EEE6206 Power Semiconductor Devices:

Section 2a: P-N Junctions

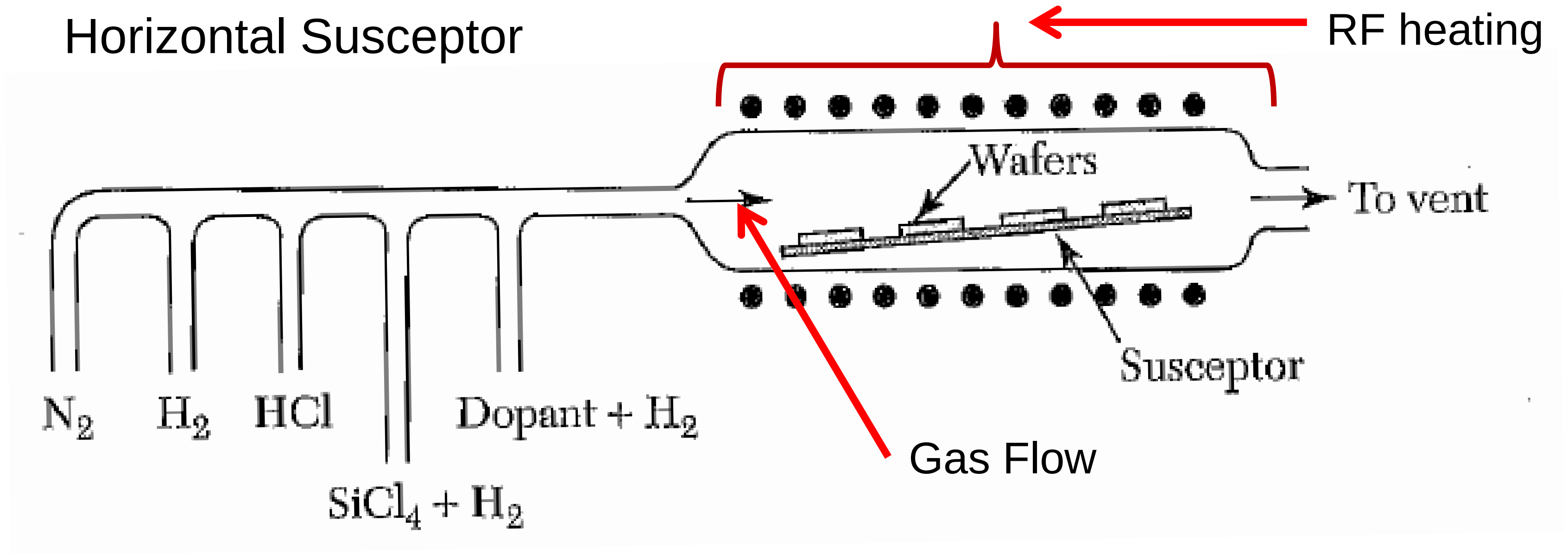
PN junction diodes

- A p-n junction servers an important role both in modern electronic applications and in understanding other semiconductor devices
- It is used extensively in rectification, switching and other operating in electronics circuits
- It is a building block for key device technologies
  - bipolar transistors, thyristors and MOSFETs

Formation of Junctions: Epitaxial Growth

- Epitaxial Growth
  - Can be used of the formation of…
    - Thin silicon layers for lateral power devices
    - Thick n- regions for vertical power devices
- Substrate may be a wafer of the same material or a different material with a similar lattice structure
  - Acts as a seed crystal
- Growth performed at temperatures considerably below the melting point of the substrate crystal
- Methods for epitaxial growth
  - Chemical vapour deposition (CVD)
  - Liquid phase epitaxy (LPE)
  - Molecular beam epitaxy (MBE)

Epitaxial growth: Chemical Vapour Deposition (CVD)



- Susceptor (horizontal, pancake, barrel)
  - mechanically support the substrates (wafers)
  - Source of thermal energy for the chemical reaction
- Mechanisms in CVD
  - Reactants are transported to the substrates (dopants and chemicals)
  - Reactants are then transferred to the surface where they are absorbed
  - Chemical reaction occurs, followed by growth of the epitaxial layer
  - Gaseous products from the reaction is desorbed from the sample into the gas stream and transferred out of the reaction chamber

Junction Formation: Implantation and Diffusion

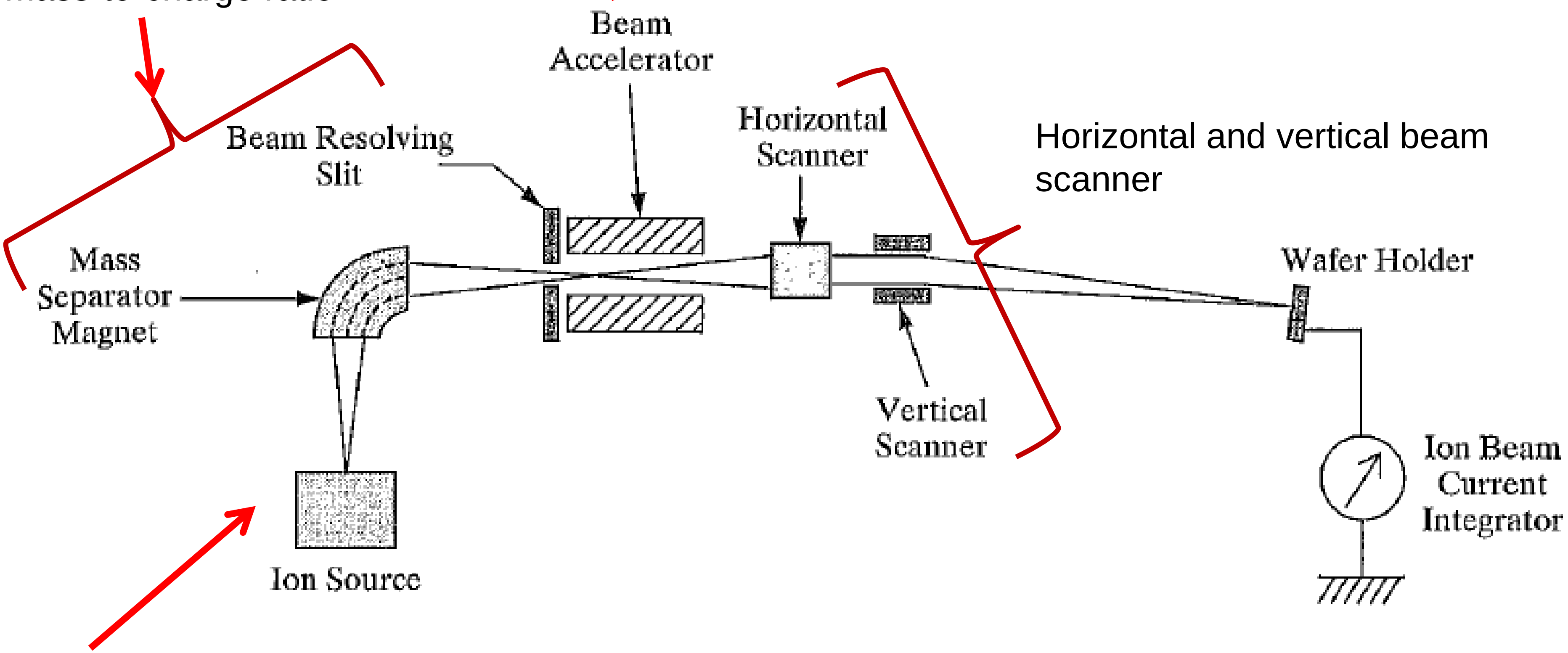
- Direct implantation of energetic ions into the semiconductor
- In this process a beam of impurity ions are accelerated to kinetic energies ranging from several eV to MeV directed at the surface of the semiconductor
- Ion doses can vary from 10^{12} ions/cm^2 for threshold voltage adjust to 10^{18} ions/cm^2 for the formation of high conductive buried layers
- As the impurity enters the semiconductor they give up their energy to the lattice and come to rest at an average penetration depth
  - Projected range: Dependant upon energy level
  - Varies from a several 100's Angstroms to ~1μm

Schematic diagram of an ion implantation system

Filters ions with the desired mass-to-charge ratio

Accelerates ions to desired implantation energy

Horizontal and vertical beam scanner

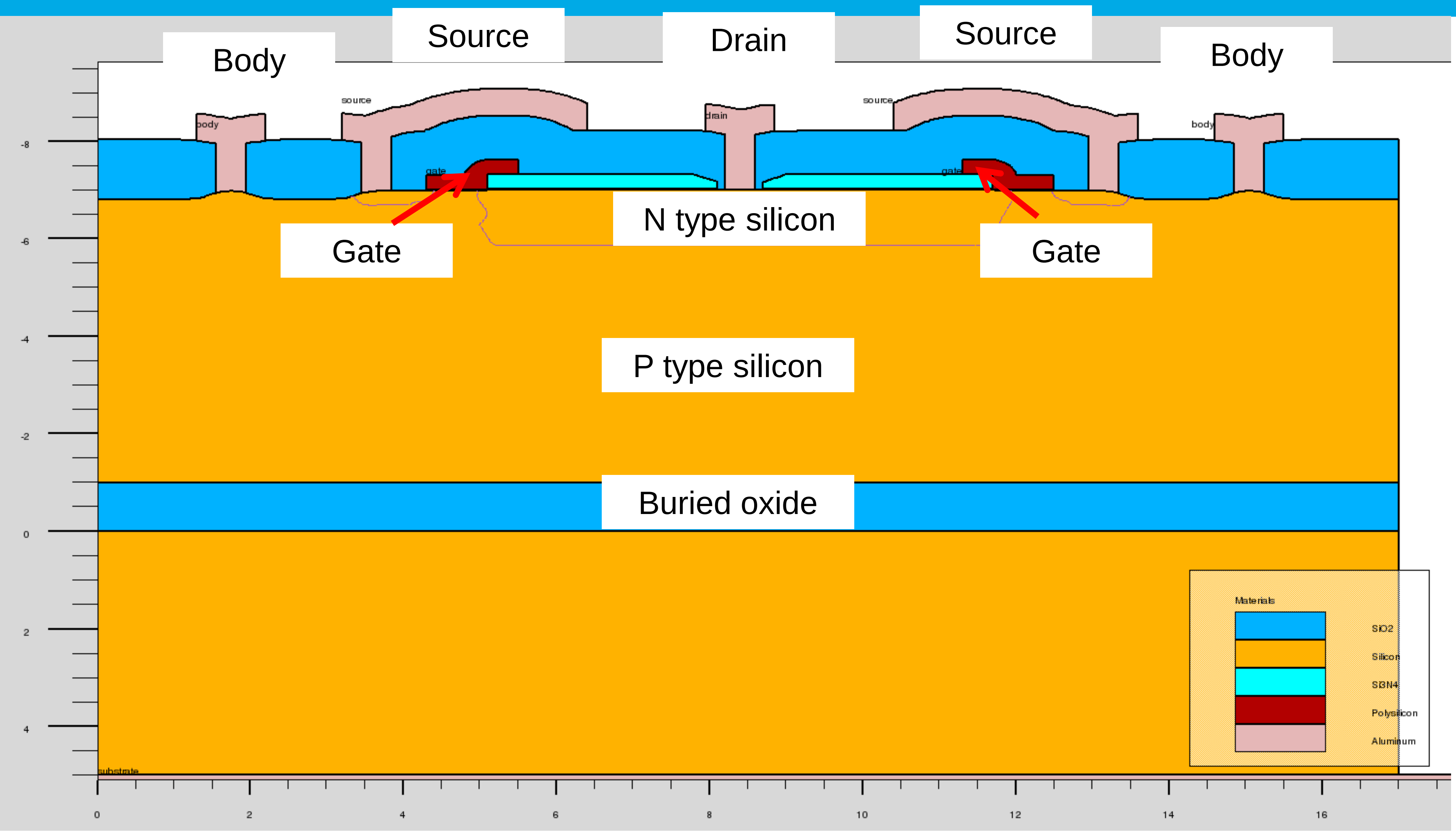


Heated filament to break up source gas (BF_3 AsH_3). An extraction voltage (~40kV) causes the ions to move from the source

Impurity activation

- After implantation impurity is activated by an annealing process
  - Causing impurities to form bonds with the silicon lattice
  - Repairing crystalline damage from impurity
  - Drives junction deeper into the substrate to control junction depth via a diffusion process
- Common technique to form p type and n type structures in Silicon and Silicon Carbide

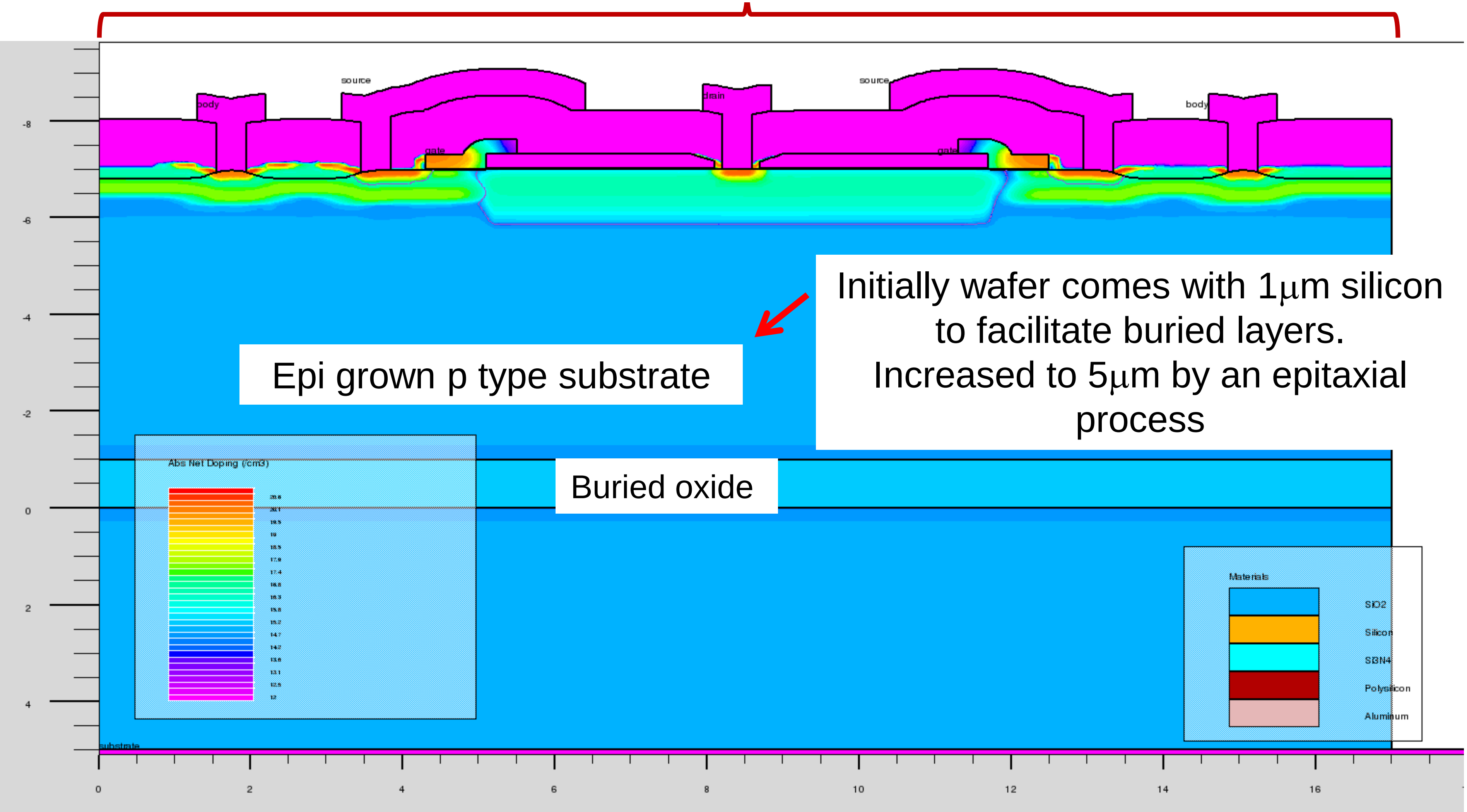
Practical example: 80V NMOS process simulation



- Buried oxide, lateral device technology
- Fully compatible with low voltage CMOS structures (BiCMOS Process)

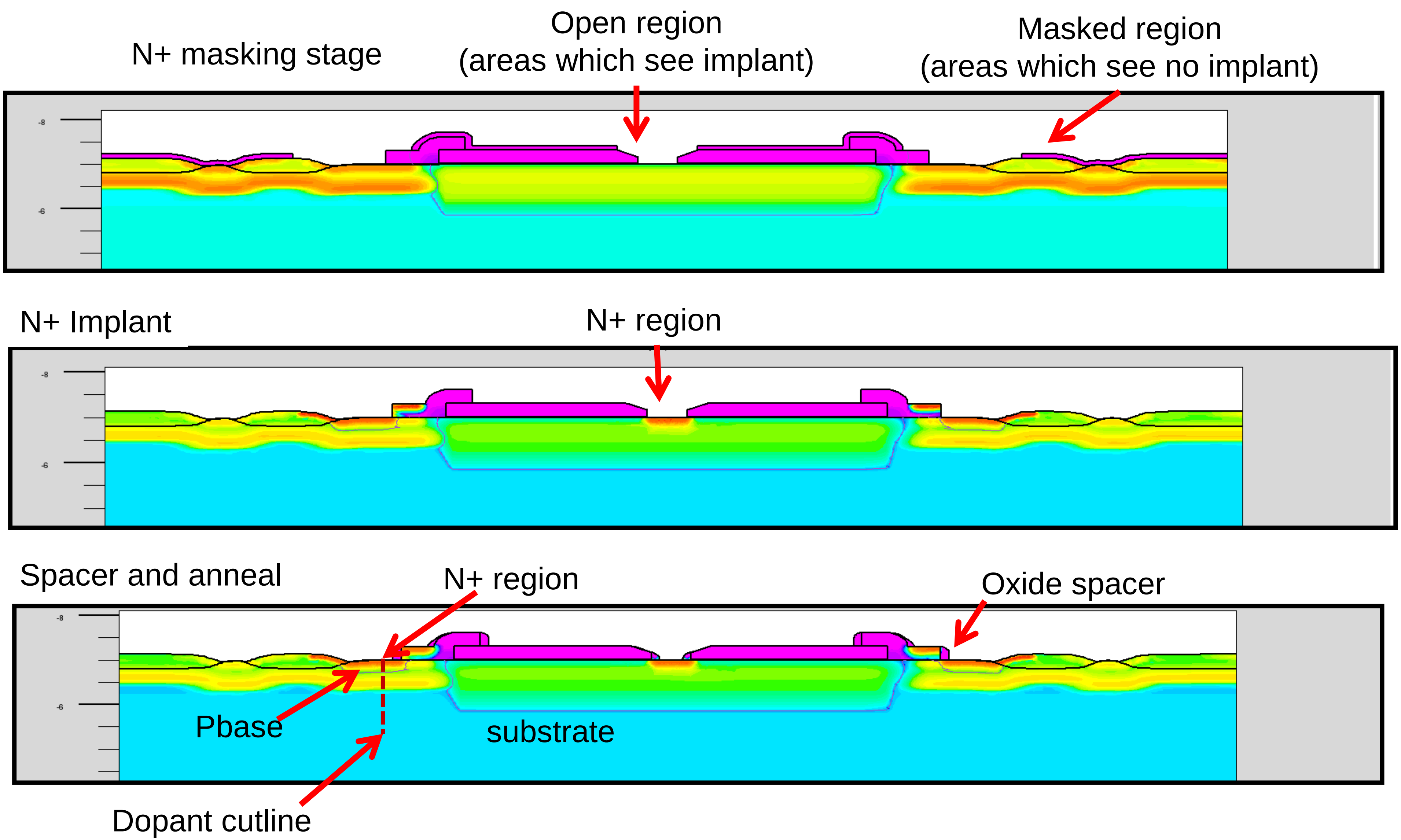
Buried oxide, lateral device process (Doping contours)

