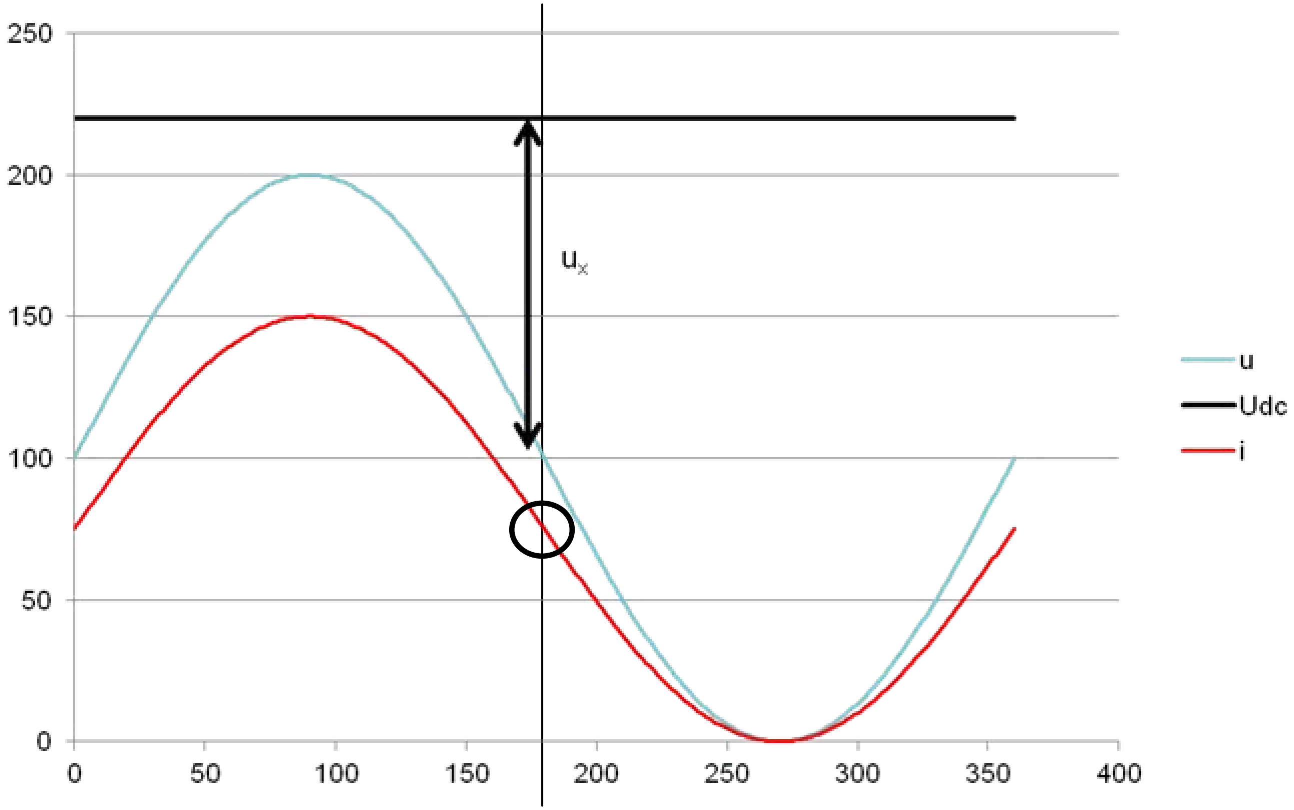
”Definition”

