EE210: Microelectronics-I

Lecture-5 : PN Junction Diode-1

Instructor - Y. S. Chauhan

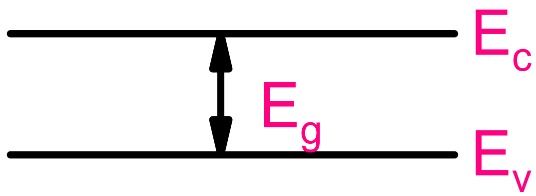
Slides from: B. Mazhari
Dept. of EE, IIT Kanpur

Outline

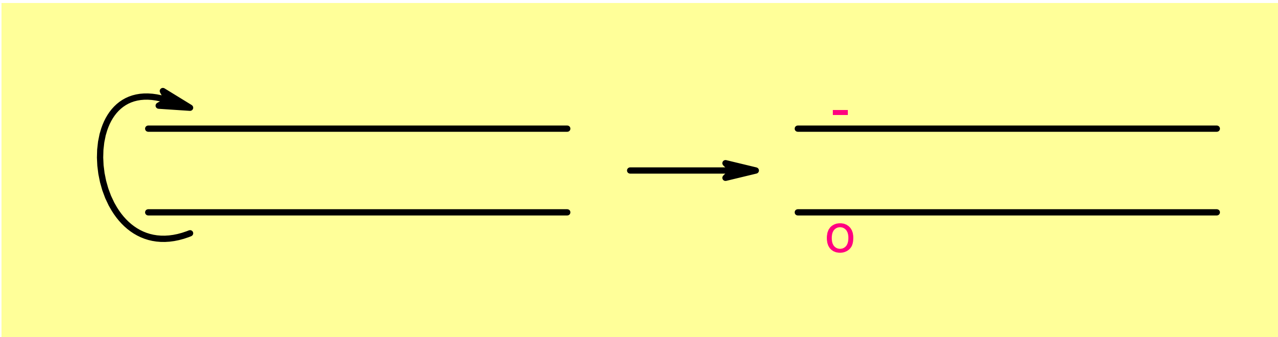
- Semiconductor: Basics
- PN Junction Diode
  - Basic Operation
  - dc model
  - small signal model