Topside device structures: All implantation and anneal

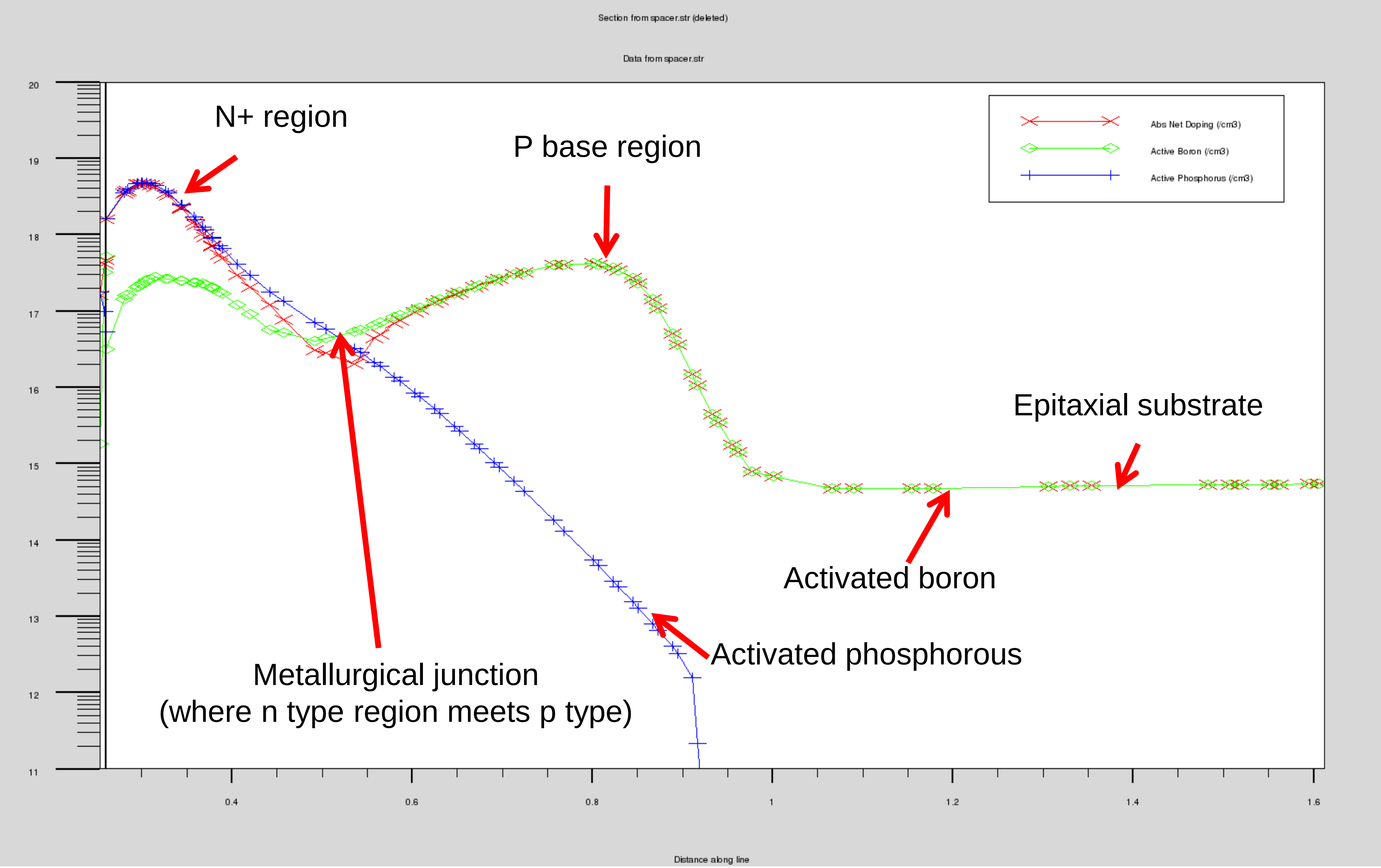


N+ implant formation

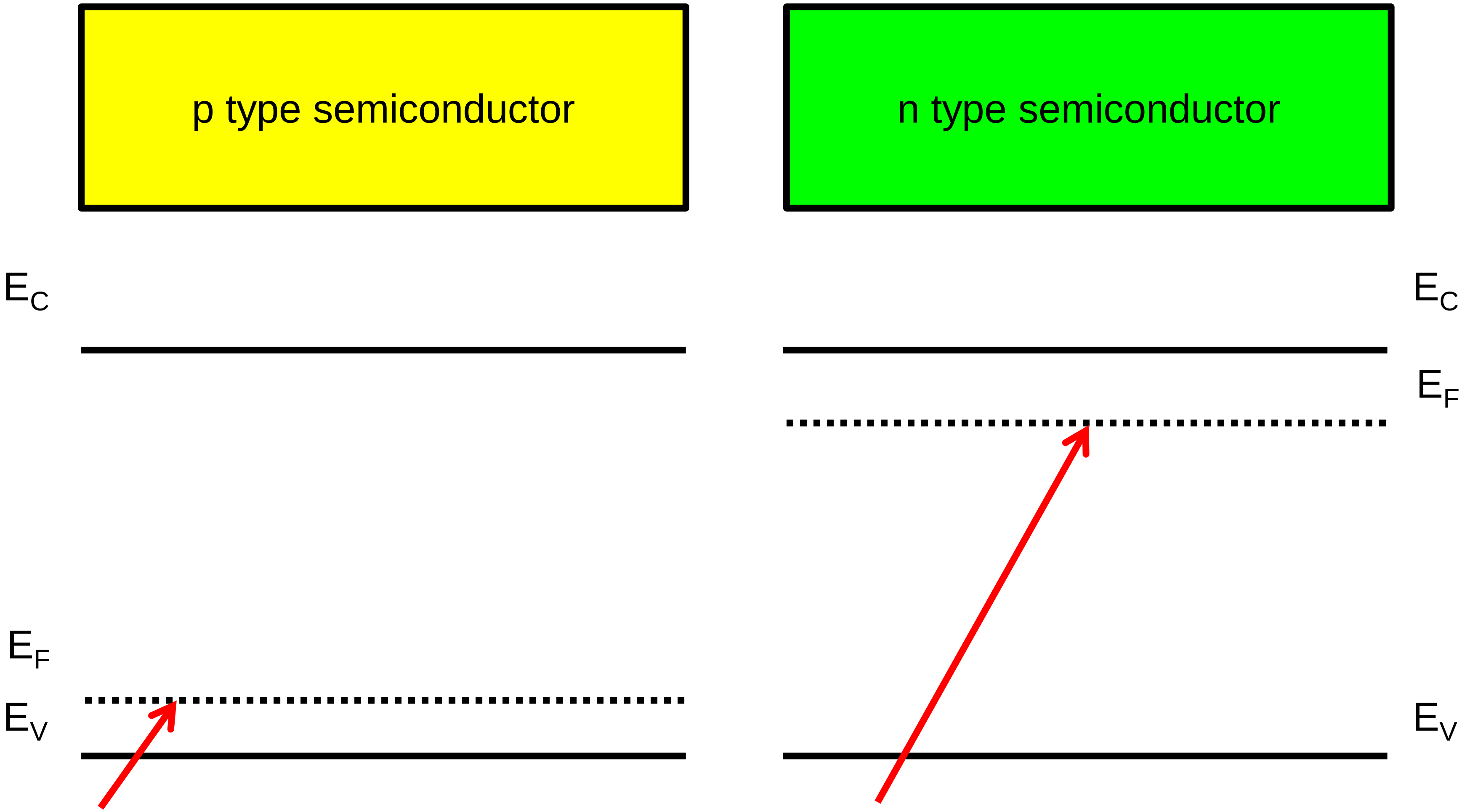
Cross section after formation of the MOSFET channel



Source dopant cutline



P-N junction: Formation



p type semiconductor:

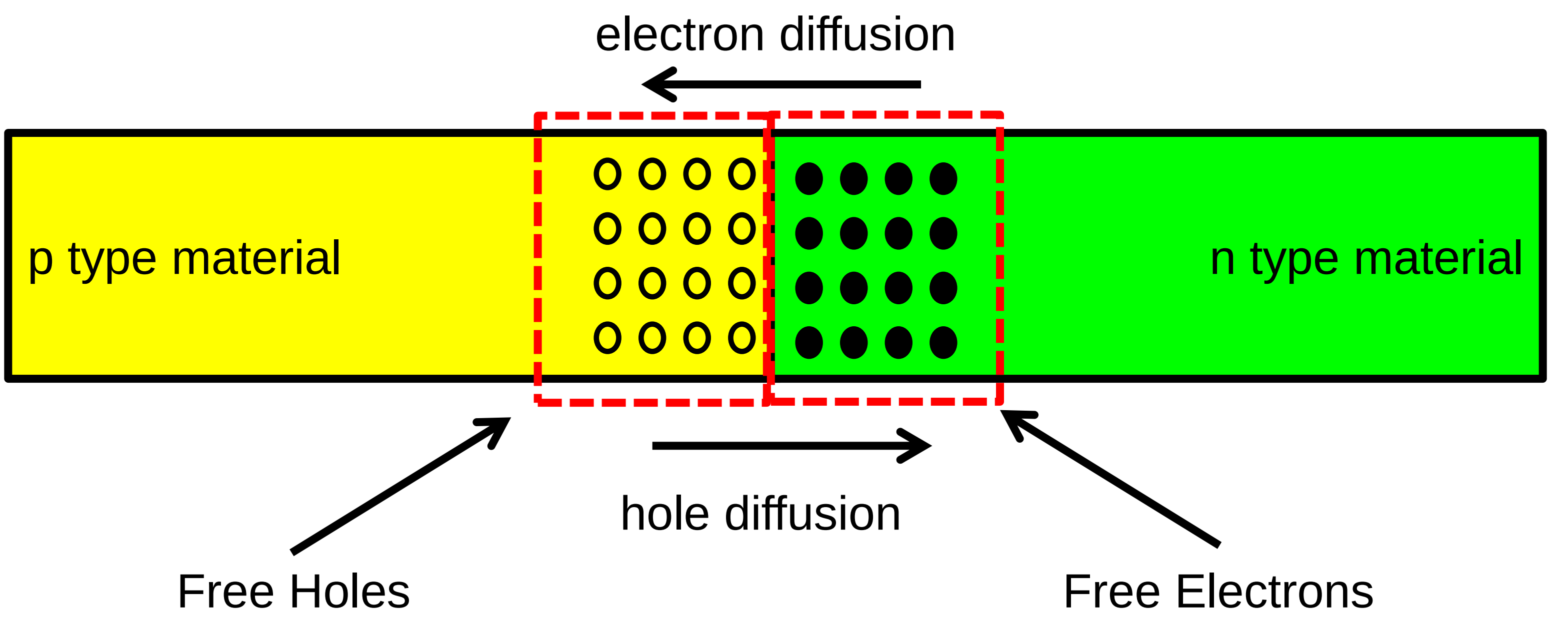
- Fermi level near valence band
  - high hole carrier concentration
  - few electrons

n type semiconductor:

- Fermi level near conduction band
  - high electron carrier concentration
  - few holes

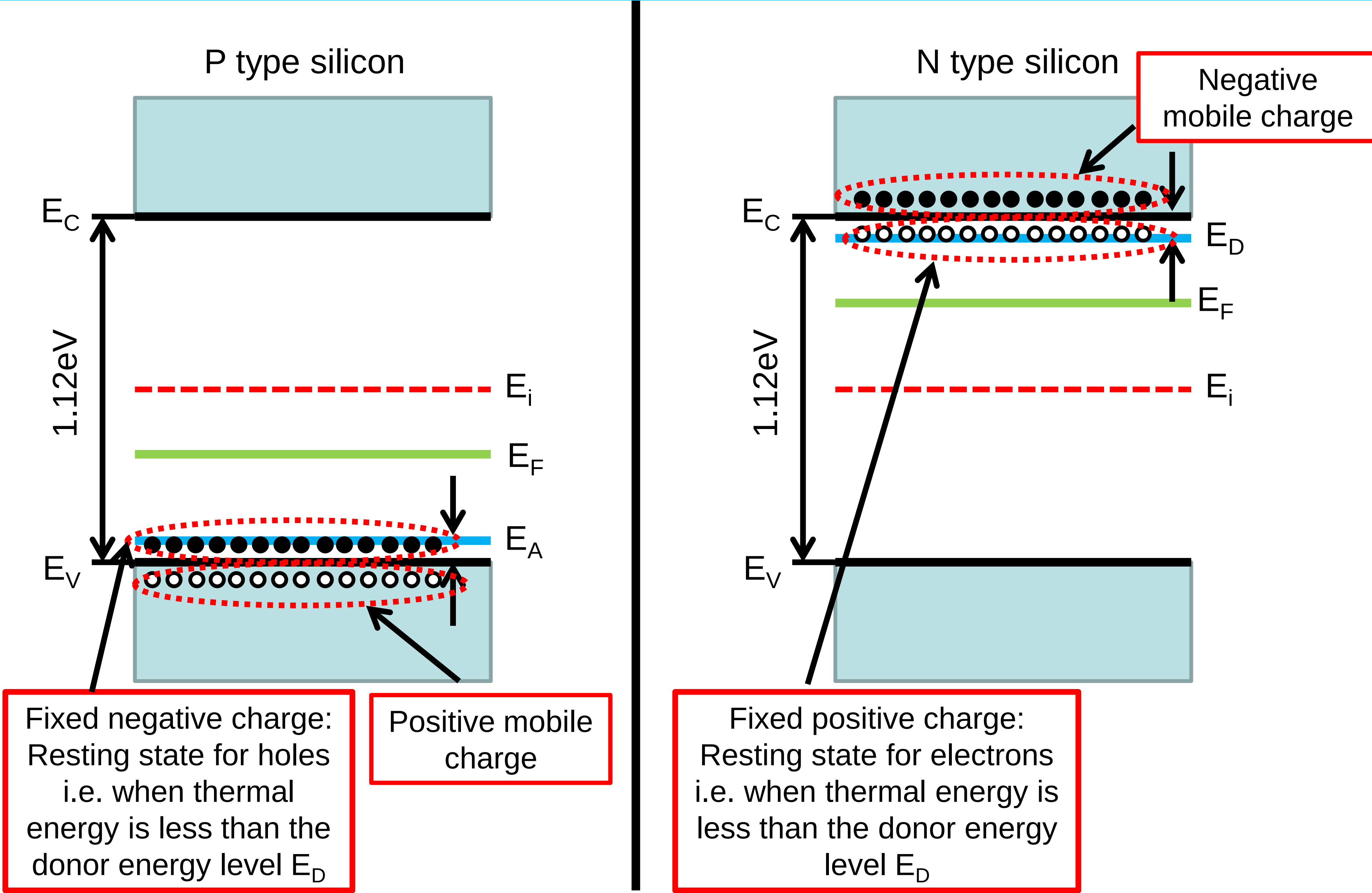
When Junction is formed…

- When n and p type material are joined
- Large carrier concentration gradient at junction cause carrier diffusion
  - **Holes diffuse from p type to n type**
  - **Electrons diffuse from n type to p type**

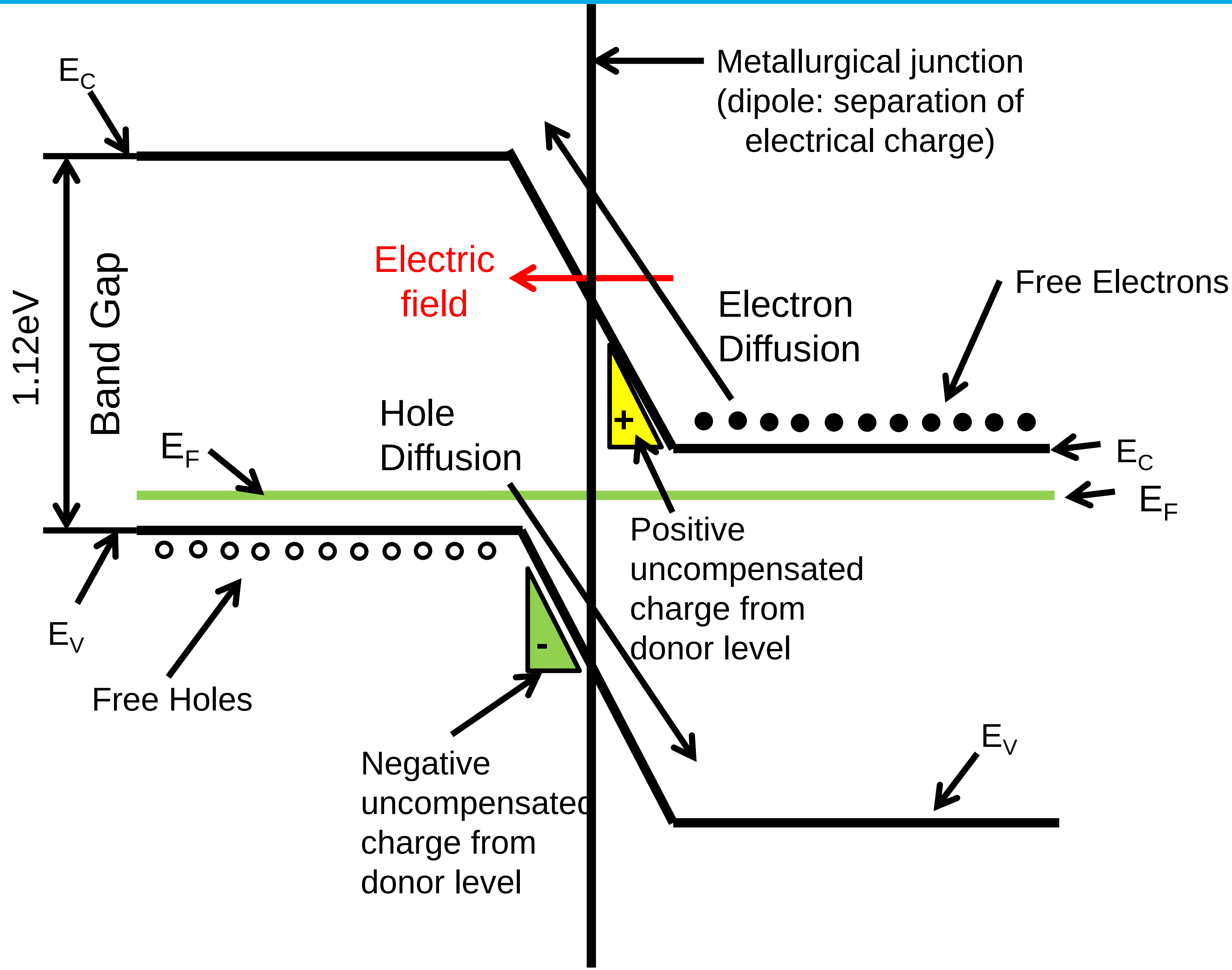


- As the carries diffuse across the metallurgical junction
- Fixed negative acceptor (N_A^-) and positive donor (N_D^+) charges are left uncompensated at the junction
- Creates a space charge (or depletion region) and electric field across the junction