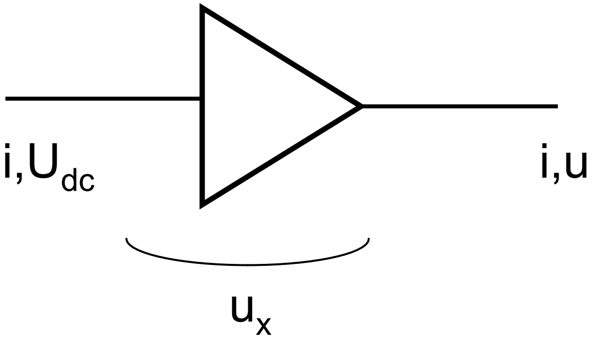
Power Electronics

=

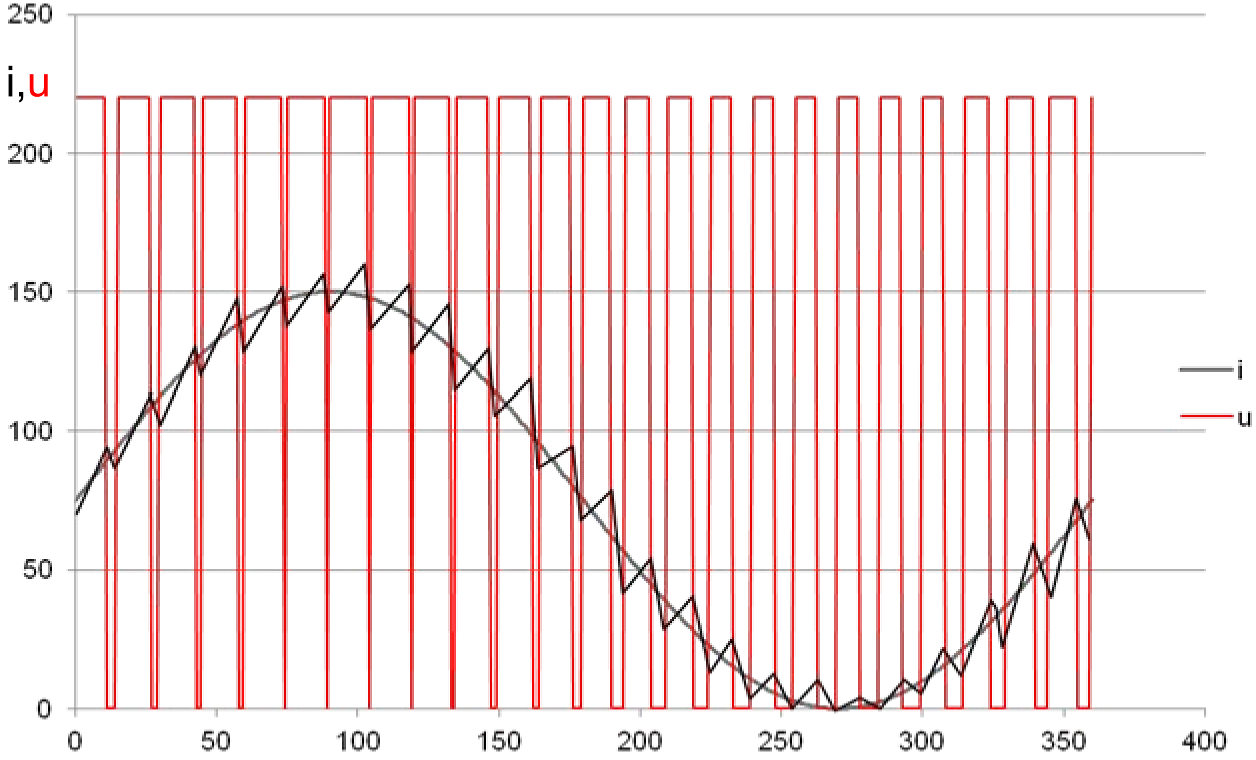
semiconductor switches are used

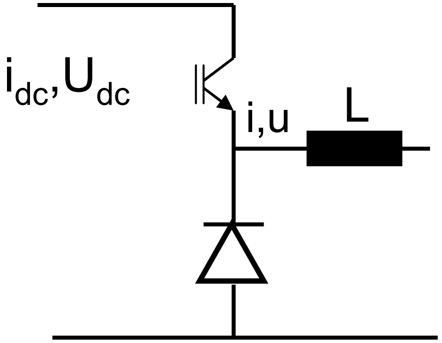
Analogue amplifier = high power loss



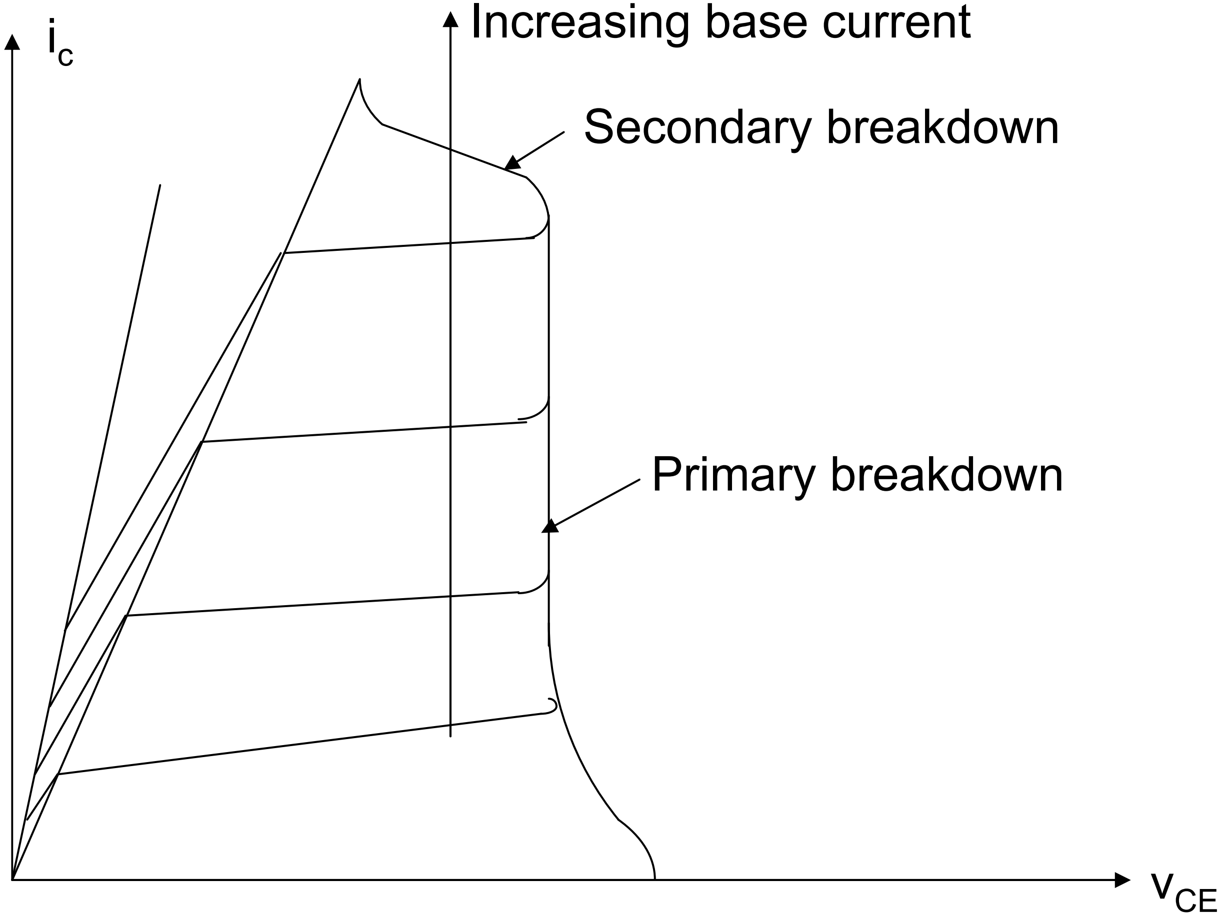


Switched amplifier = low power loss





Characteristics



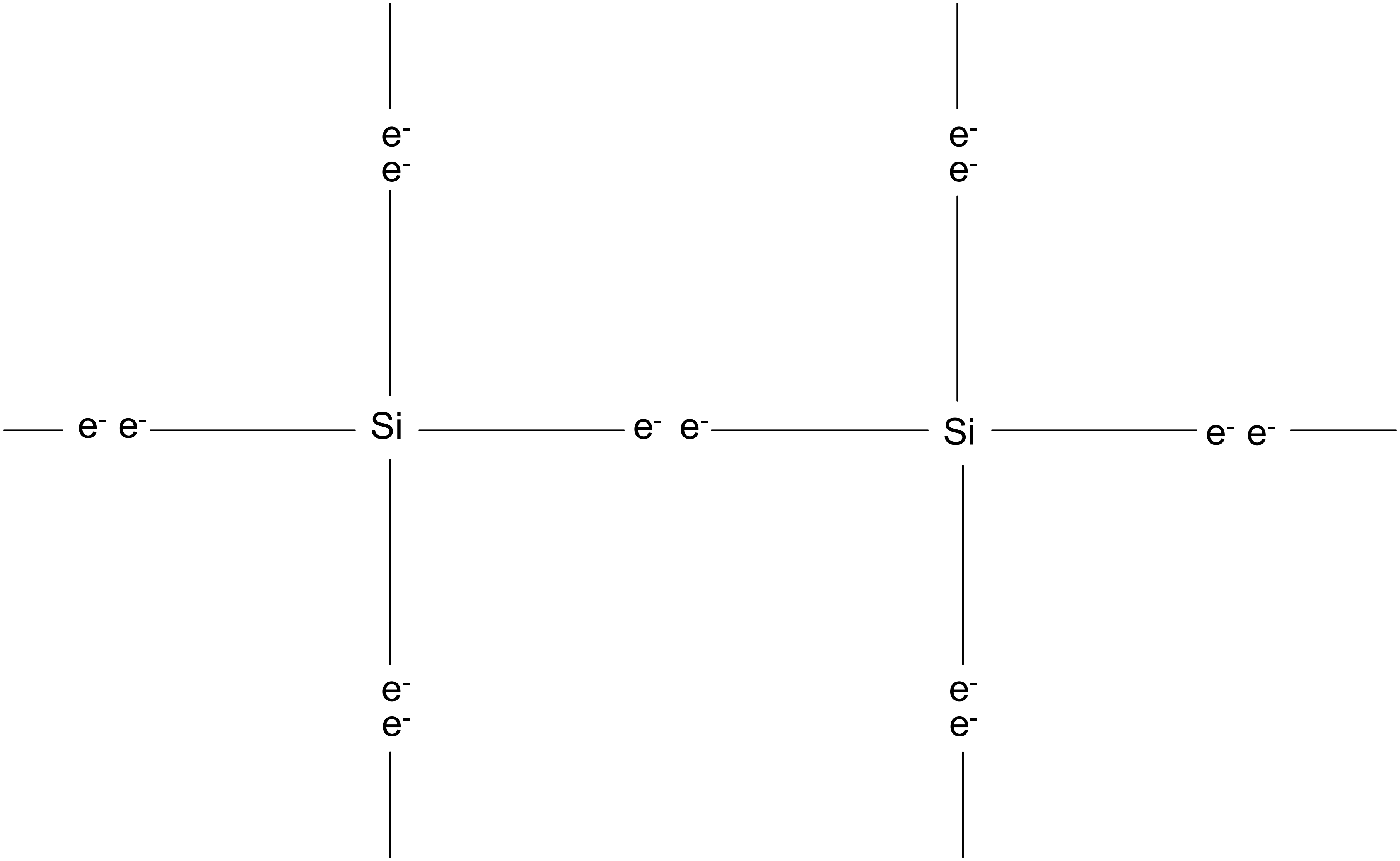
Increasing base current

Secondary breakdown