Semiconductors: Basics

Energy Bands



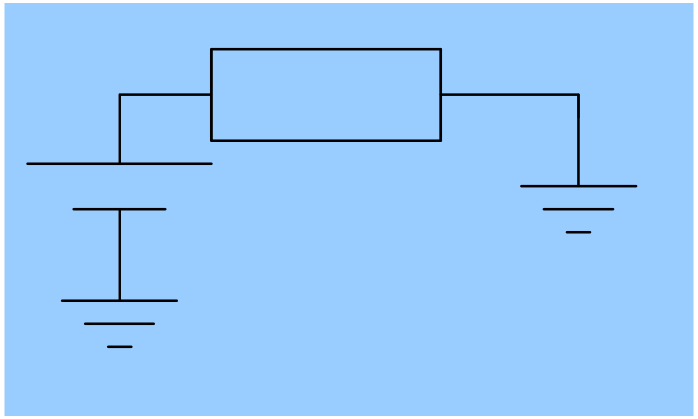
E_g=1.12 eV for Silicon

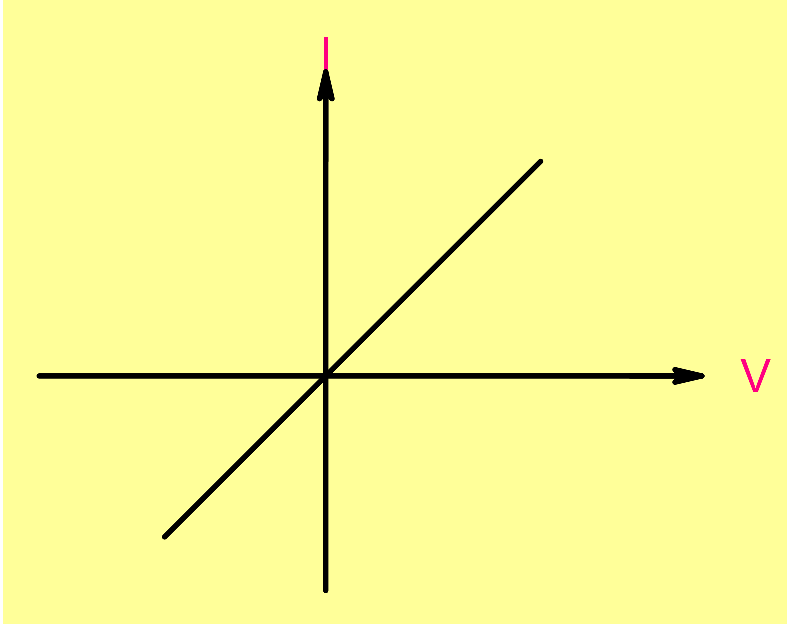


$n = p = n_i$

$n_i = 1.45 \times 10^{10}\ \mathrm{cm}^{-3}$ (T = 300K)

$$n_i \propto \exp\left(-\frac{E_g}{2kT}\right)$$





$$I = \frac{V}{R}\ ;\ R = \frac{1}{\sigma} \times \frac{L}{W}$$

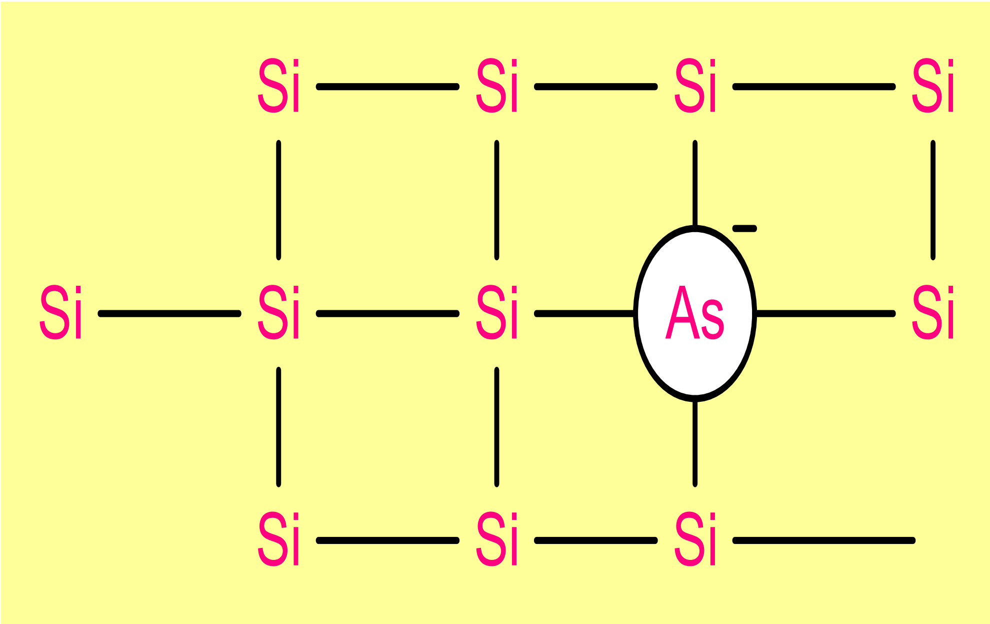
$\sigma_i = q(\ \mu_n + \mu_p\ )n_i$

$\sigma_i \approx 4 \times 10^{-6}\ \Omega^{-1}\ cm^{-1}$

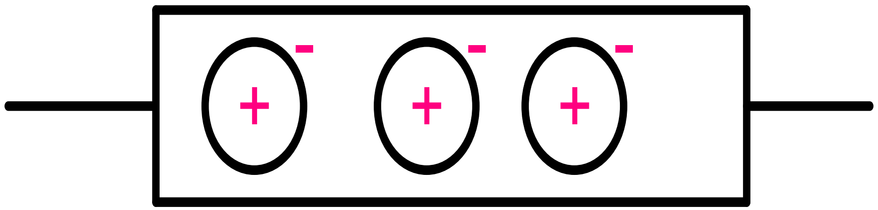
$\rho_i \approx 2 \times 10^{5}\ \Omega\ cm$