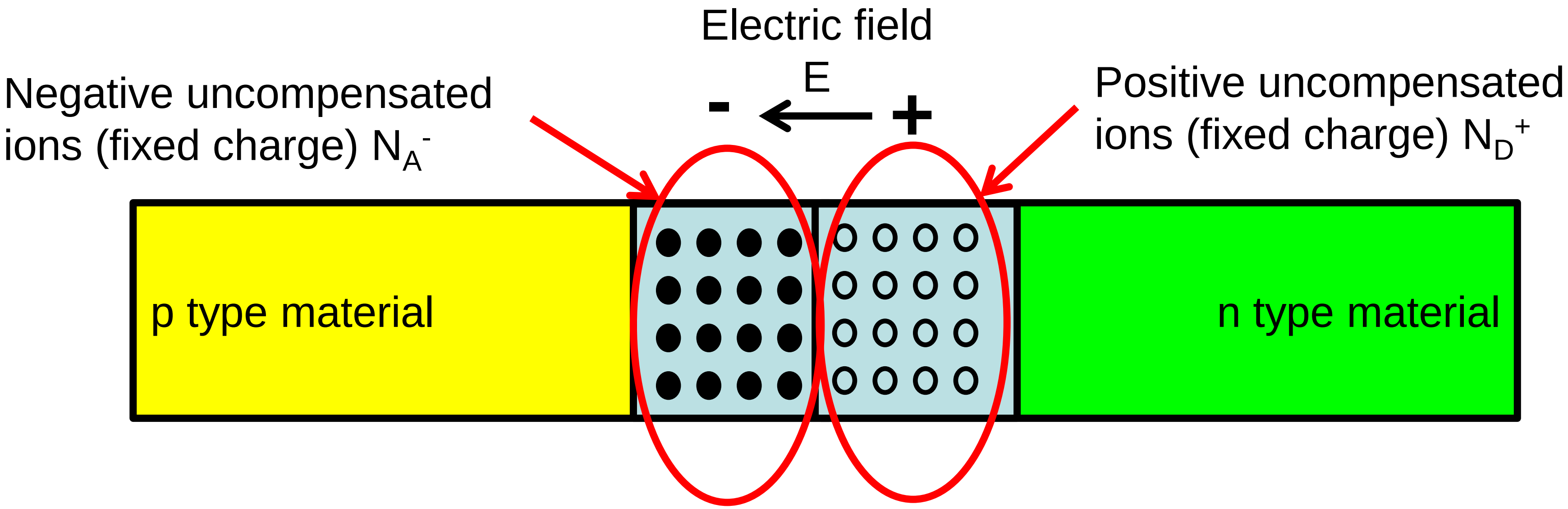
Fixed charge



Junction Energy Diagram

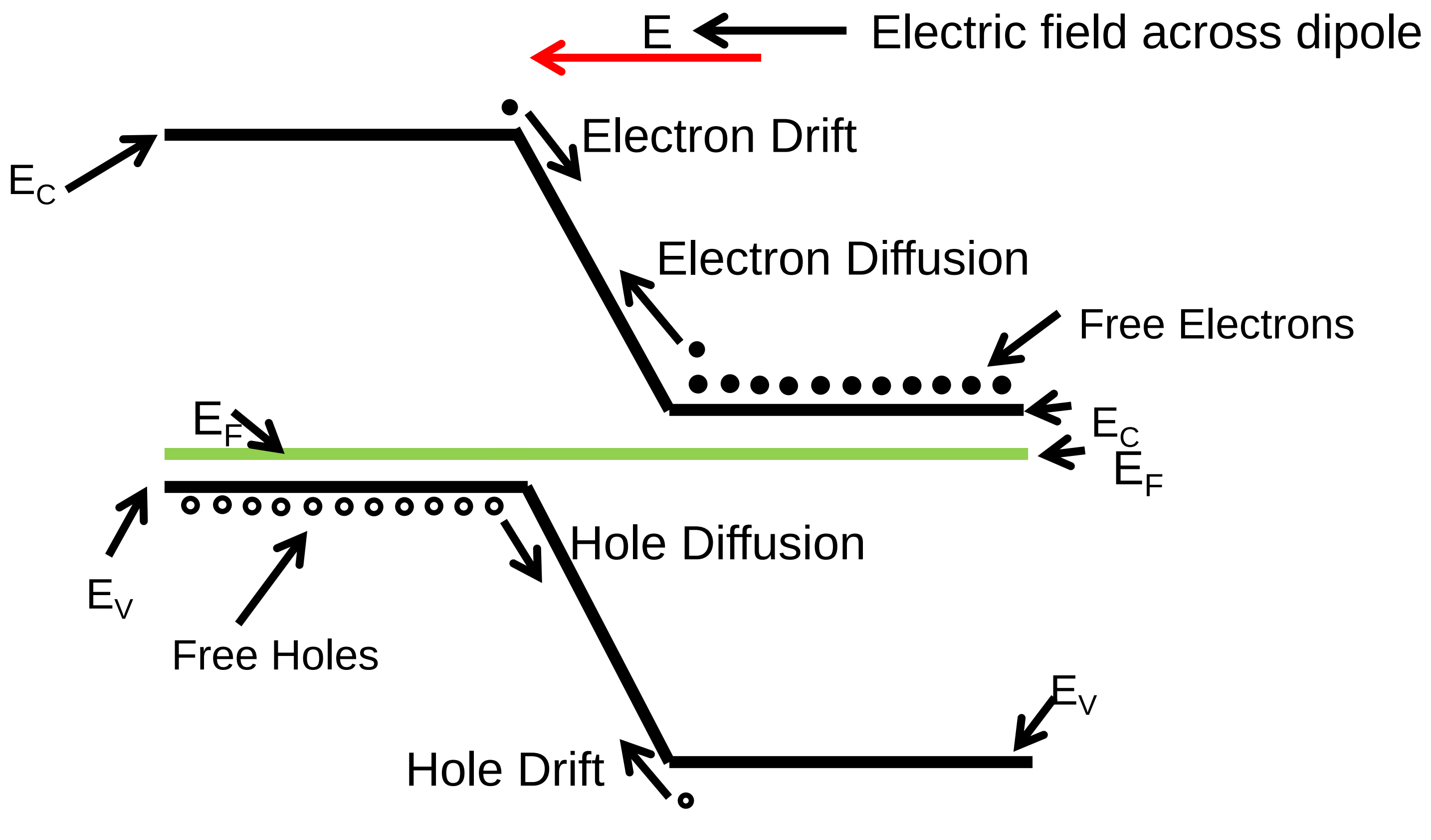


- Under thermal equilibrium diffusion and drift currents will be equal as under zero bias current=0



Equilibrium Fermi Levels

- At thermal equilibrium
  - Steady state condition at a uniform temperature without any external bias
- The individual electron and hole current components flowing across the junction **must** be zero



Equilibrium Fermi Levels

- For each carrier both drift and diffusion components of current must cancel each other out
  - Taking hole current density for example:

$$J_p = J_p(drift) + J_p(diffusion) = 0$$

$$J_p = q\mu_p pE - qD_p \frac{dp}{dx} = 0$$

Electrostatic potential

Einstein's relation

$$J_p = q\mu_p p\left(\frac{1}{q}\frac{dE_i}{dx}\right) - kT\mu_p \frac{dp}{dx} = 0$$

Equilibrium Fermi Levels

- The expression for hole concentration

$$p = n_i e^{\left(\frac{E_i - E_F}{kT}\right)}$$

and its derivative

$$\frac{dp}{dx} = \frac{p}{kT}\left(\frac{dE_i}{dx} - \frac{dE_F}{dx}\right)$$

- Yields:

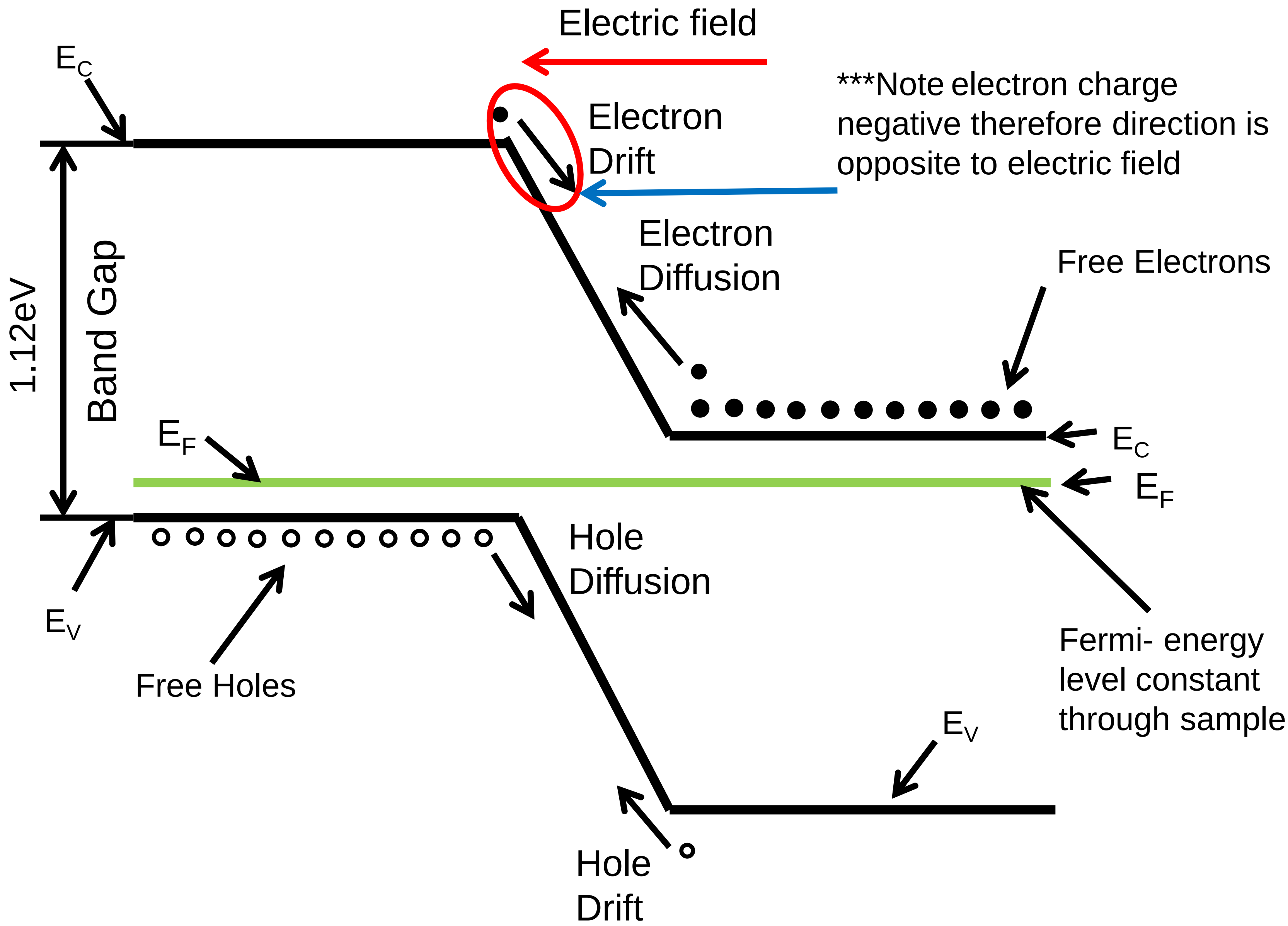
$$J_p = q\mu_p p\left(\frac{1}{q}\frac{dE_i}{dx}\right) - kT\mu_p\left(\frac{p}{kT}\left[\frac{dE_i}{dx} - \frac{dE_F}{dx}\right]\right) = 0$$

$$J_p = \mu_p p\frac{dE_i}{dx} - \mu_p p\frac{dE_i}{dx} - \mu_p p\frac{dE_F}{dx} = 0$$

$$J_p = \mu_p p\frac{dE_F}{dx} = 0$$ or $$\frac{dE_F}{dx} = 0$$

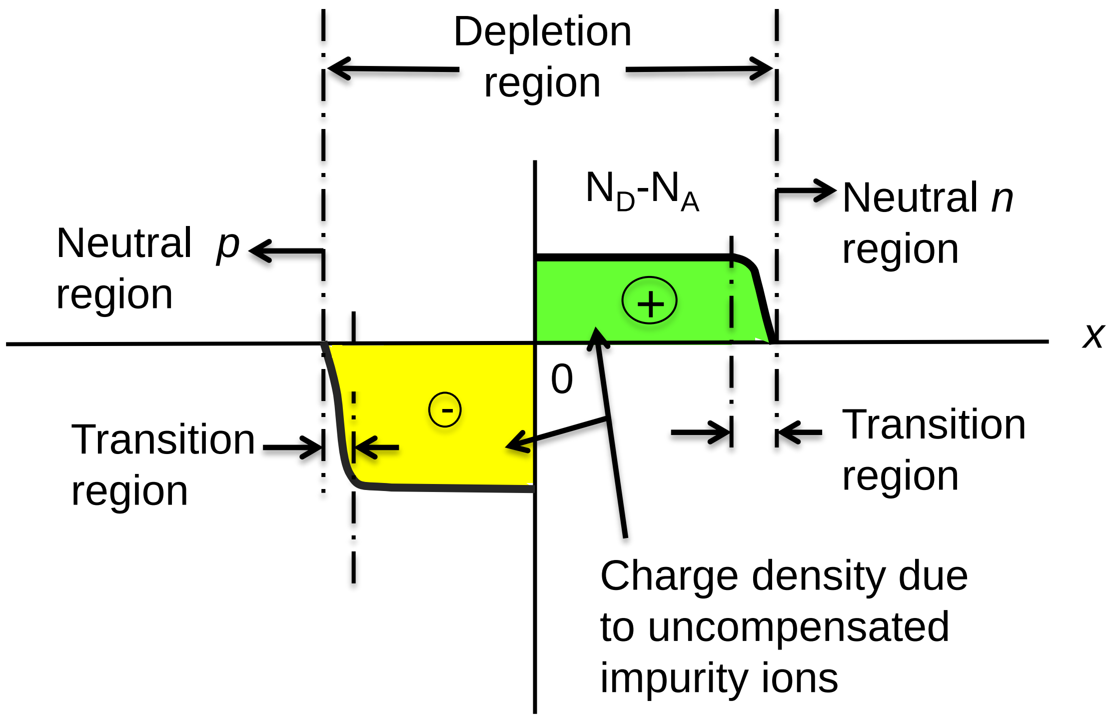
- Therefore for zero net electron and hole currents the Fermi level must be constant throughout the sample

Fermi level position

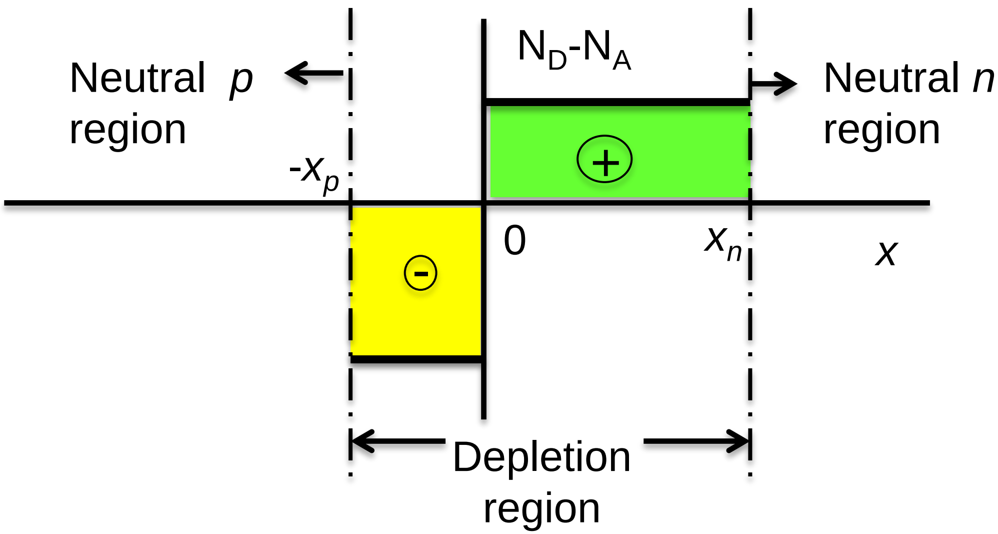


Space Charge

- Moving from a neutral region towards the junction, we encounter a narrow transition region.
- Here the space charge of impurity ion is partially compensated by the mobile carriers
- Beyond the transition region we enter the completely depleted region where the mobile carriers are zero, called the depletion region (or space charge region)



- For typical p-n junctions the transition regions are small compered to the depletion region and is therefore neglected and the depletion region can be represented by a rectangular representation
  - $-x_p$ and $x_n$denote the depletion layer widths in the p and n regions



Poisson's equation: Neutral Regions

- Constant Fermi level required at thermal equilibrium results in an unique space charge distribution at the junction
- The space charge distribution and electrostatic potential (Ψ) is given by Poisson's Equation:

Local charge density

$$\frac{d^2\Psi}{dx^2} \equiv -\frac{dE}{dx} = \frac{\rho_s}{\varepsilon_r \varepsilon_s} = -\frac{\boldsymbol{q}}{\boldsymbol{\varepsilon_s}}(\boldsymbol{N_D} - \boldsymbol{N_A} + \boldsymbol{p} - \boldsymbol{n})$$

Dielectric constant of semiconductor

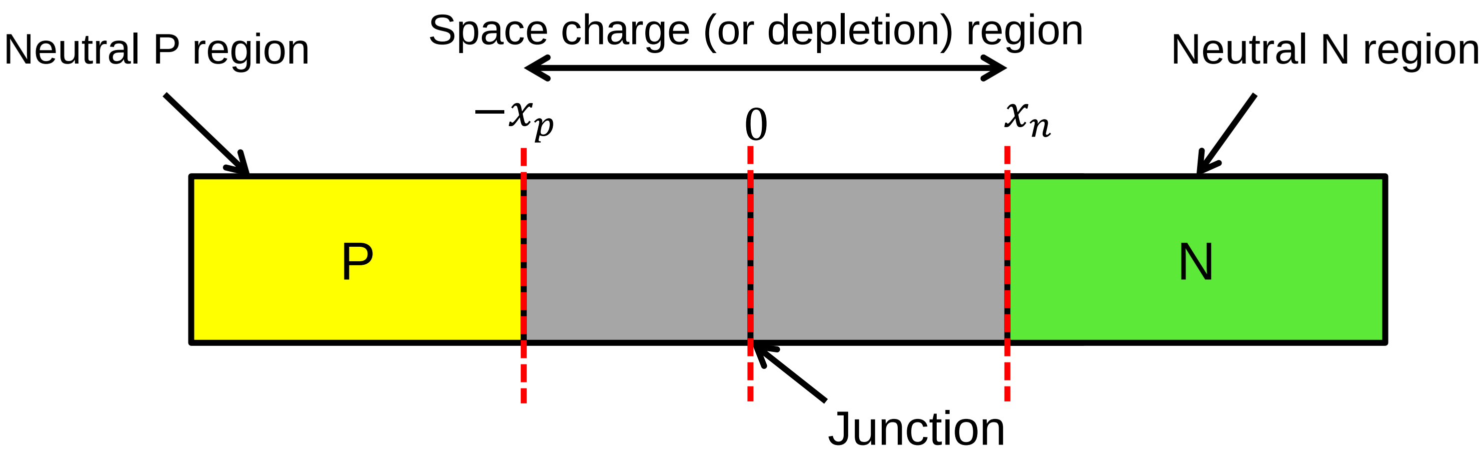
- In regions far away from the metallurgical junction, charge neutrality is maintained and the total space charge is zero
- In these regions, this simplified Poisson's Equation to:

$$\frac{d^2\Psi}{dx^2} = 0 \qquad \text{and} \qquad N_D - N_A + p - n = 0$$

Poisson's equation: Space charge region

- As we move closer to the metallurgical junction,
  - The depletion region causes charge neutrality no be no longer maintained
    - i.e. the number of electrons is no longer is equal to the number of holes $(\mathrm{n} \neq p)$
- If we consider the p type region we assume:
  - $N_D = 0$ and $p \gg n$
- The electrostatic potential (Ψ_{p}) with is given by:

$$0 = N_D - N_A + p - n = N_A$$



- Setting the co-ordinates from the edge of the depletion region $(x \leq -x_p)$ yields the electrostatic potential in the p region:

$$\Psi_p \equiv -\frac{1}{q}(E_i - E_F)\Big|_{x \leq -x_p}$$

- Likewise for the n region $(x \geq x_n)$:

$$\Psi_n \equiv -\frac{1}{q}(E_i - E_F)\Big|_{x \geq x_n}$$

Electrostatic potential

- Potential in the p region at a distance greater than x_p from the junction:

$$\Psi_p \equiv -\frac{1}{q}(E_i - E_F)\Big|_{x \le -x_p}$$

$$p = n_i exp^{\frac{E_i - E_F}{kT}} \qquad\qquad E_i - E_F = kT\, ln\left(\frac{N_A}{n_i}\right)$$

$$\boldsymbol{\Psi_p \equiv -\frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right)}$$