Primary breakdown

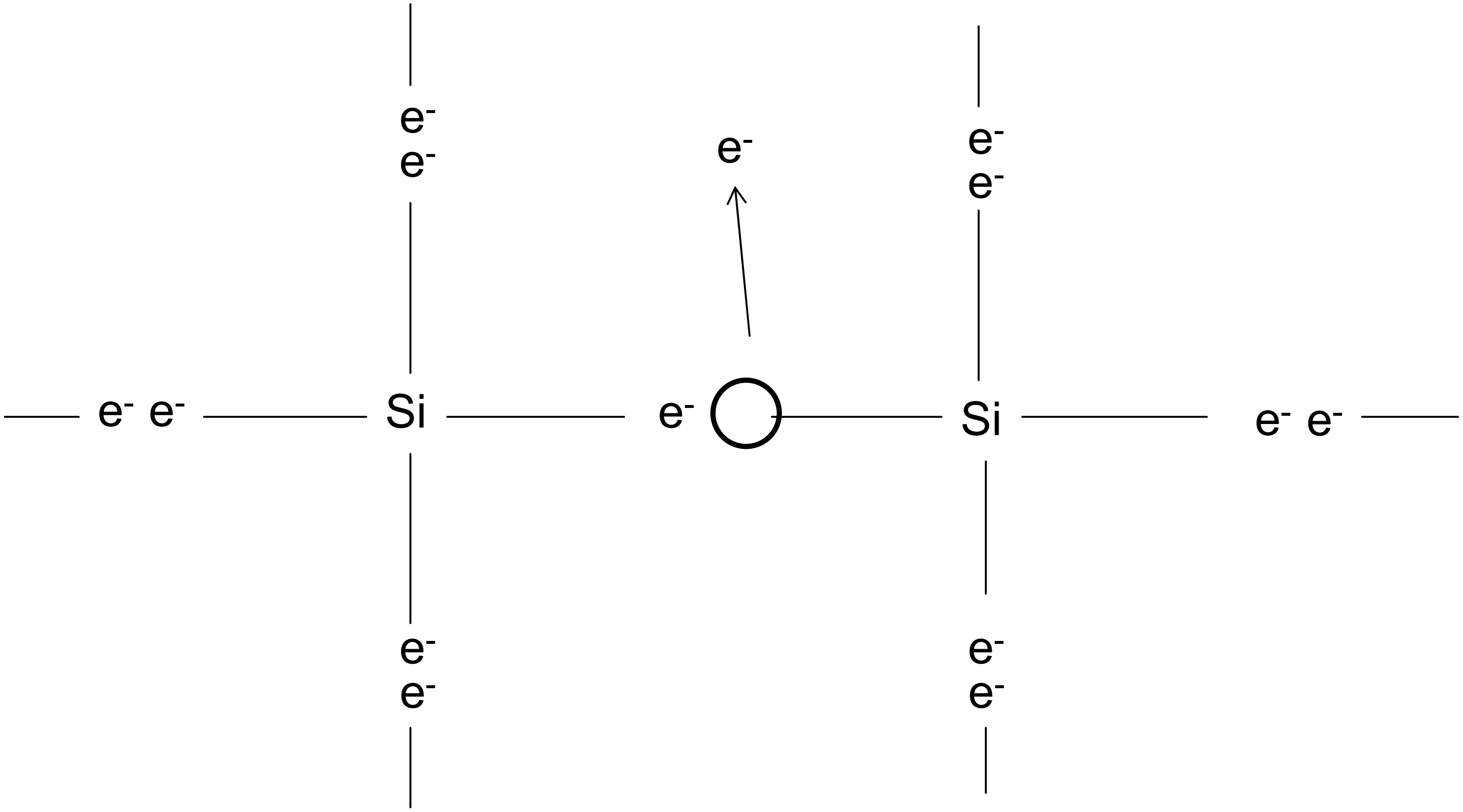
Semiconductor

Pure silicon, 4 valence elctrons

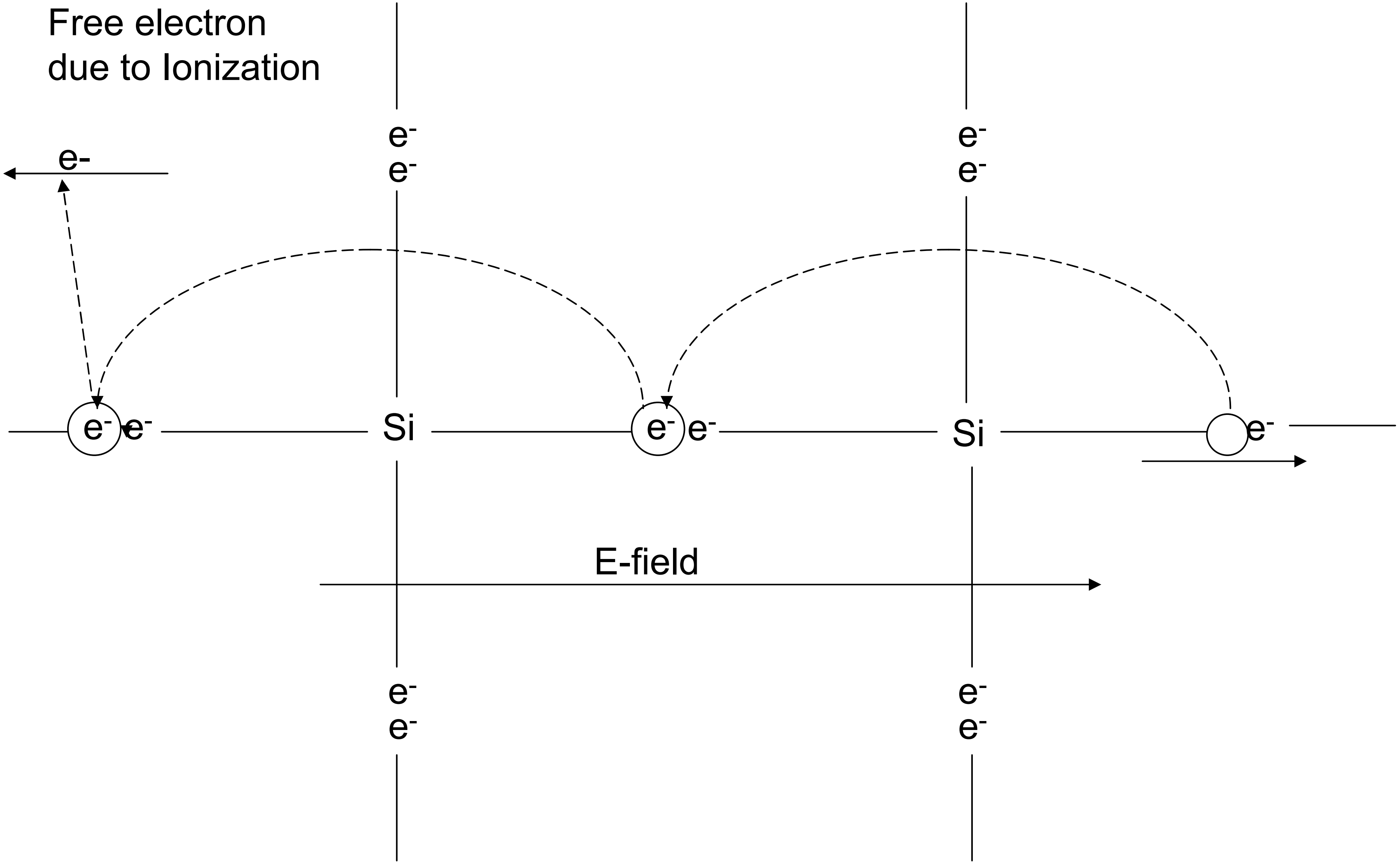


Thermal ionisation

Free electrons and holes and naturally generated due to thermal ionization, the higher the temperature, the more carriers are generated



Electron/hole conduction



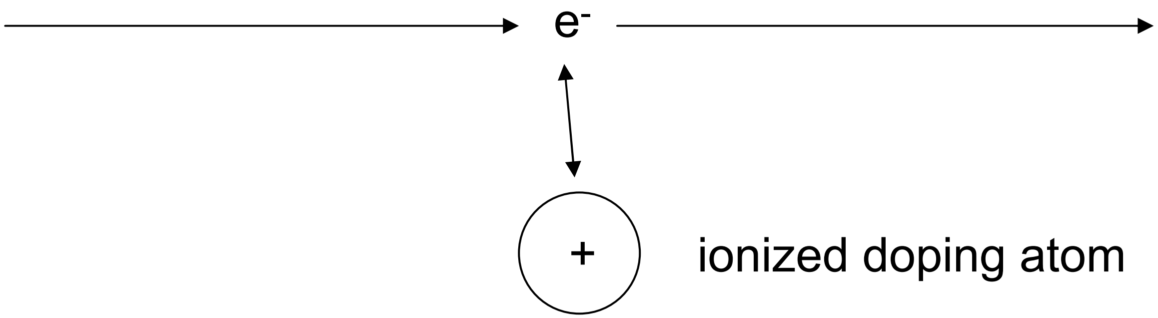
Mobility = the proportionality between the carrier velocity and the electric field

The resistivity of a semiconductor is inversely proportional to the mobility of the carriers.
A high mobility gives a low resistance, and thus reduced power loss

The mobility of the electrons and the holes

Electrons have higher mobility than the holes, since the effective mass of the electron is only one third of the hole effective mass