$$n_i \propto \exp(-\frac{E_g}{2kT})$$

Doping N-Type Semiconductor



$$N_D \longrightarrow N_D^{+} + e^{-}$$



$N_D = 10^{16}\ \mathrm{cm}^{-3}$

$n \approx 10^{16}\ \mathrm{cm}^{-3}$

$p \approx n_i^2/n \approx\ 2\ \times 10^{4}\ \mathrm{cm}^{-3}$

$n >> p$

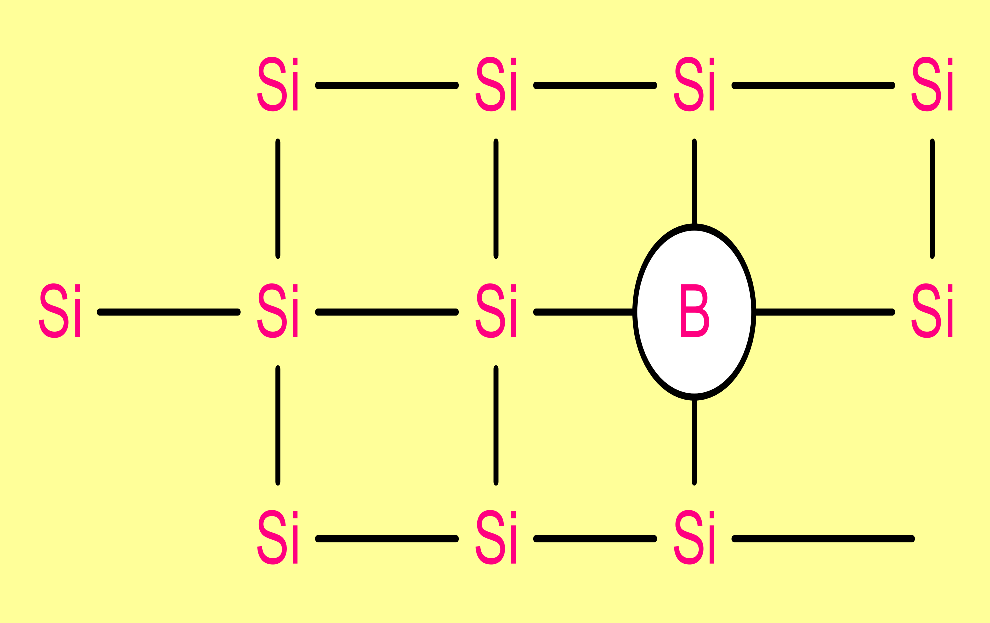
Small amount of impurity results in large change in resistivity !

No. of Silicon atoms / volume = $5 \times 10^{22}\ cm^{-3}$

$$\frac{10^{16}}{5 * 10^{22}} = 2 \times 10^{-7} \qquad (0.2PPM)$$

$$\rho : \quad 2 \times 10^{5} \quad \Omega\ cm \xrightarrow{N_D = 10^{16}\ cm^{-3}} \mathbf{1.5} \quad \Omega\ cm$$