- Likewise for the n region at a distance greater than $x_n$from the junction:

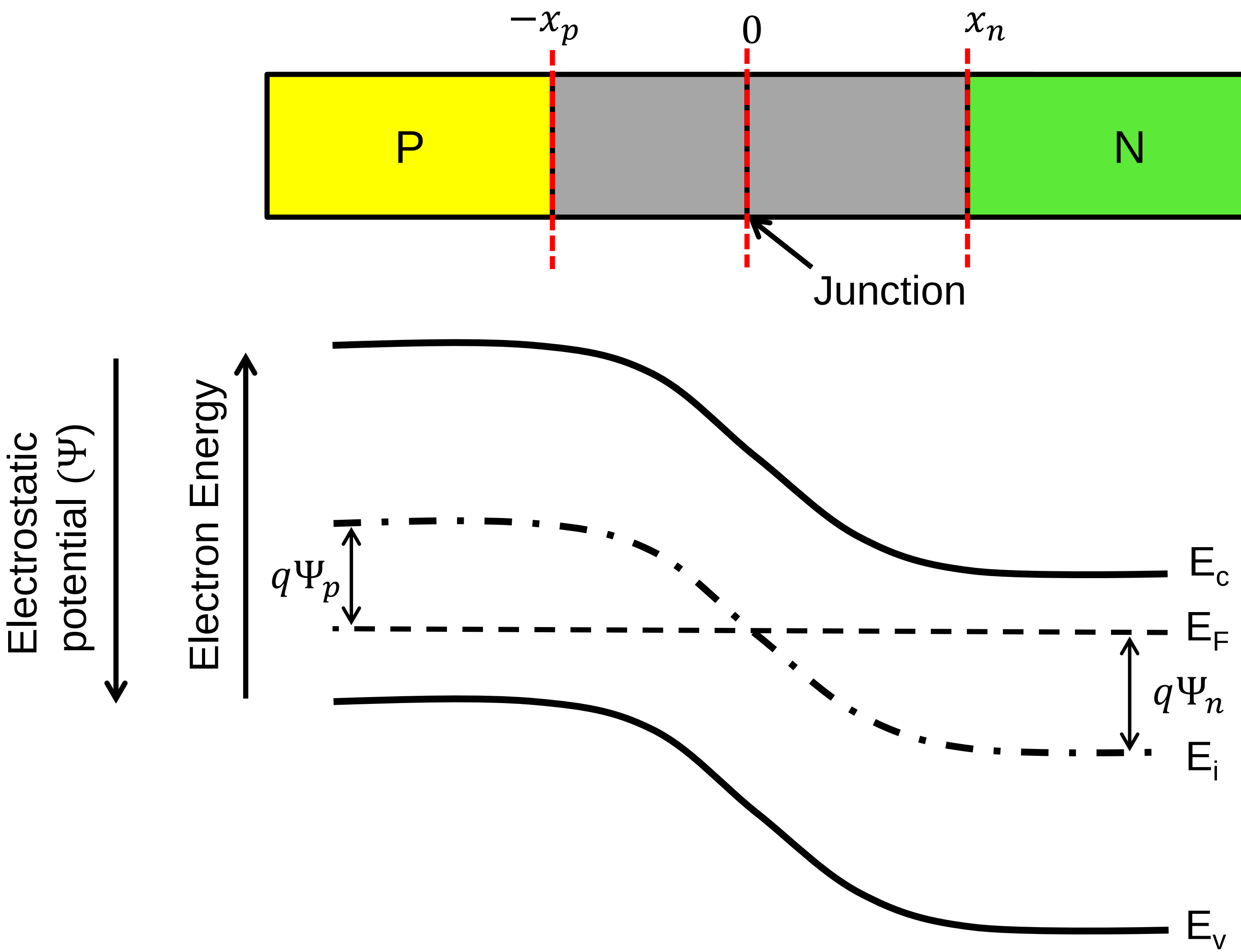
$$\Psi_n \equiv -\frac{1}{q}(E_i - E_F)\Big|_{x \ge x_n}$$

$$n = n_i exp^{\frac{E_F - E_i}{kT}} \qquad\qquad E_i - E_F = -kT\, ln\left(\frac{N_D}{n_i}\right)$$

$$\boldsymbol{\Psi_n \equiv \frac{kT}{q}\ln\left(\frac{N_D}{n_i}\right)}$$

- Therefore due to the relative position of the intrinsic energy level p material will always be shown as a **negative** electrostatic potential whereas the n material will be **positive**

Electro-static potential of a junction



Built in potential

- The difference between electrostatic potential between the n and p sides is termed the built in potential (V_{bi})

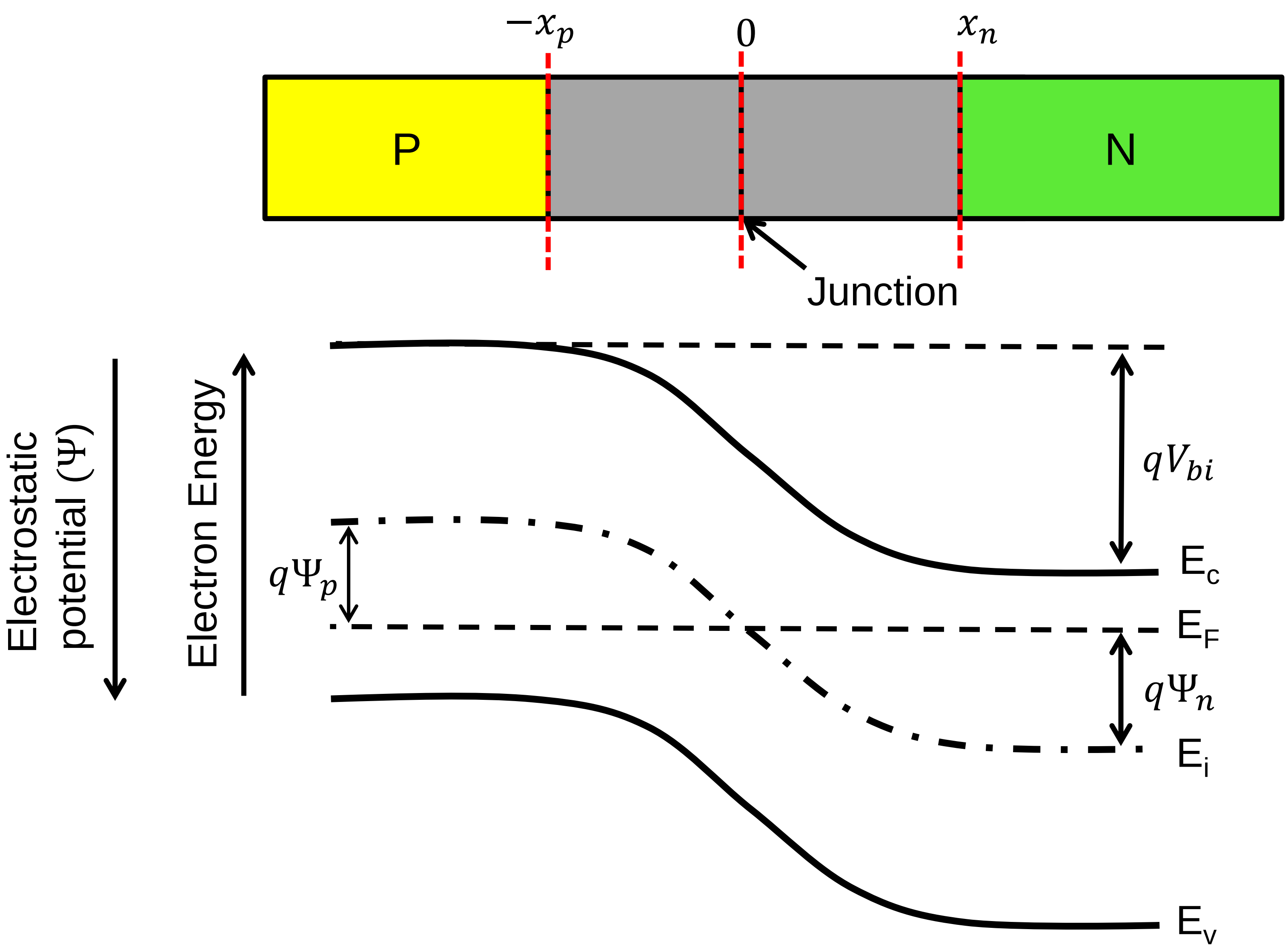
$$V_{bi} = \Psi_n - \Psi_p$$

$$\Psi_p \equiv -\frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right) \qquad \Psi_n \equiv \frac{kT}{q}\ln\left(\frac{N_D}{n_i}\right)$$

$$V_{bi} = \frac{kT}{q} ln\left(\frac{N_D}{n_i}\right) + \frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right)$$

$$\boldsymbol{V_{bi} = \frac{kT}{q} ln\left(\frac{N_A N_D}{{n_i}^2}\right)}$$

Junction built in potential



Example: Built in potential

- Calculate the built in potential for a silicon PN junction with $N_A=10^{18}$ cm^{-3} and $N_D=10^{15}$ cm^{-3} at 300K considering a intrinsic carrier concentration (n_i) of $5.22x10^9$

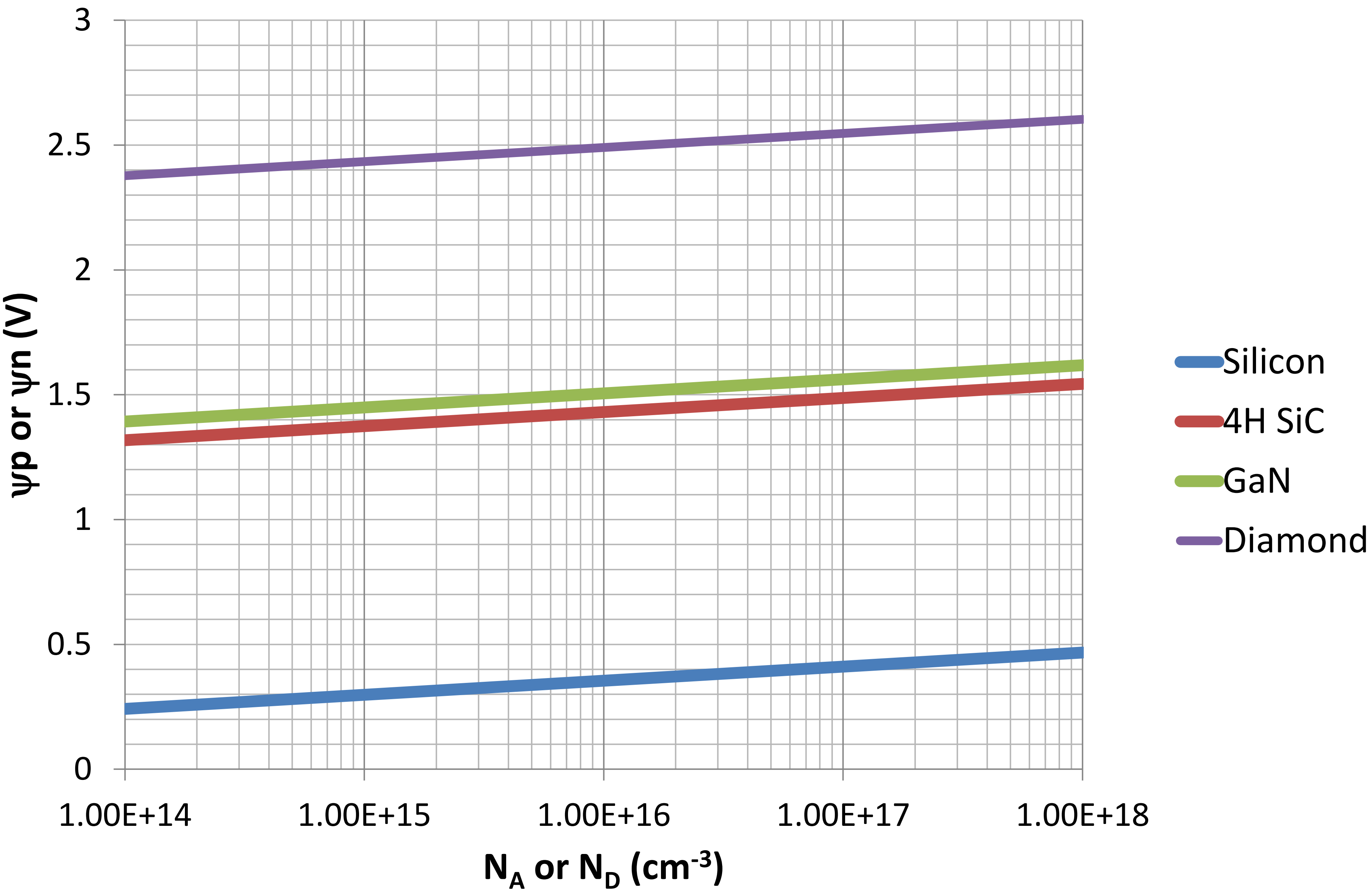
Example: Built in potential

- Calculate the built in potential for a silicon PN junction with $N_A=10^{18}$ cm^{-3} and $N_D=10^{15}$ cm^{-3} at 300K considering a intrinsic carrier concentration (n_i) of $5.22\text{x}10^9$

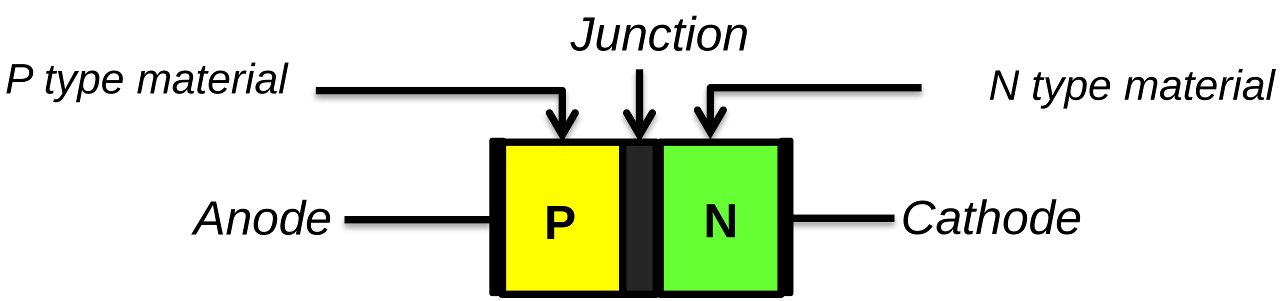
$$V_{bi} = \frac{kT}{q} ln\left[\frac{N_A N_D}{{n_i}^2}\right]$$

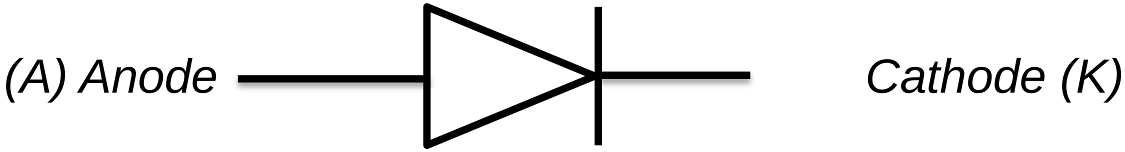
$$\left(\frac{1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}}\right) ln\left[\frac{1 \times 10^{18} \times 1 \times 10^{15}}{(5.22 \times 10^9)^2}\right] = 0.765V$$

Built-in potentials on the p and n side of abrupt junctions



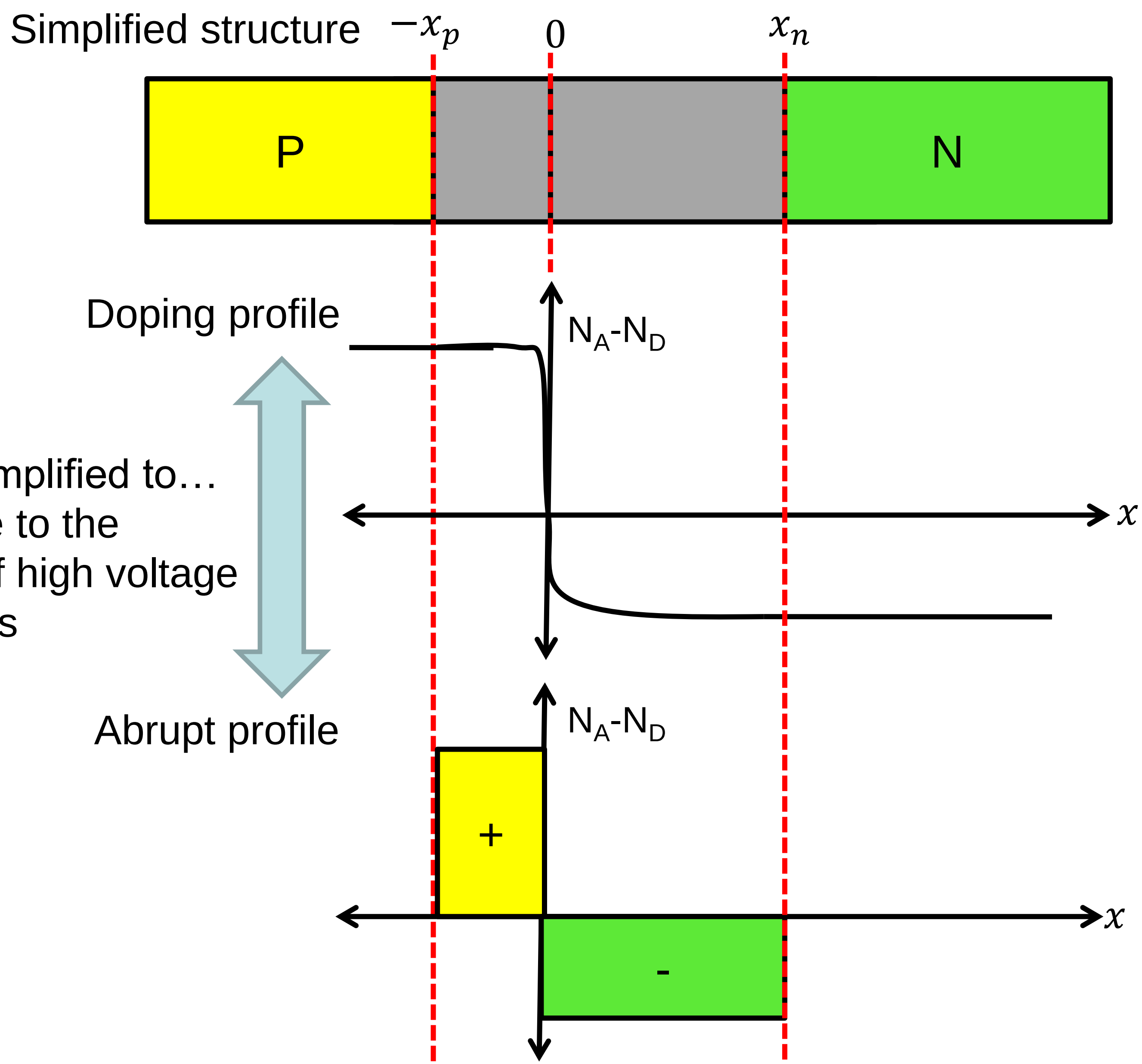
- The built in potential and its behaviour to applied bias is the most important characteristic of a p-n junction
- Most important feature of a p-n junction is that they rectify
  - Allows current to flow in one direction