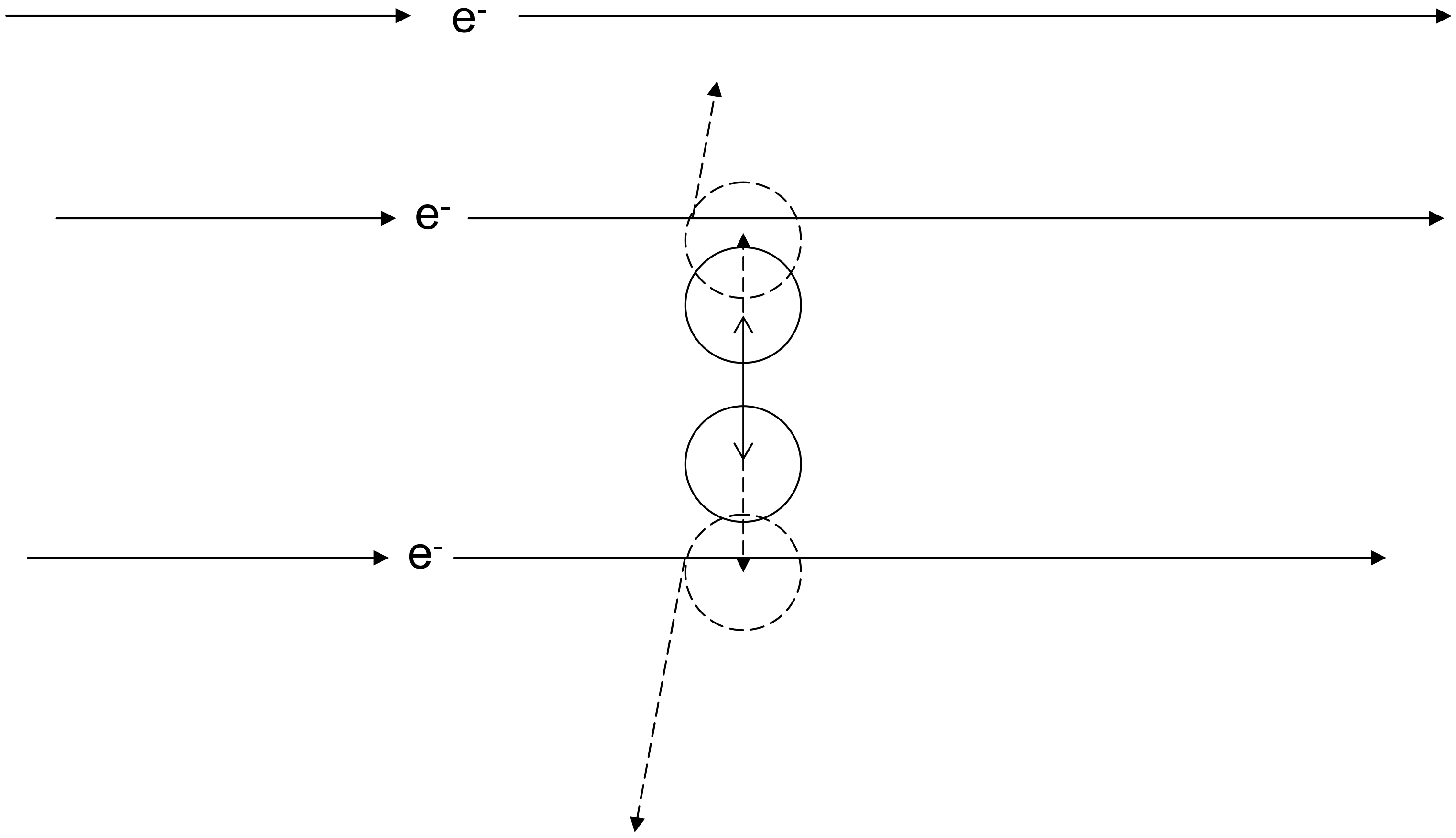
Termed impurity scattering = the mobility is increased with increased temperture



- At low temperature the mobility is low because the carriers are affected by a ionized doping atoms. This interaction takes a long time since the passing time is long as the thermal velocity of the carrier is low
- At higher temperature the thermal velocity increases and thus the affection time is reduced and the mobility increases

Lattice scattering = the carrier mobility is decreased with increased temperature

At higher temperature the atom vibration increases and the and the risk for collision is increased and the mobility is reduced