P-Type Semiconductor



$$N_A + e^- \longrightarrow N_A^- + h^+$$

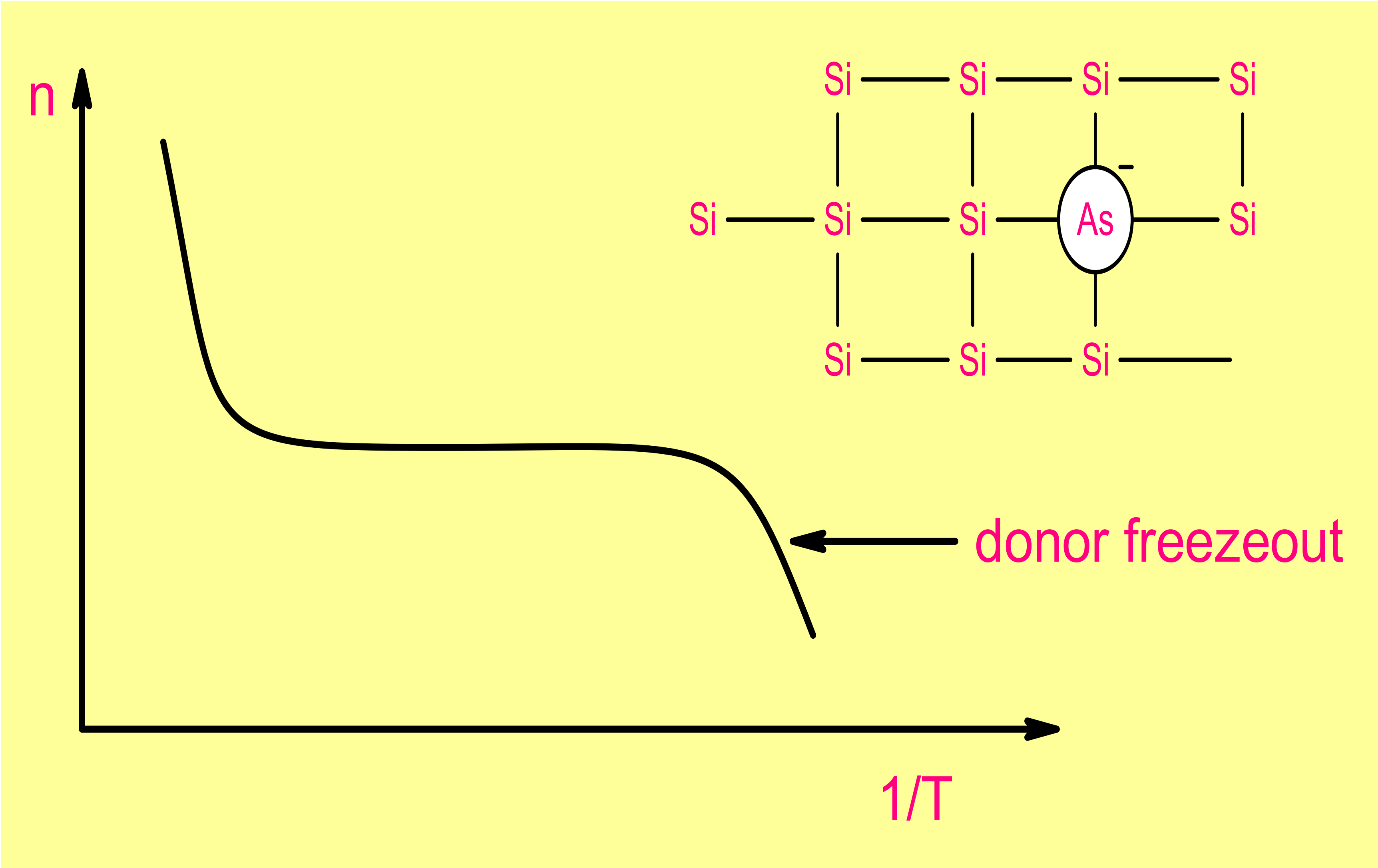
$N_A = 10^{16}\ cm^{-3}$

$p \approx 10^{16}\ cm^{-3}$

$n \approx n_1^2 / p = 2 \times 10^4\ cm^{-3}$

$p >> n$

Number of carriers is dependent on temperature !