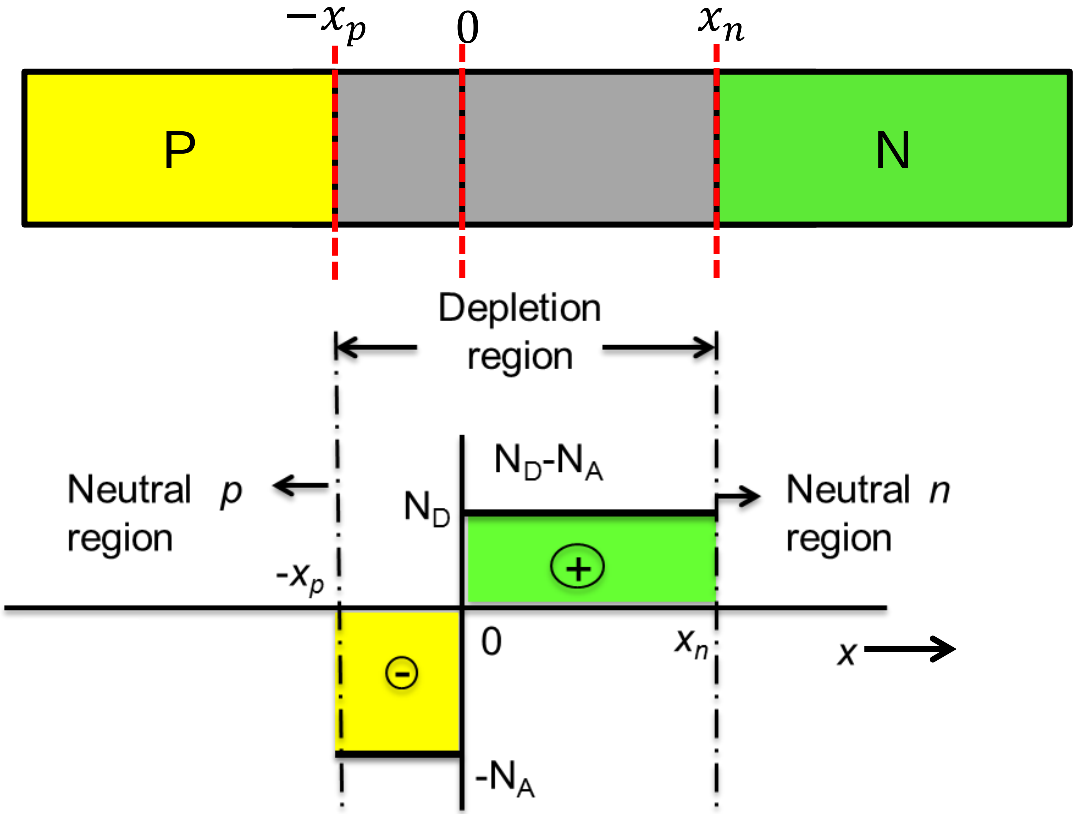
Diode Circuit Schematic Symbol

Approximate doping profile for abrupt junctions



Can be simplified to…
Applicable to the majority of high voltage P-N diodes

Depletion regions for abrupt junctions



- In the depletion region, free carriers are totally depleted
  - Poisson's equation simplifies to:

$$\frac{d^2\psi}{dx^2} = \frac{qN_A}{\varepsilon_s} \; for \; -x_p \le x < 0$$

$$\frac{d^2\psi}{dx^2} = -\frac{qN_D}{\varepsilon_s} \; for \; 0 < x \le x_n$$

Electric field at the junction

- Due to space charge neutrality the total negative charge **must** equal positive charge

$$N_A x_p = N_D x_n$$

- Total depletion layer width (W) is given by:

$$W = x_p + x_n$$

- The electric field is obtained by integrating Poisson's equation:

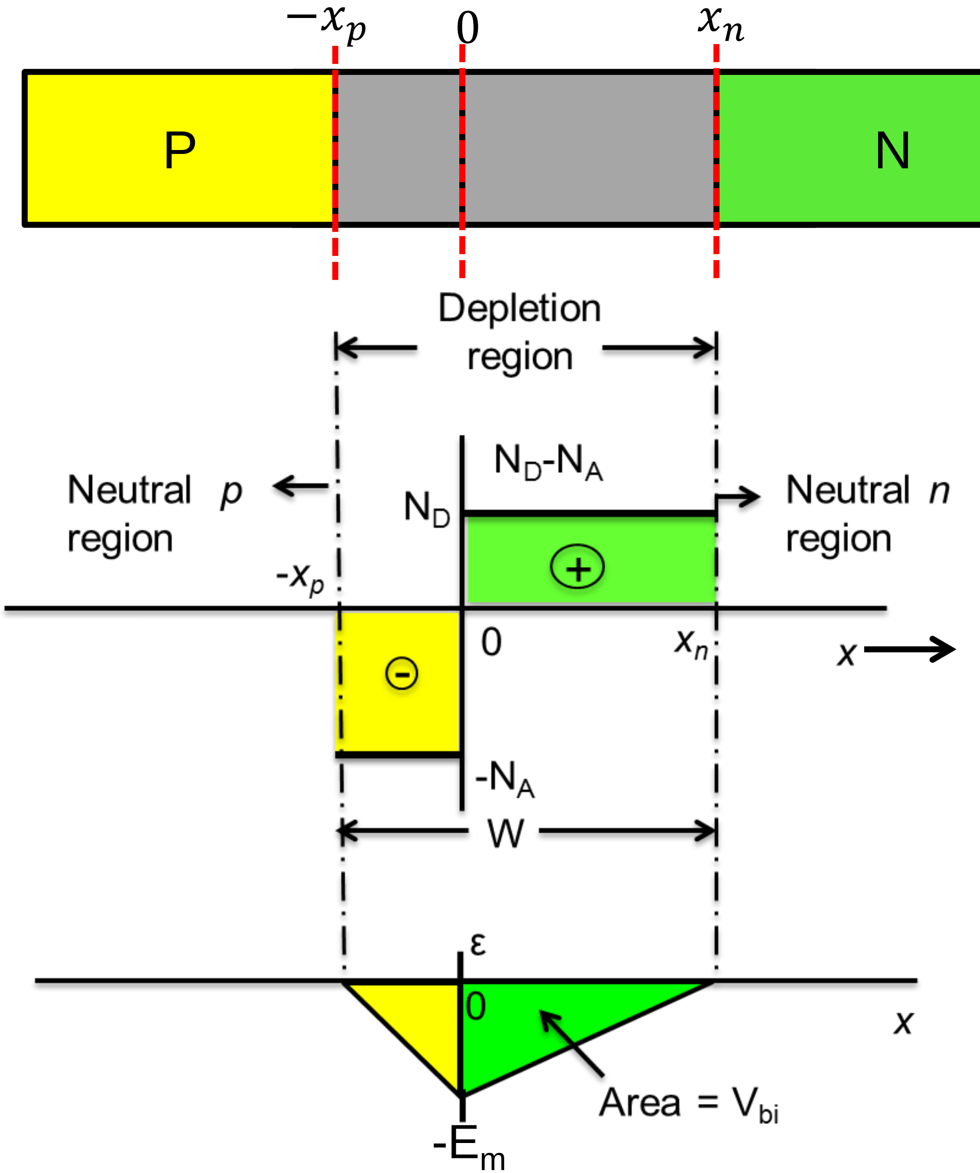
$$E_{(x)} = -\frac{d\psi}{dx} = -\frac{qN_A\left(x + x_p\right)}{\varepsilon_s} \; for \; -x_p \leq x < 0$$

$$E_{(x)} = -E_m + \frac{qN_D(x)}{\varepsilon_s} = \frac{qN_D(x - x_n)}{\varepsilon_s} \; for \; 0 < x \leq x_n$$

- Maximum (E_m) electric field occurs at $x = 0$ and is given by:

$$E_m = \frac{qN_D x_n}{\varepsilon_s} = \frac{qN_A x_p}{\varepsilon_s}$$

Depletion regions for abrupt junctions and electric field



Depletion Width

- Integrating the electric field across the junction yields its potential

$$V_{bi} = -\int_{-x_p}^{x_n} E(x) = \int_{-x_p}^{0} E(x)dx \Big| p\ side \ - \int_{0}^{-x_n} E(x)dx | n\ side$$

$$V_{bi} = \frac{qN_A {x_p}^2}{2\epsilon_s} + \frac{qN_D {x_n}^2}{2\epsilon_s} = \frac{E_m\left(x_p + x_n\right)}{2} = \frac{1}{2}E_m W$$

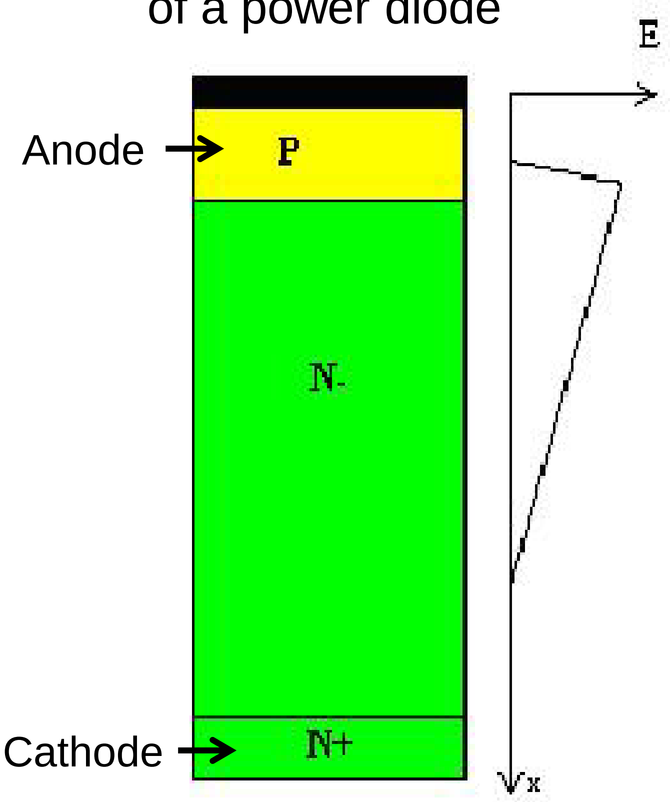
- Therefore the area of the field triangle corresponds to the potential across the junction
- Combining this with space charge neutrality gives the depletion width as a function of junction of potential

$$W = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{N_A + N_D}{N_A N_D}\right) V_{bi}}$$

One side abrupt junction

- Due to the greater electron mobility (1450 compared to 450 m²/ (V. s), majority of diodes are p(+)/n(-)/n(+) in nature
  - termed abrupt junction

Simplified cross-section of a power diode



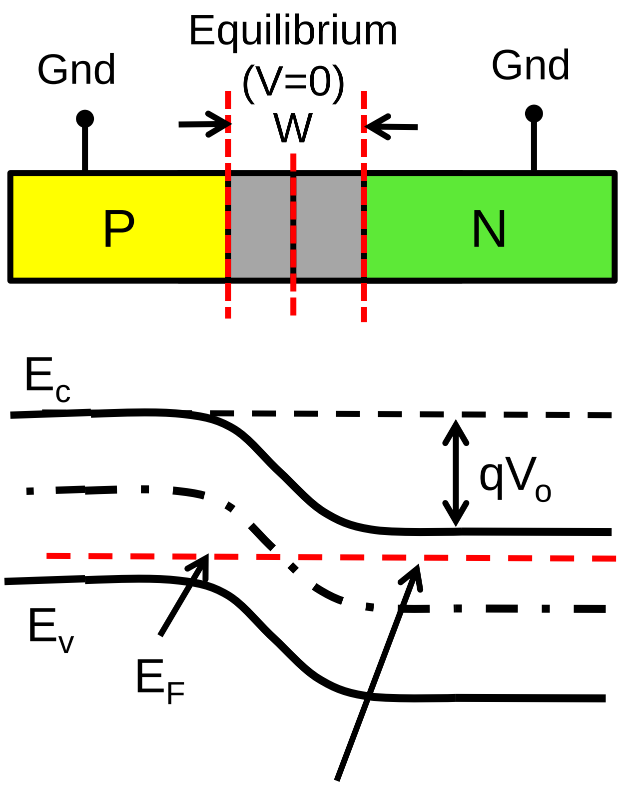
- When the impurity concentration is much greater on one side of the abrupt junction
- Considering a P+/n- junction the depletion width into the p+ region is significantly less than that of the n- therefore it can be disregarded
- This simplifies the depletion width expression to:

$$W \cong x_n = \sqrt{\frac{2\varepsilon_s V_{bi}}{qN_D}} \quad \textbf{and} \quad E_m = \frac{qN_D W}{\varepsilon_s}$$

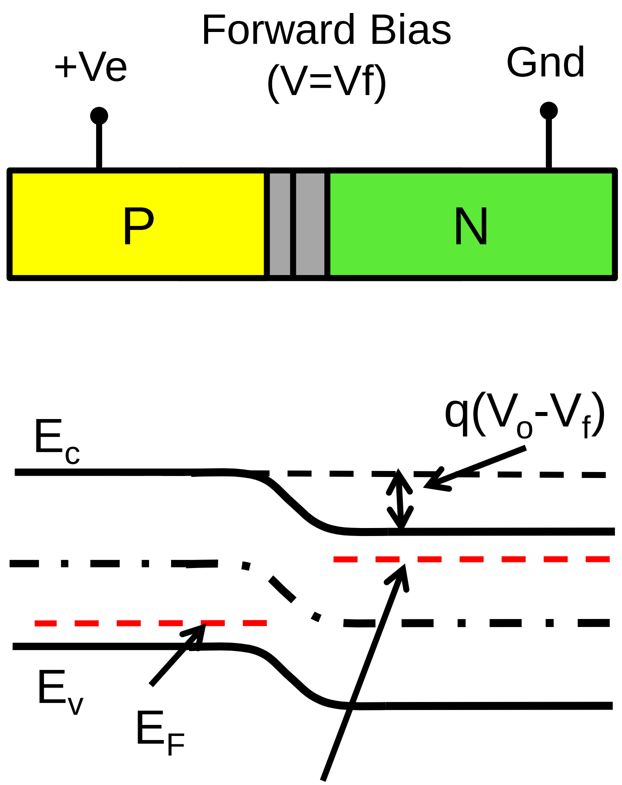
- The Junction capacitance can be obtained from:

$$C_j = \frac{\varepsilon_s}{W} \quad \text{F/cm}^2$$

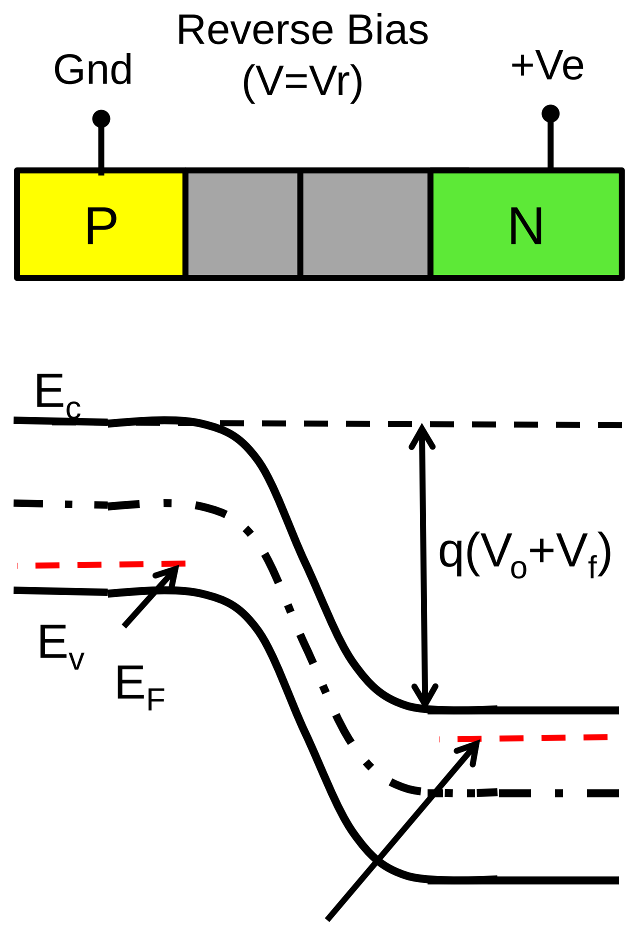
Effects of applied bias at a p-n junction



Both n and p material at same potential:
Fermi level constant

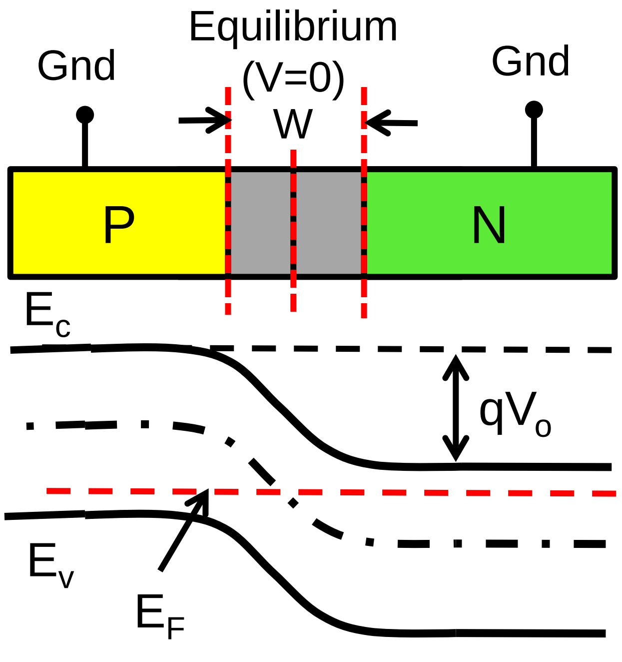


N material increased energy
Fermi level separates:
n energy level higher than p
Voltage barrier (Vbi) reduced until overcome (increased conduction)