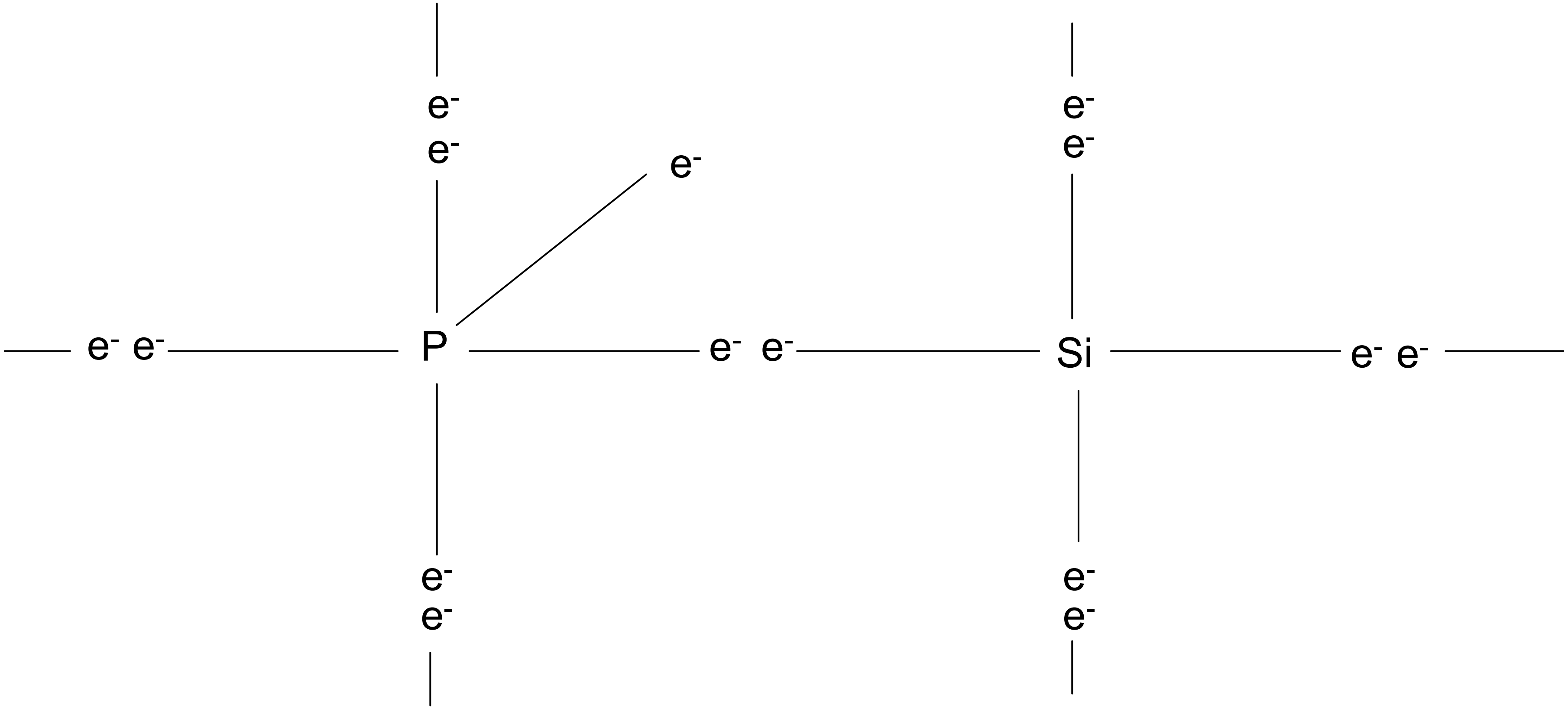
Doping

N-doping

By adding a material with 5 valence electrons, the fifth electron is an extra free electron.

The probability of free electrons is increased, majority carriers.

The probability for holes is unchanged, minority carriers.

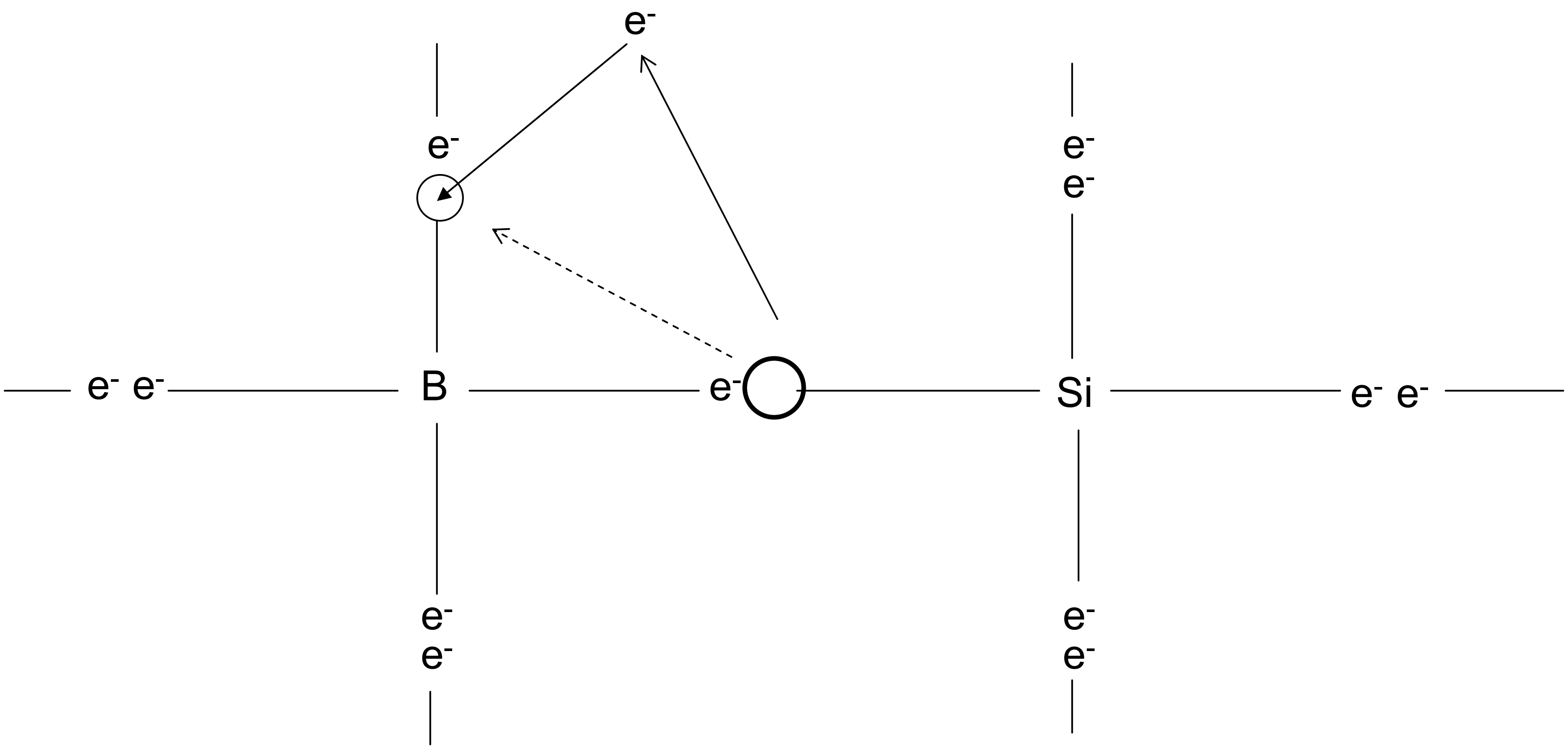


P-doping

By adding a material with 3 valence electrons, free electrons are easily captured in covalent bondings.

The probability of free <u>electrons</u> is reduced, <u>minority</u> carriers

The probability for <u>holes</u> is unchanged, <u>majority</u> carriers



P and N doping materials

- In P doped silicon, the holes are majority carriers and electrons are minority carriers. The material is an electron acceptor
- In N doped silicon, the electrons are majority carriers, and holes are minority carriers. The material is an electron donor

Concentration notation

- n^+ area with high concentration of free electrons, i.e. highly doped with donor atoms
- n^- area with low concentration of free electrons, i.e. doped with a low amount of donor atoms
- N_d The concentration of donor atoms

- p^+ area with high concentration of holes, i.e. highly doped with acceptor atoms
- p^- area with low concentration of holes, i.e. doped with a low amount of acceptor atoms
- N_a The concentration of acceptor atoms

Minority carrier life time

- The <u>minority</u> carrier <u>life-time</u> is the time-constant with which the excess carriers decrease
- At thermal equilibrium, the density of free carriers is constant. The free electron-hole pairs are created with the same rate as they disappear
- Carriers are disappearing
  - via recombination, i.e. the covalent bonding is re-established
  - carriers are captured by impurity atoms
  - carriers are captured by crystal imperfections

Recombination

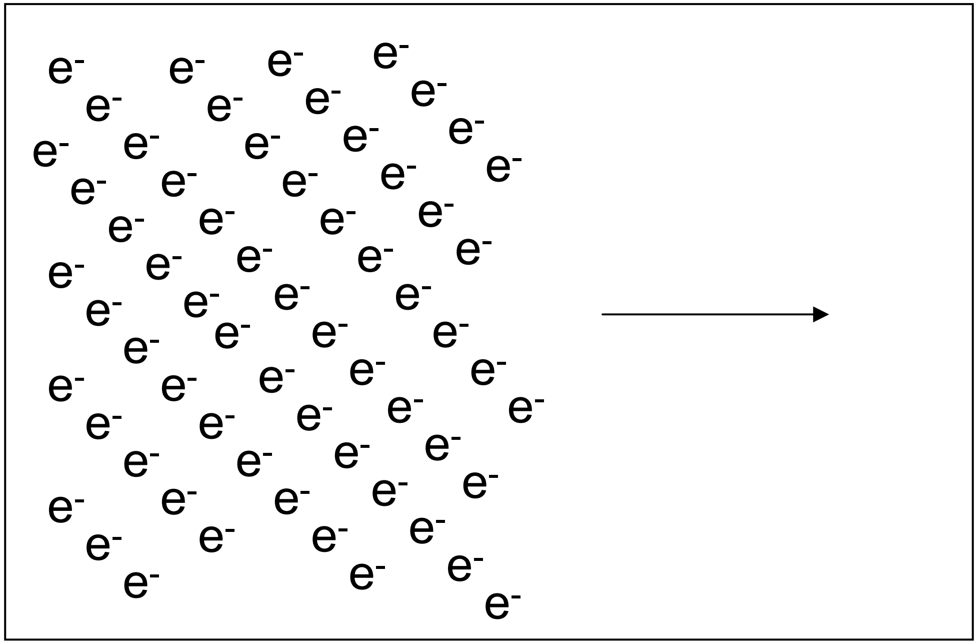
- Minority carrier life time increases with increasing temperature. At higher temperature the minority carrier has higher energy, higher speed. The probability that a free electron and hole come close enough to recombine decreases.
  The minority carrier time constant, and thus the turn-off time, increases.

- Auger recombination. At higher carrier concentration, the probability that a free electron and hole come close enough to recombine increases .
  The minority carrier time constant decreases. With high carrier concentration, i.e. with high current, the carrier life time decreases, resulting in increased conduction losses.

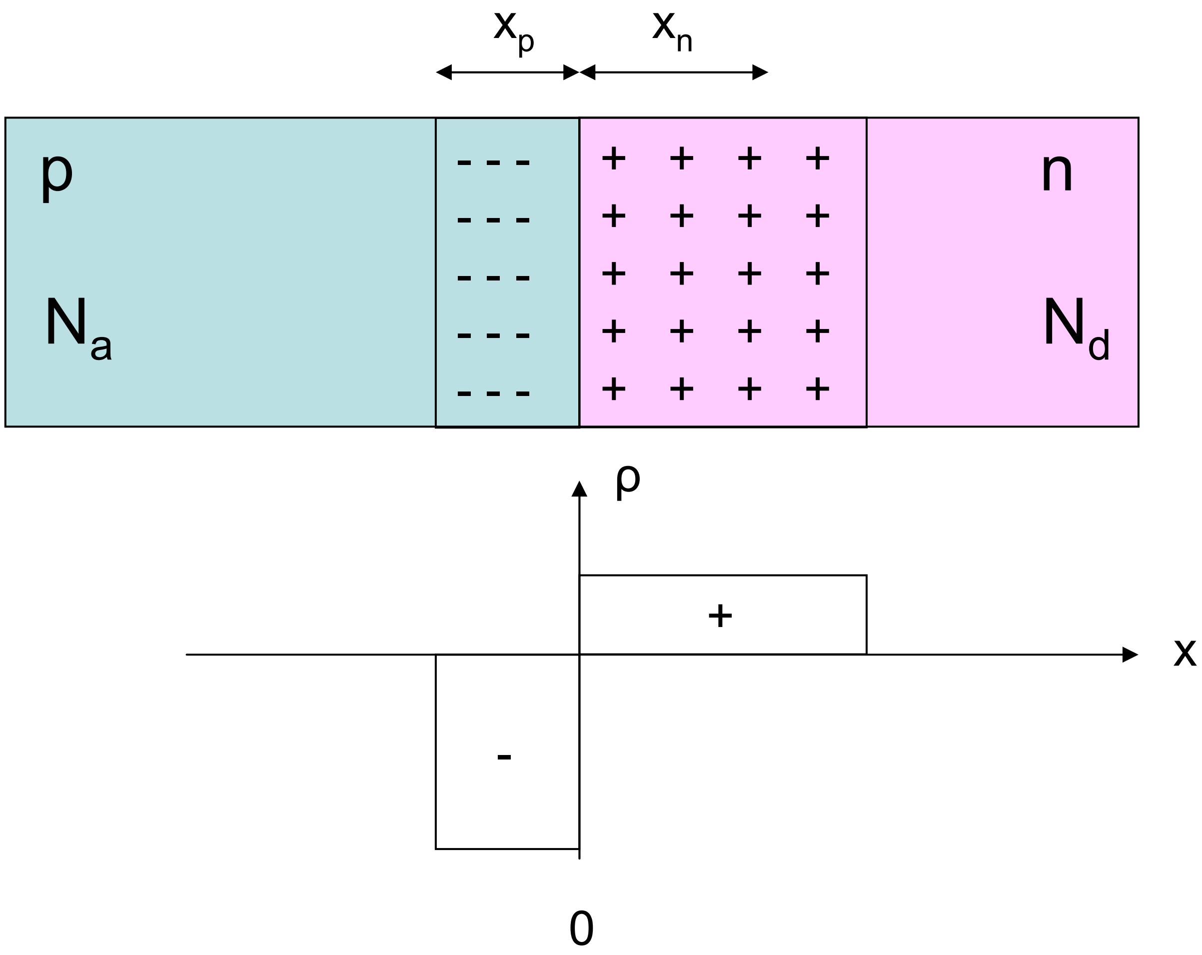
Drift current

Diffusion current

From higher concentration to lower concentration, trying to equalize the concentration difference