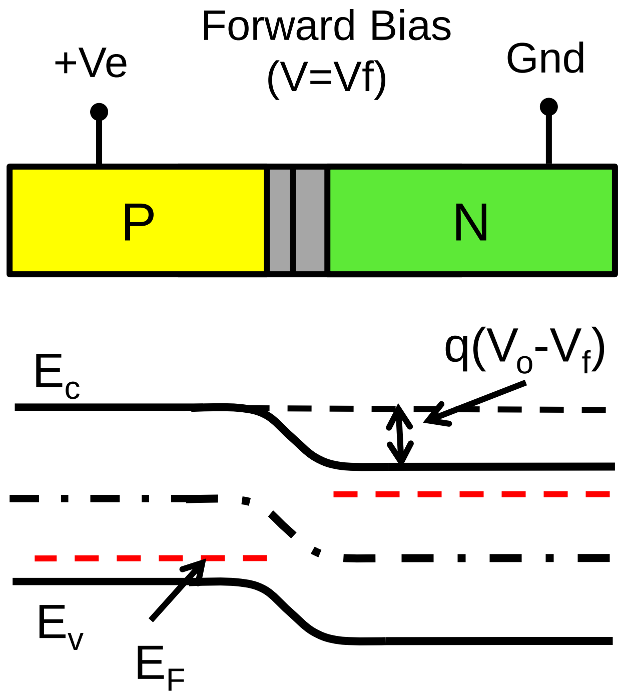


Applied bias reduces N material energy level
Voltage barrier (Vbi) increase reducing current conduction

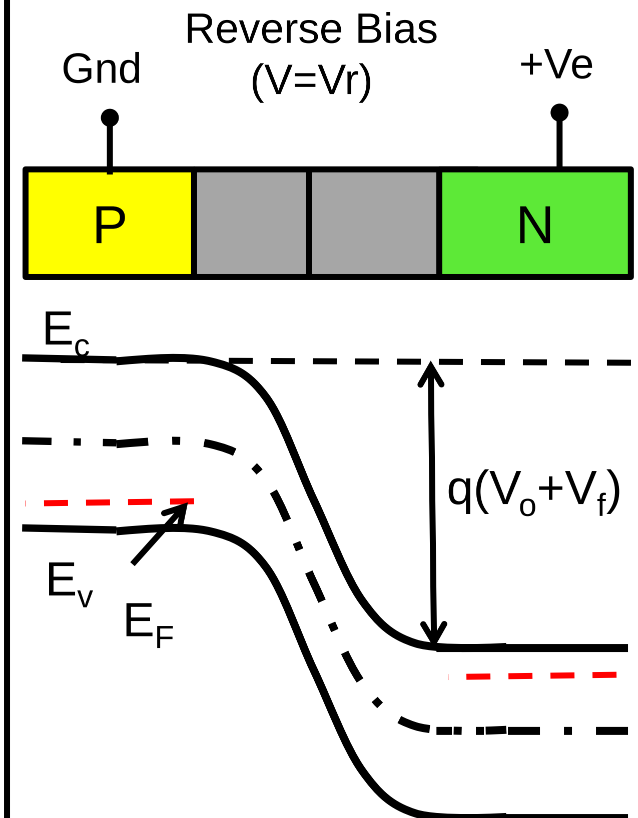
Current flow across junction



	Particle Flow	Current
h^+ diffu	→	→
h^+ drift	←	←
e^- diffu	⇠	⇢
e^- drift	⇢	⇠

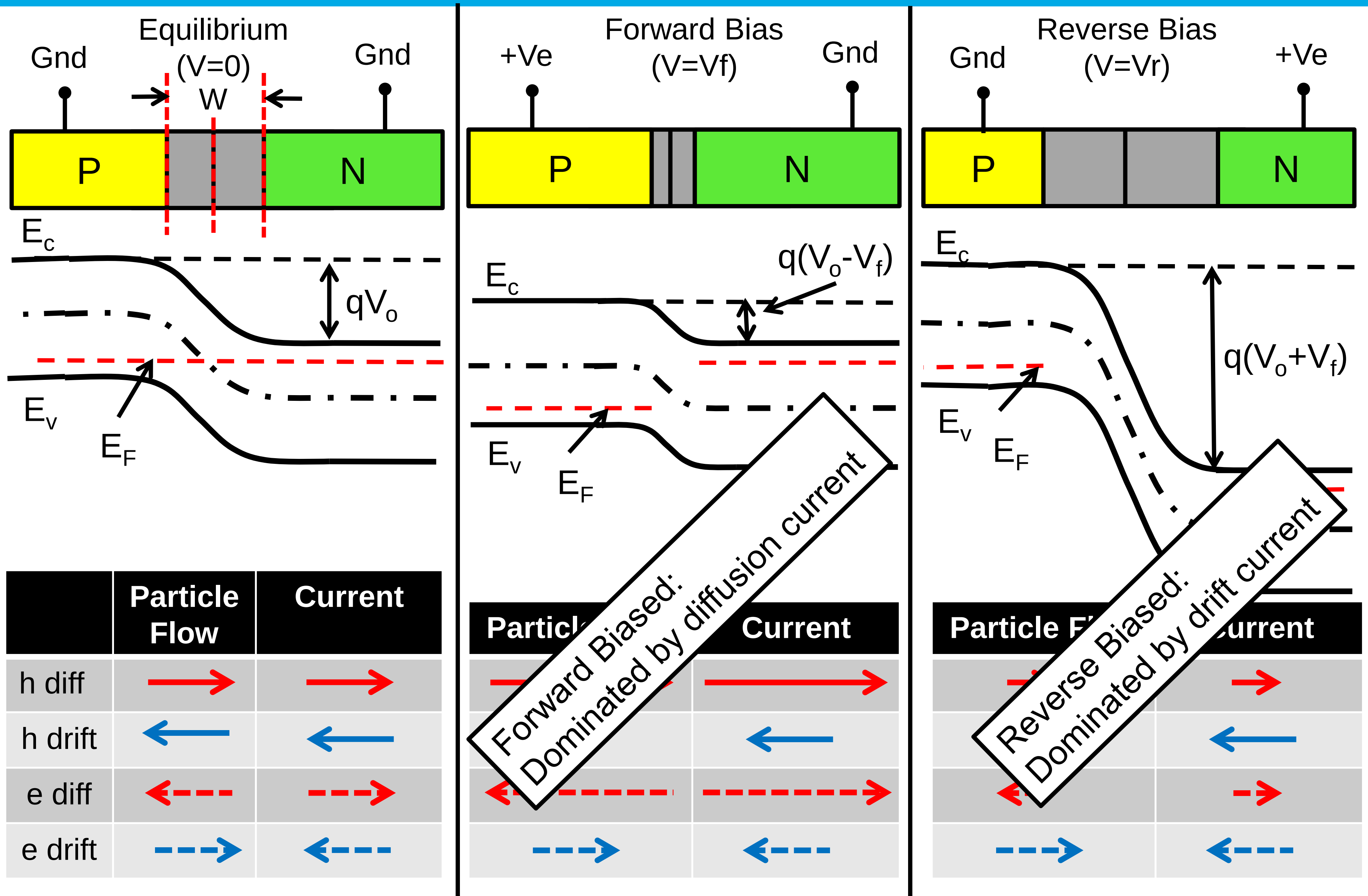


Particle Flow	Current
→	→
←	←
⇠	⇢
⇢	⇠

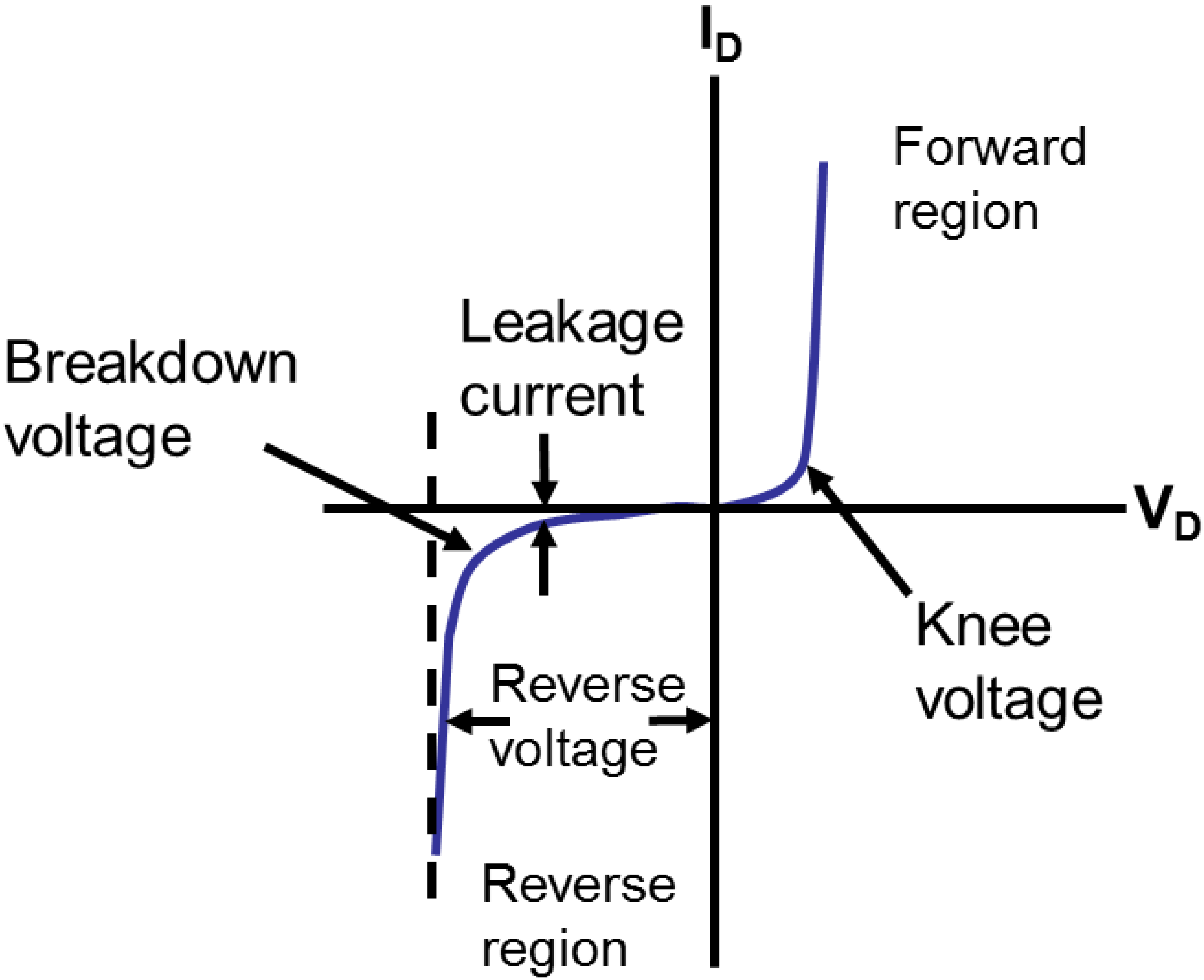


Particle Flow	Current
→	→
←	←
⇠	⇢
⇢	⇠

Current flow across junction

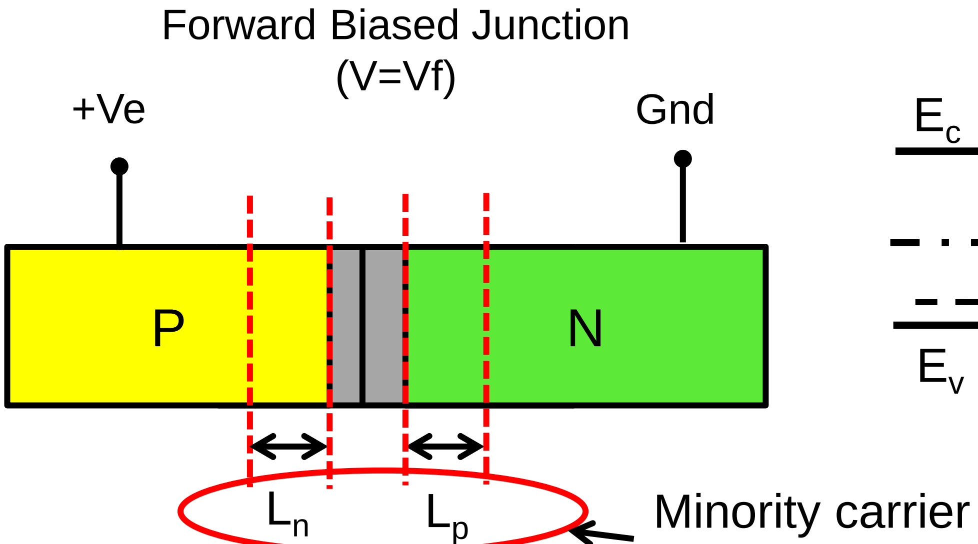


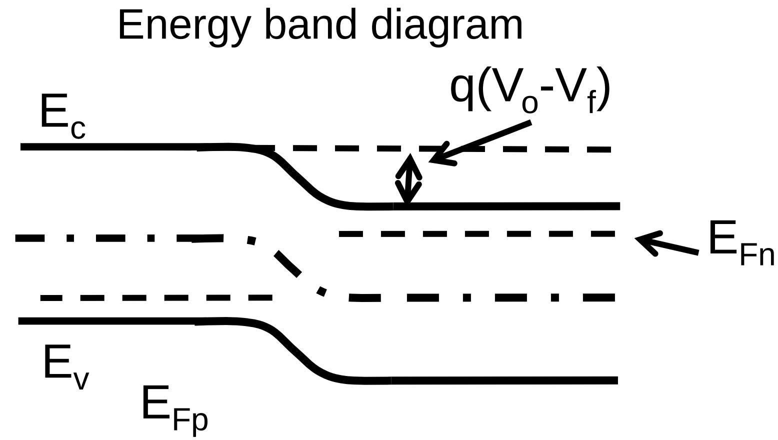
Typical current-voltage characteristics



Current voltage characteristics: Forward bias

- A voltage applied to the junction will disturb the balance between diffusion and drift currents of electrons and holes
- Under forward bias, the applied voltage reduces the electrostatic potential across the depletion region
  - Drift current is reduced in comparison to diffusion current
  - Hole diffusing from the p side and electron diffusion from the n side are enhanced
    - Minority carrier injection occurs

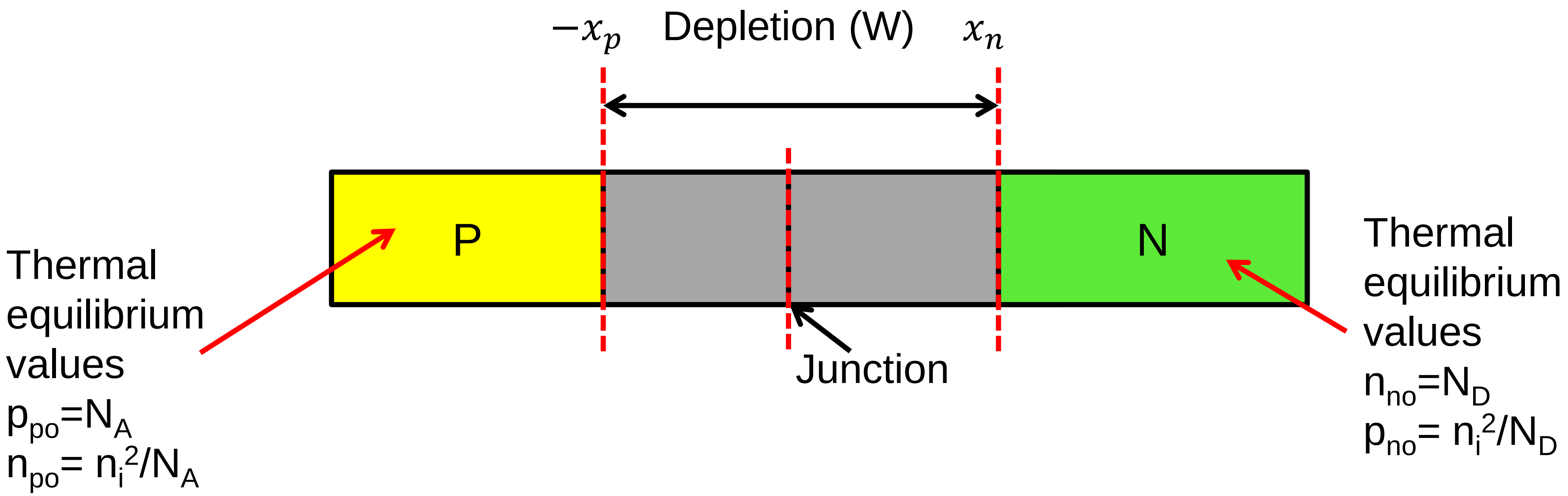




Ideal forward current voltage characteristics: Assumptions

- Depletion region has abrupt boundaries and outside the boundary the semiconductor is assumed to be neutral
- Carrier densities at the boundaries are related by the electrostatic potential difference across the junction
- Low injection condition: injected minority carrier densities are smaller compered with the majority carrier density
- Neither generation or recombination currents exist in the depletion region
- Electron and hole currents are constant throughout the depletion region

- At thermal equilibrium the majority carrier density in the neutral regions is equal to the doping concentration
  - In the following n and p denotes the semiconductor type
  - Subscript o specifies thermal equilibrium conditions
  - i.e. n_{no} n_{po} are the equilibrium electron densities in the n and p sides of the junction



- Using this terminology, diode turn on voltage (V_{bi}) can be written as:

$$V_{bi} = \frac{kT}{q} ln\left[\frac{p_{po}n_{no}}{n_i{}^2}\right] = \frac{kT}{q} ln\left[\frac{n_{no}}{n_{po}}\right]$$

Mass action law

$p_{po}n_{pn}=n_i^2$

- Rearranging we have:

$$\boldsymbol{n_{no} = n_{po}e^{qV_{bi}/kT}} \quad \text{and} \quad \boldsymbol{p_{po} = p_{no}e^{qV_{bi}/kT}}$$

- Electron and hole density at the depletion region boundary ($-x_p$ and x_n) are related through their electrostatic potential difference at thermal equilibrium
- From our second assumption:
  - Carrier densities at the boundaries are related by the electrostatic potential difference across the junction
  - We expect that this relationship holds when this electrostatic potential difference is changed by and applied bias

Minority carrier densities at the depletion region boundary

- For a forward biased junction the electrostatic potential is reduced by $(V_{bi} - V)$ and increased by $(V_{bi}+V_R)$ for a reverse biased
- This modifies the previous equation:

$$n_{no} = n_{po} e^{qV_{bi}/kT} \quad \text{to:} \quad n_n = n_p e^{q(V_{bi}-V)/kT}$$

Equilibrium conditions

Non equilibrium conditions

- Where n_n and n_p are the non equilibrium electron densities at the boundaries of the depletion region in the n and p sides
- We are only assuming low injection conditions
  - Therefore injected carrier concentration is less than the majority, therefore $n_n \cong n_{no}$
  - Substituting this and combining these equations yields the electron density at the boundary of the depletion region of the p side $(x = -x_p)$

$$n_n = n_p e^{qV_{bi}-V/kT} \qquad n_{no} = n_p e^{qV_{bi}-V/kT}$$

Low injection assumption

$$n_{po} e^{qV_{bi}/kT} = n_p e^{qV_{bi}-V/kT}$$

$$\boldsymbol{n_p = n_{po} e^{qV/kT}} \quad \text{or} \quad \boldsymbol{n_p - n_{po} = n_{po}\left(e^{qV/kT} - 1\right)}$$

Injection level

- Likewise for hole carrier concentration the depletion boundary in the n region $(x = x_n)$:

$$\boldsymbol{p_n = p_{no} e^{qV/kT}} \quad \text{or} \quad \boldsymbol{p_n - p_{no} = p_{no}\left(e^{qV/kT} - 1\right)}$$

- These equation define the boundary conditions to calculate the ideal current-voltage characteristics of a p-n junction