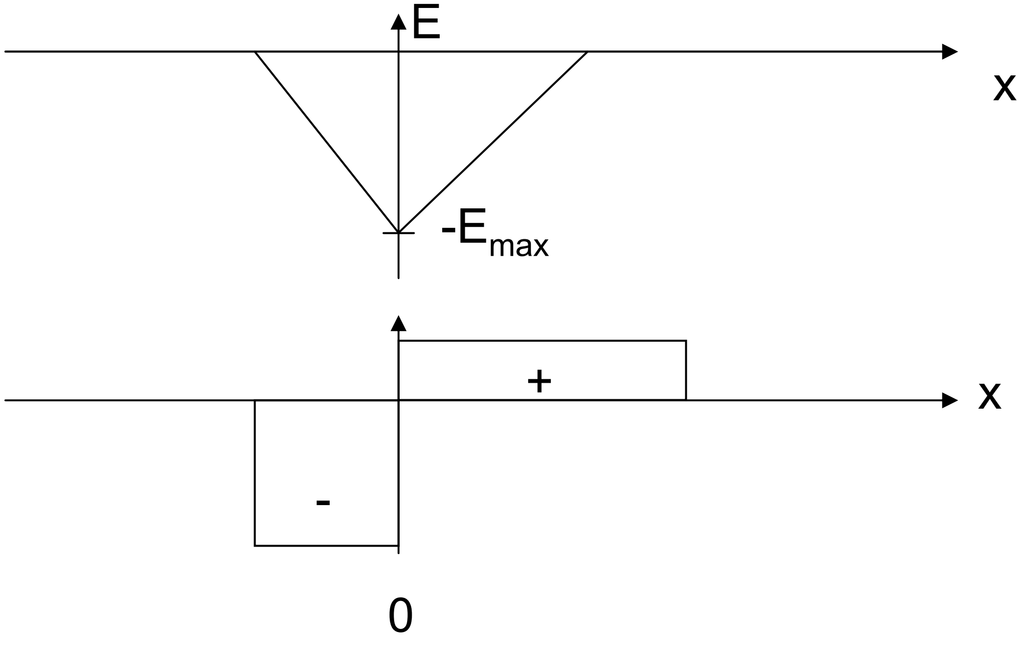
PN-junction and depletion area



E-field in the depletion area

Poison’s equation $$\nabla \cdot E = \frac{\partial E}{\partial x} = \frac{\rho}{\varepsilon}$$

$$E(x) = \begin{cases} -\frac{q_e \cdot N_a}{\varepsilon} \cdot \left(x + x_p\right) & -x_p < x < 0 \\ \frac{q_e \cdot N_d}{\varepsilon} \cdot \left(x - x_n\right) & 0 < x < x_n \end{cases}$$

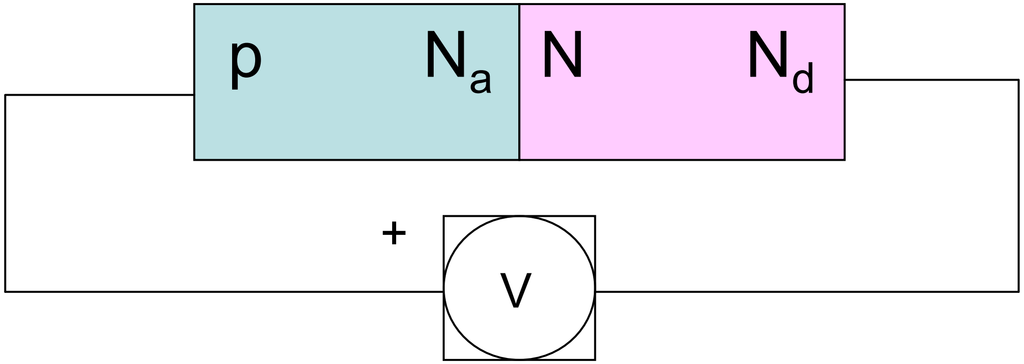


Potential barrier in a pn-junction

$$V_B = \frac{q_e}{2 \cdot \varepsilon} \cdot \left(N_a \cdot x_p^2 + N_d \cdot x_n^2 \right)$$

$$x_n, x_p \propto \sqrt{1 - \left(\frac{V}{V_B} \right)}$$

Bias



Field strength

$$\left|E_{\max}\right| = \sqrt{\frac{V_B \cdot q_e}{2 \cdot \varepsilon} \cdot \left(\frac{N_a \cdot N_d}{N_a + N_d} \right) \cdot \left(1 - \frac{V}{V_B} \right)}$$

Forward bias no e-field when $V>V_B$v-> fully conducting

Reverse bias e-field increases with increased voltage

Exercise

Calculate the e-field at an un-biased PN-junction?
See equation (4.16). There is an error in the expression in the book!

$$N_a >> N_d$$

$$N_d = 10^{15}\,cm^{-3} = 10^{21}\,m^{-3}$$

$$\varepsilon_r(\,for\ Si) = 11.7$$

$$V = 0V$$

$$Assume V_B = 0.7V$$

$$\left|E_{\max}\right| = \sqrt{\frac{V_B \cdot q_e}{2\cdot\varepsilon}\cdot\left(\frac{N_a \cdot N_d}{N_a + N_d}\right)\cdot\left(1-\frac{V}{V_B}\right)} = \sqrt{\frac{V_B \cdot q_e}{2\cdot\varepsilon_r\cdot\varepsilon_0}\cdot\frac{N_a}{N_a}\cdot\left(\frac{N_d}{1+\frac{N_d}{N_a}}\right)\cdot\left(1-\frac{V}{V_B}\right)} \approx$$

$$\approx \sqrt{\frac{V_B \cdot q_e}{2\cdot\varepsilon_r\cdot\varepsilon_0}\cdot N_d\cdot\left(1-\frac{V}{V_B}\right)} = \sqrt{\frac{0.7\cdot 1.6\cdot 10^{-19}}{2\cdot 11.7\cdot\frac{10^{-9}}{36\pi}}\cdot 10^{21}} \approx \sqrt{5.4\cdot 10^{21-19+9}} \approx 10^{6}\,\frac{V}{m}$$