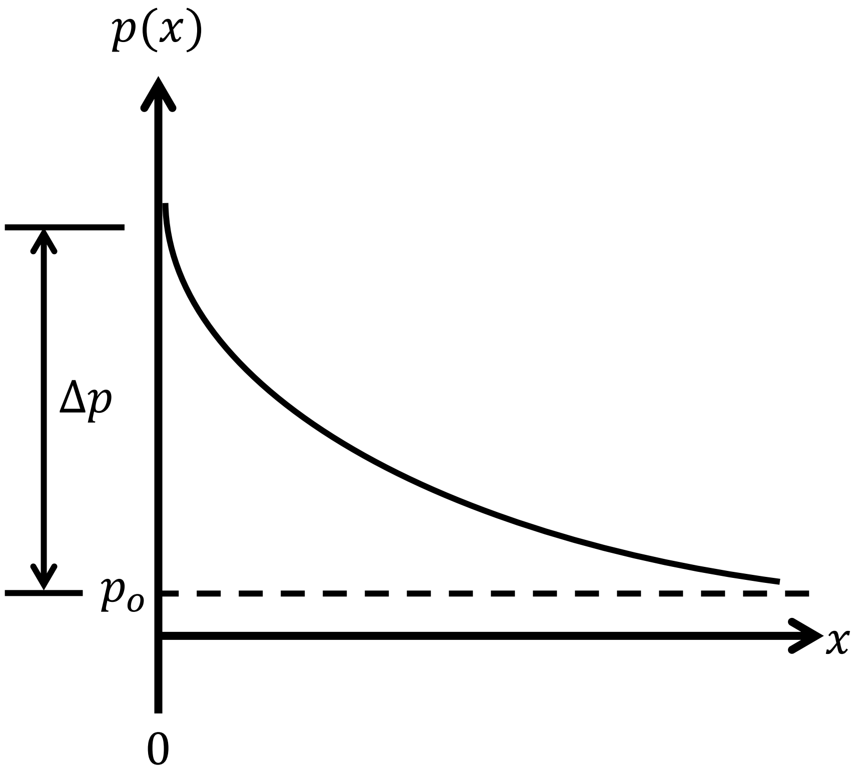
- Under our idealised assumptions
  - No current generated within the depletion region
    - All currents must come from the neutral regions
    - In the neutral region there is no electric field
- Continuity equation:

$$\frac{dp_n}{dt} = p_n\mu_p\frac{dE}{dx} + \mu_p E\frac{dp_n}{dx} + D_p\frac{d^2p_n}{dx^2} + G_p - \frac{p_n - p_{no}}{\tau_p}$$

- Due to assumptions: reduces to…

$$\frac{d^2p_n}{dx^2} - \frac{p_n - p_{no}}{D_p\tau_p} = 0$$

Solution to the continuity equation: Injection of holes at $x = 0$



- In steady state we expect the distribution of excess holes to decay to zero for large values of x
- The solution to the steady state continuity equation takes the form of:

$$\delta p = C_1 e^{x/L_p} + C_2 e^{-x/L_p}$$

- C_1 and C_2 can be evaluated from:
  - Since recombination must reduce $\delta p(x)$ to zero at large values of x, $\delta_p = 0$ at $x = \infty$ therefore $C_1 = 0$
  - Likewise $\delta p = \Delta p$ at $x = 0$ gives $C_2 = \Delta p$

Therefore the solution is: $\boldsymbol{\delta p(x) = \Delta p e^{-x/L_p}}$

Minority carrier injection into the n region

- The minority carrier injection level in the n region is:

$$p_n - p_{no} = \Delta p e^{-x/L_p}$$
$$\Delta p = p_{no}\left(e^{qV/kT} - 1\right)$$

$$\boldsymbol{p_n - p_{no} = p_{no}(e^{qV/kT} - 1)e^{-(x-x_n)/L_p}}$$

- Where L_p is the diffusion length for holes (minority carriers) in the n region
- The total hole current injected into the n region (at $x = x_n$)

$$J_p(x_n) = -qD_p \frac{dp_n}{dx}|x_n = \frac{qD_p p_{no}}{L_p}\left(e^{qV/kT} - 1\right)$$

Hole diffusion length (L_p)

$$L_p = \sqrt{D_p \tau_p}$$

Minority carrier injection from the n into the p region

- Likewise, the carrier electron injection into the p region is given by:

$$n_p - n_{po} = \Delta n e^{x/L_n}$$

$$\Delta n = n_{po}\left(e^{qV/kT} - 1\right)$$

$$\boldsymbol{n_p - n_{po} = n_{po}\left(e^{qV/kT} - 1\right)e^{(x+x_p)/L_n}}$$

- The total electron current injected into the p region (at $x = -x_p$) is given by:

$$J_n(-x_p) = -qD_n \frac{dn_p}{dx}\Big|_{-x_p} = \frac{qD_n n_{po}}{L_n}\left(e^{qV/kT} - 1\right)$$

Electron diffusion length (L_n)

$$L_n = \sqrt{D_n \tau_n}$$

Total current density

- Total current density (J) is the algebraic sum of the electron (J_n) and hole (J_p) components

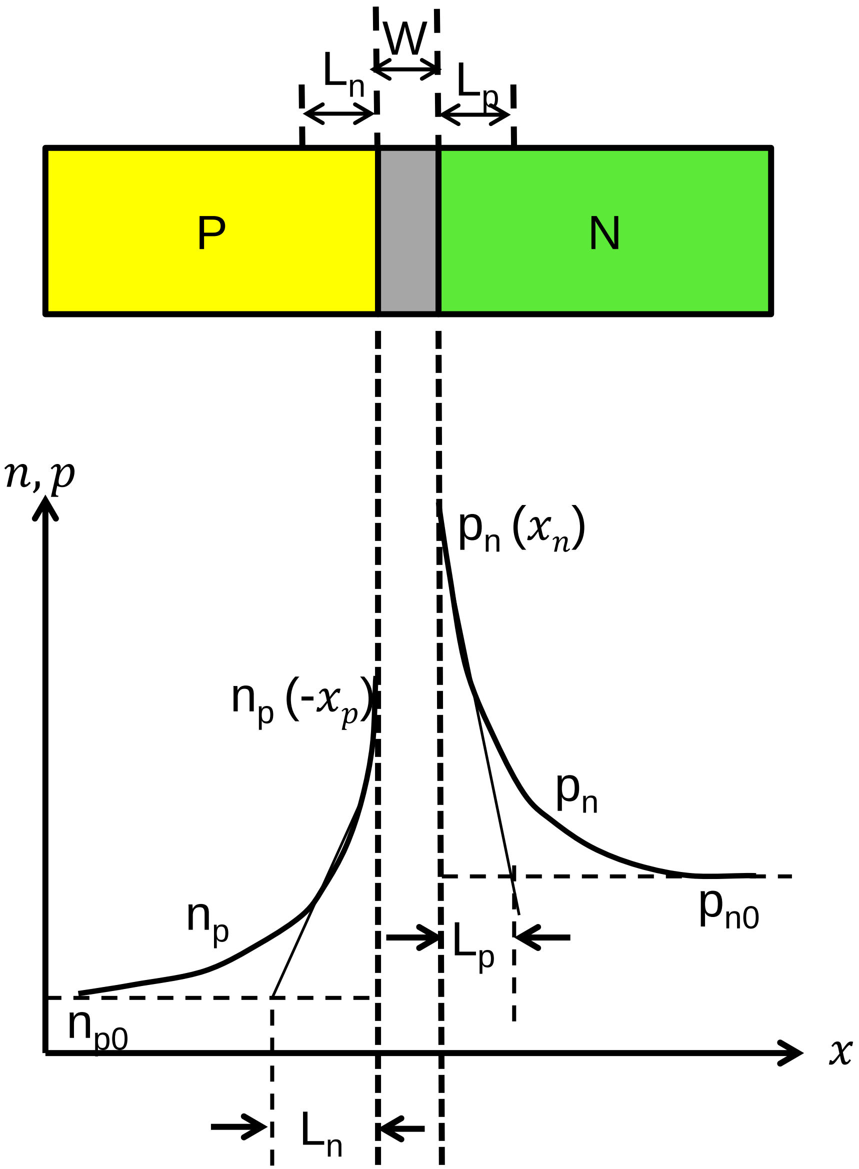
$$Total\ current(J) = J_p(x_n) + J_n(-x_p)$$

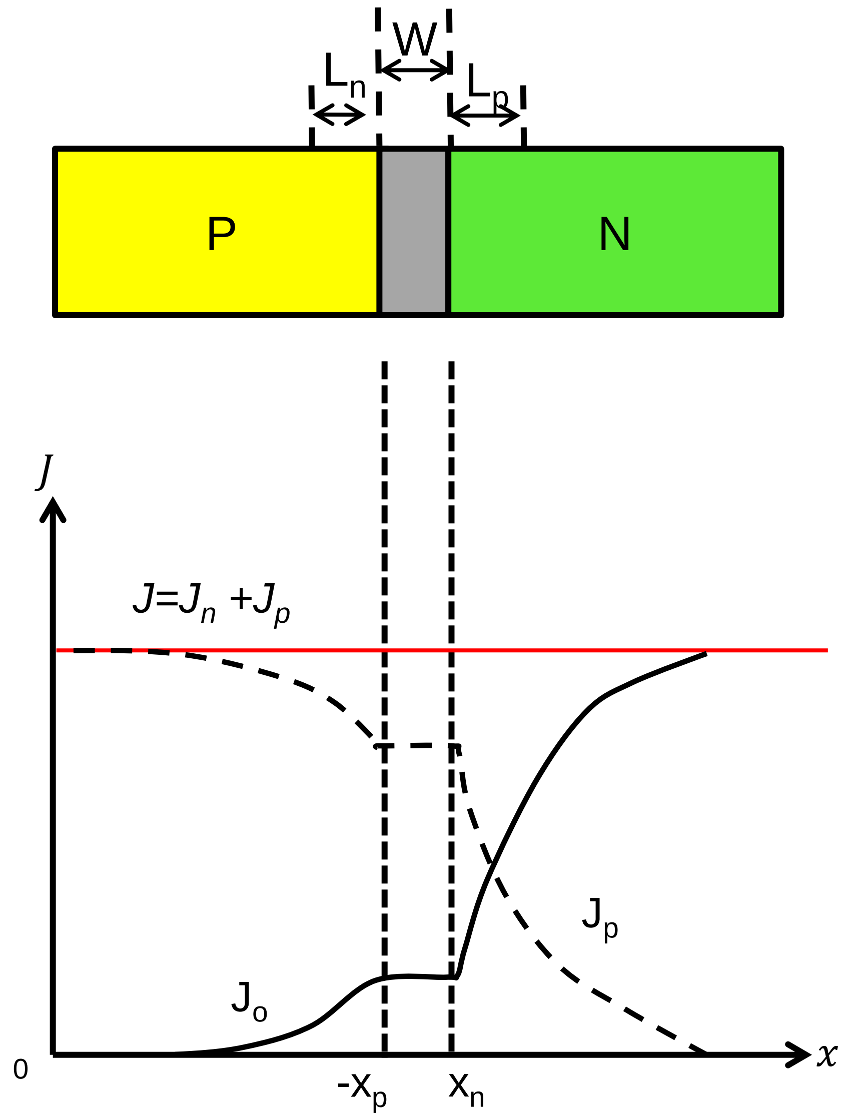
$$J = \frac{qD_n n_{po}}{L_n}\left(e^{qV/kT} - 1\right) + \frac{qD_p p_{no}}{L_p}\left(e^{qV/kT} - 1\right)$$

$$\boldsymbol{J = J_s\left(e^{qV/kT} - 1\right) \quad J_s \equiv \frac{qD_p p_{no}}{L_p} + \frac{qD_n n_{po}}{L_n}}$$

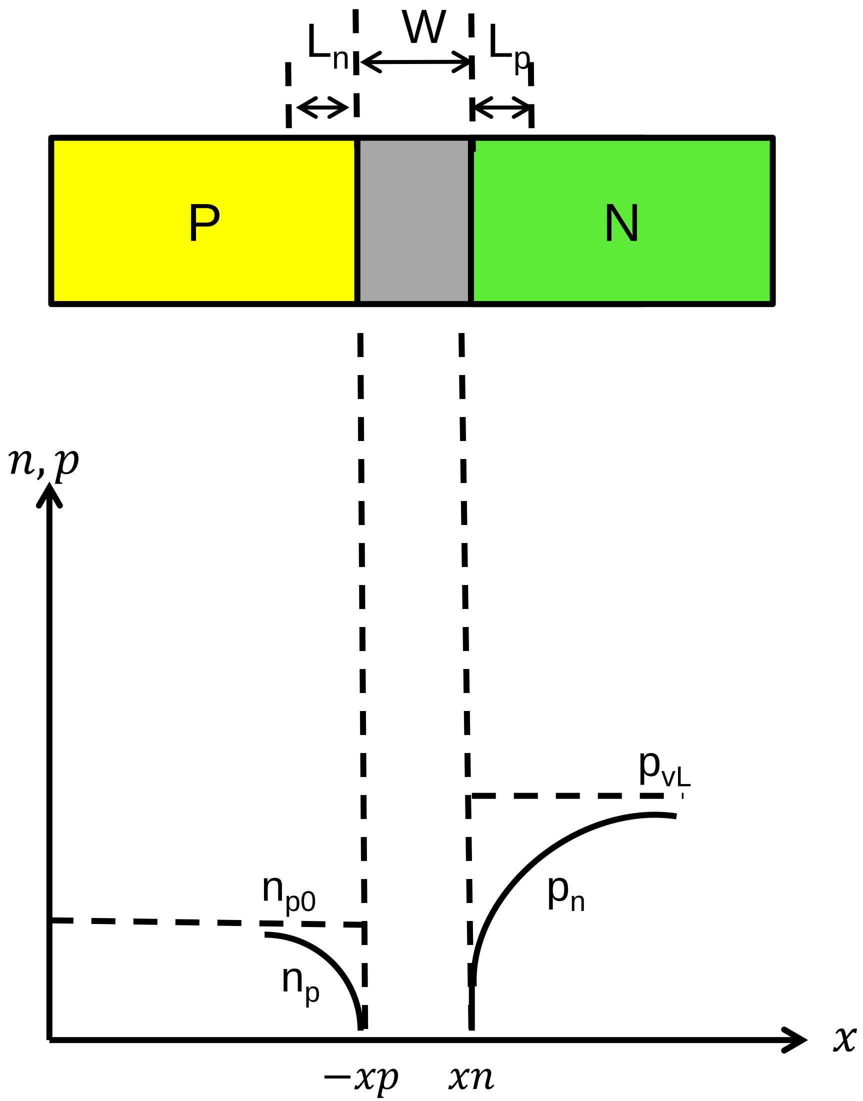
- Where J_s is the saturation current density

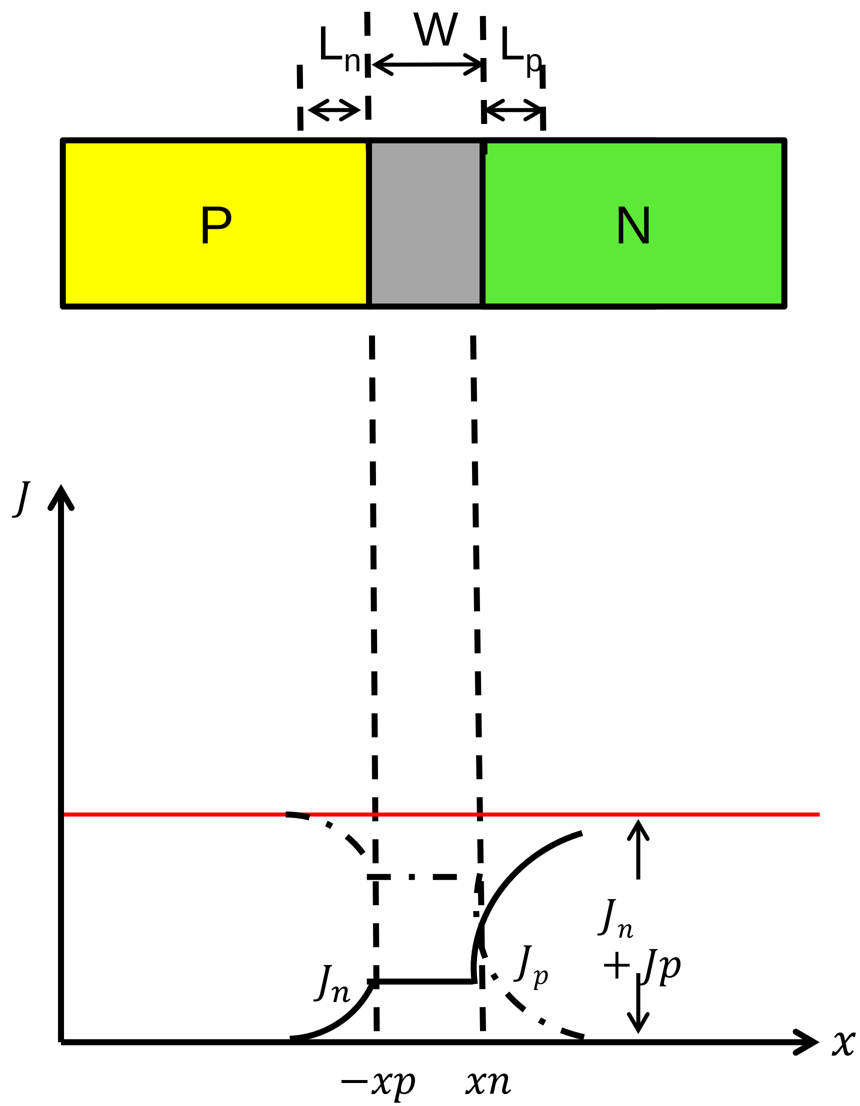
Injected minority carrier distribution under forward bias





Injected minority carrier distribution under reverse bias





Example: Diode saturation current

- Calculate the ideal reverse saturation current in a Si P-N diode with a cross-sectional area of 2 x 10^{-4} cm^2 the diode parameters are:
- N_A= 5e16cm^{-3}, N_D=1e16cm^{-3}, n_i=9.65e9cm^{-3}, D_n=21cm^2/s, D_P=10cm^2/s, t_n=t_p=5e-7s

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$$J_s = \frac{qD_p p_{no}}{L_p} + \frac{qD_n n_{po}}{L_n} = q{n_i}^2\left[\frac{1}{N_D}\sqrt{\frac{D_p}{\tau_p}} + \frac{1}{N_A}\sqrt{\frac{D_n}{\tau_n}}\right]$$

$$= 1.6 \times 10^{-19} \times (9.65 \times 10^9)^2 \times \left[\frac{1}{10^{16}}\sqrt{\frac{10}{5 \times 10^{-7}}} + \frac{1}{5 \times 10^{16}}\sqrt{\frac{21}{5 \times 10^{-7}}}\right]$$

$$= 8.58 \times 10^{-12}\frac{A}{cm^2} = 8.58 \times 10^{-12} \times 2 \times 10^{-4} = 1.72 \times 10^{-15}A$$

Example: Forward current calculation

- What is the forward current of the previous diode at a bias of 1V considering a V_{bi} of 0.7V

Example: Forward current calculation

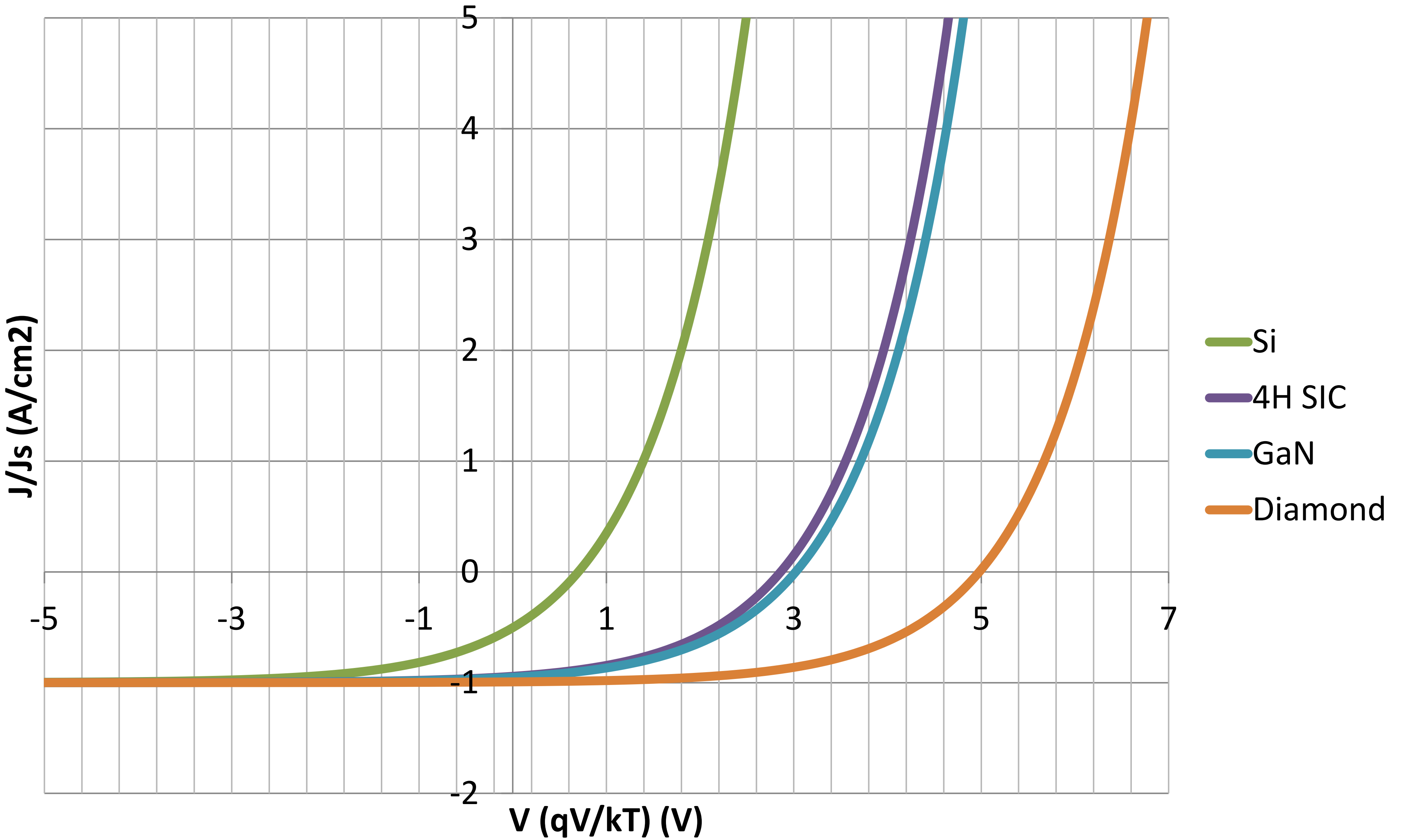
- What is the forward current of the previous diode at a bias of 1V considering a V_{bi} of 0.7V

$$J = J_s\left(e^{(V_a - V_{bi})\frac{q}{kT}} - 1\right) = 8.58 \times 10^{-12}\left(e^{(1-0.7)\frac{1}{0.0259}} - 1\right)$$

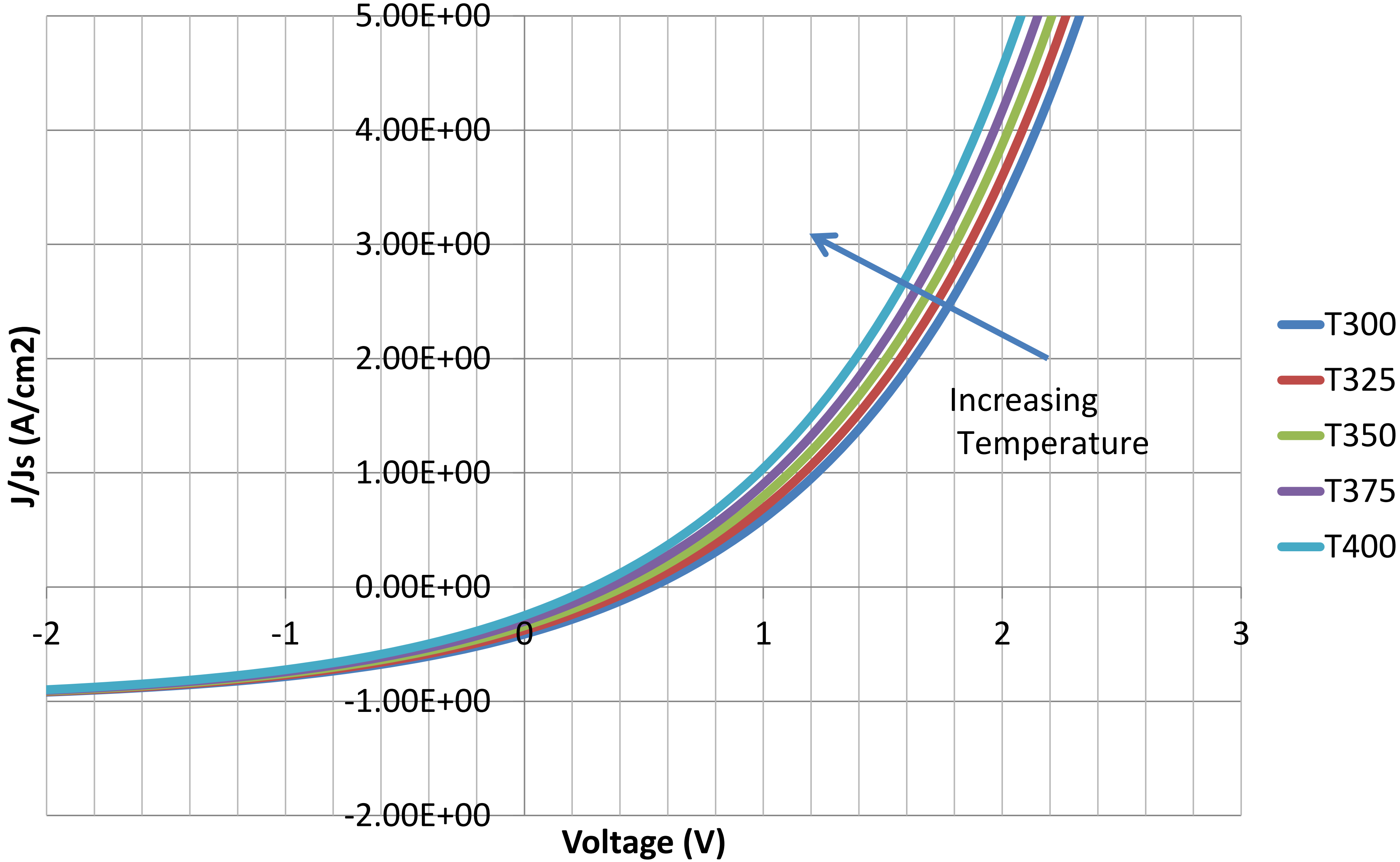
$$= 9.49 \times 10^{-7} A\ cm^{-2}$$

$$= 9.49 \times 10^{-7} \times 2 \times 10^{-4} = 1.898 \times 10^{-10}\ A$$

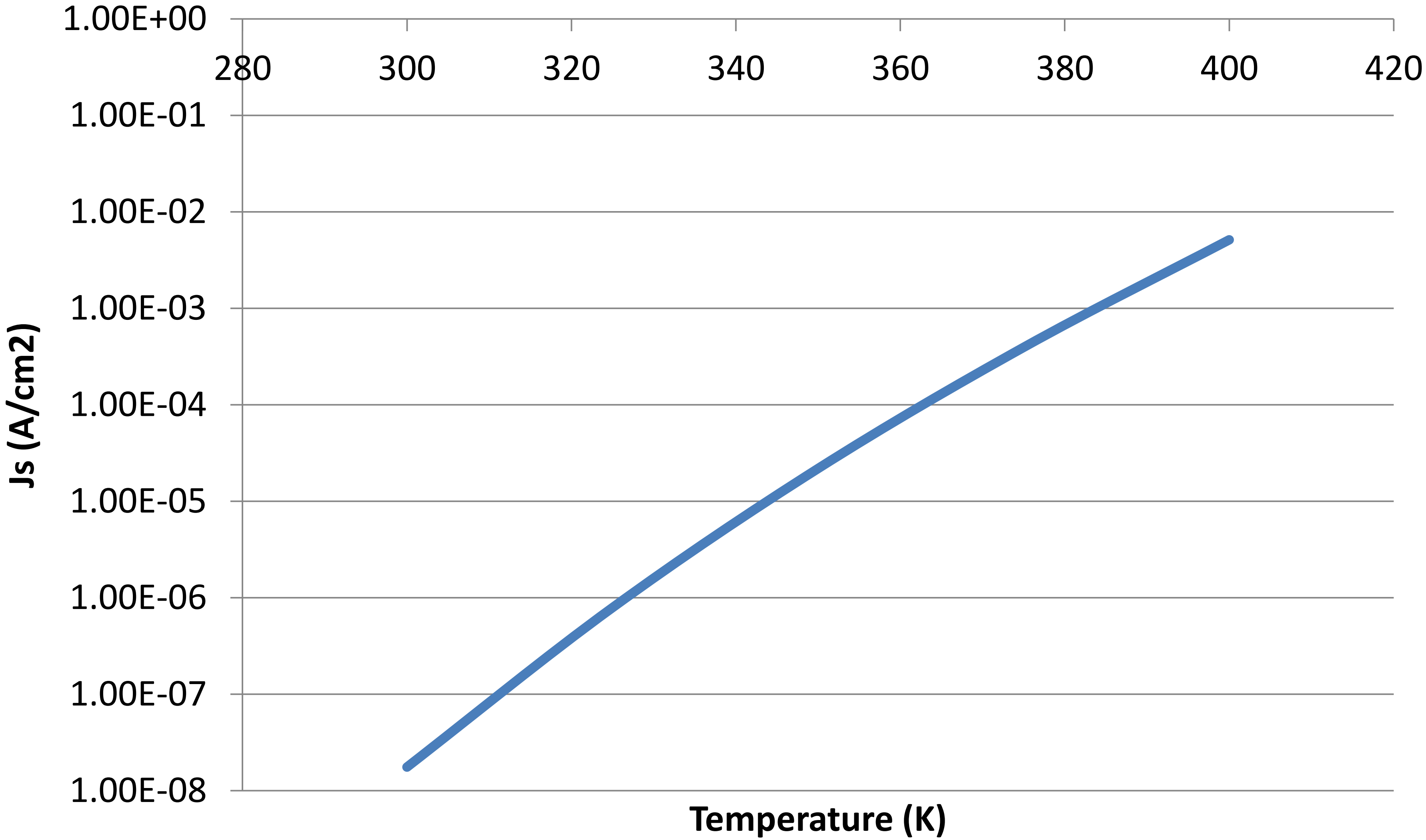
Ideal current/voltage characteristics for Si and WBG



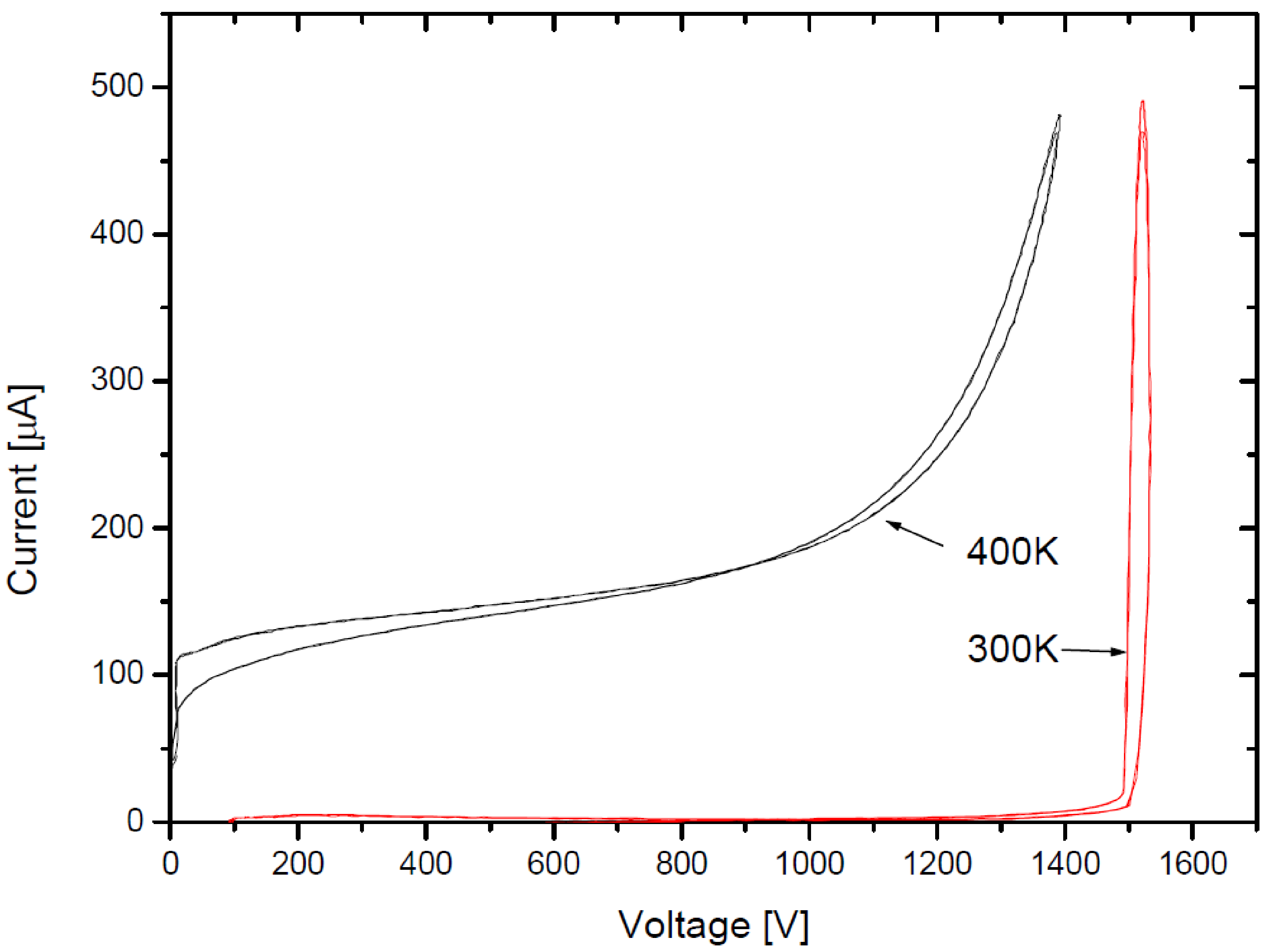
Temperature effect on ideal current voltage characteristic (Si)



Influence of temperature with saturation current density



Off-state performance of 1200V 60A rated diode



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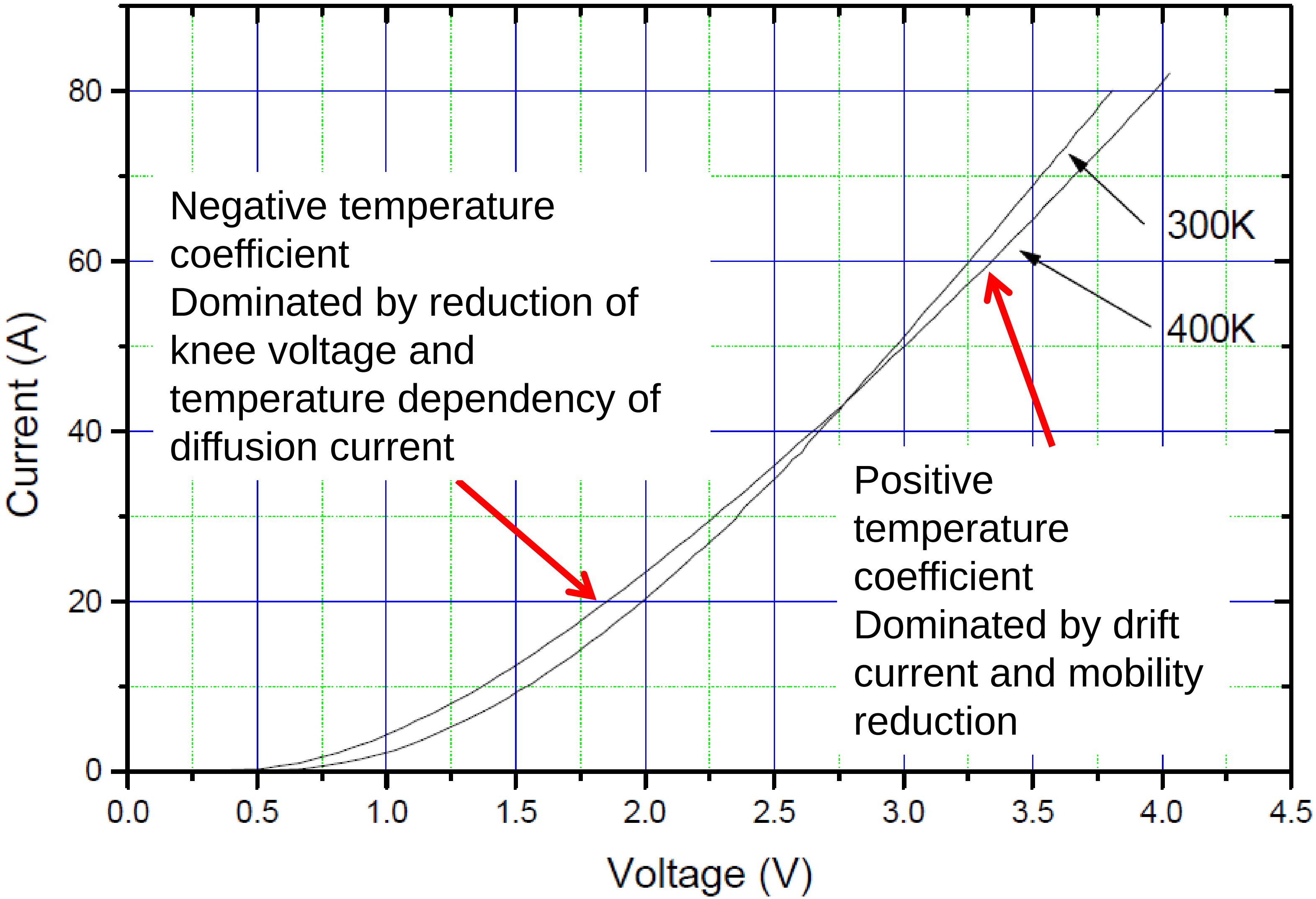

WBG P-N Junctions

- Diode knee voltage influenced by:
  - Doping concentration
  - Ambient temperature
  - Semiconductor band gap
- Therefore wide band gap (WBG) semiconductors would turn on > 3V
  - 1200V silicon diode structure
    - On-state forward voltage drop ~3.2V at rated current
    - Due to the knee voltage a wide band gap device would turn of at ~3V
    - Solution: **Schottky junctions**

Further reading

- Ben G Streetman: Solid State Electronic Devices: ISBN: 0-13-149726-X
  - Chapter 5
- S.M.Sze: Semiconductor Devices: Physics and technology: ISBN0-471-33372-7
  - Chapters 4