PN Junction Diode

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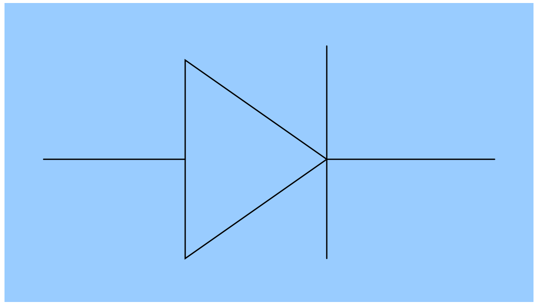
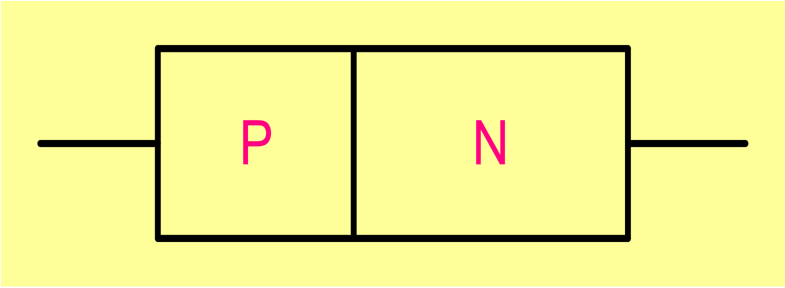
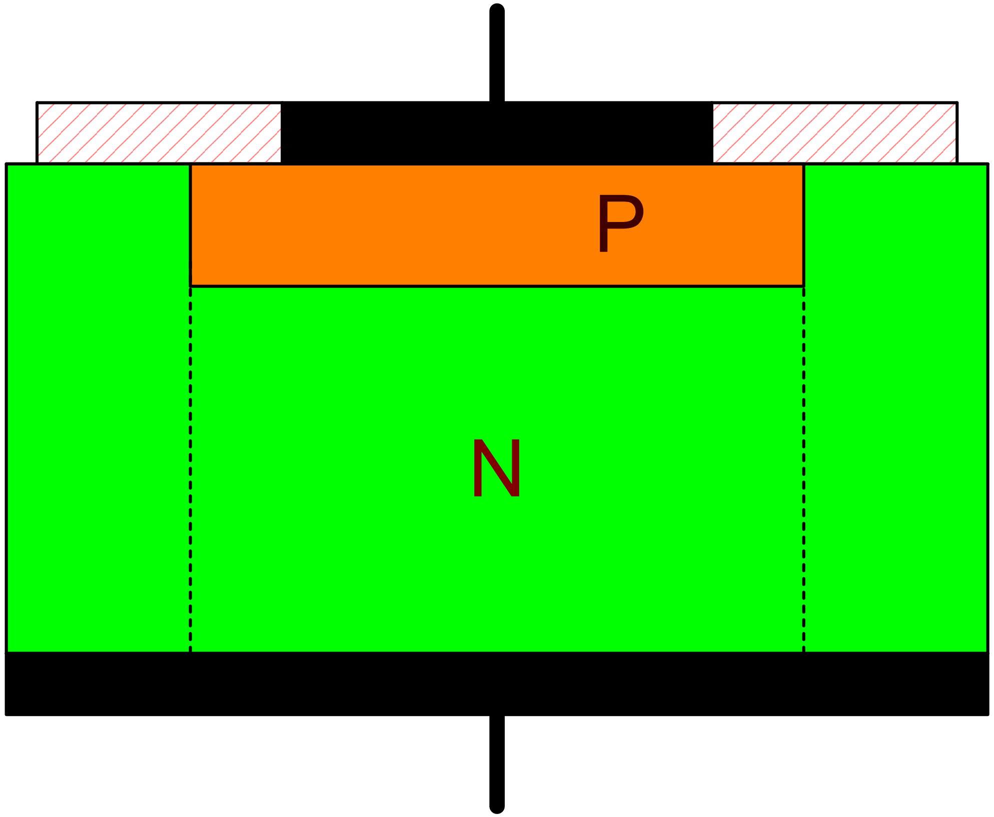
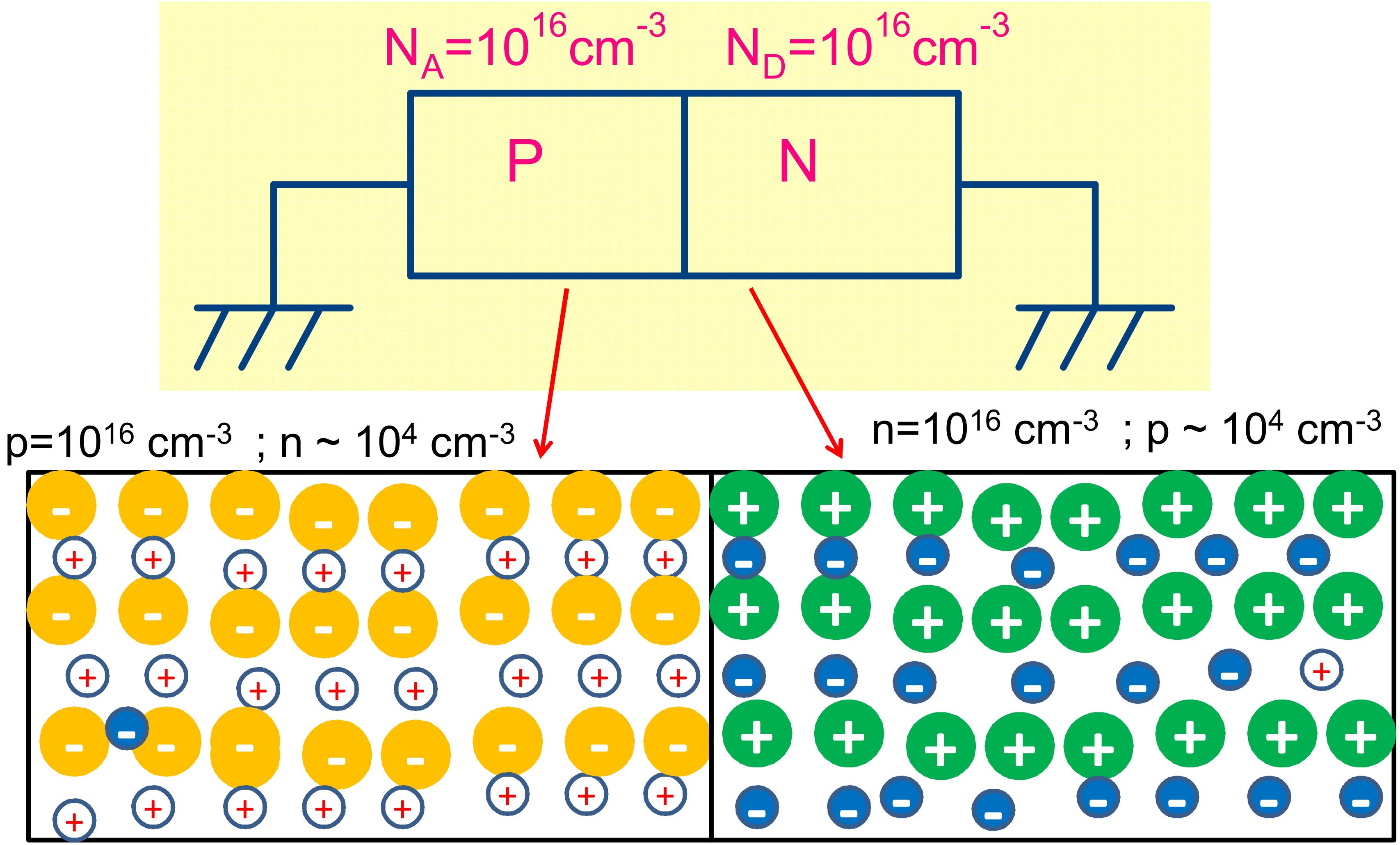




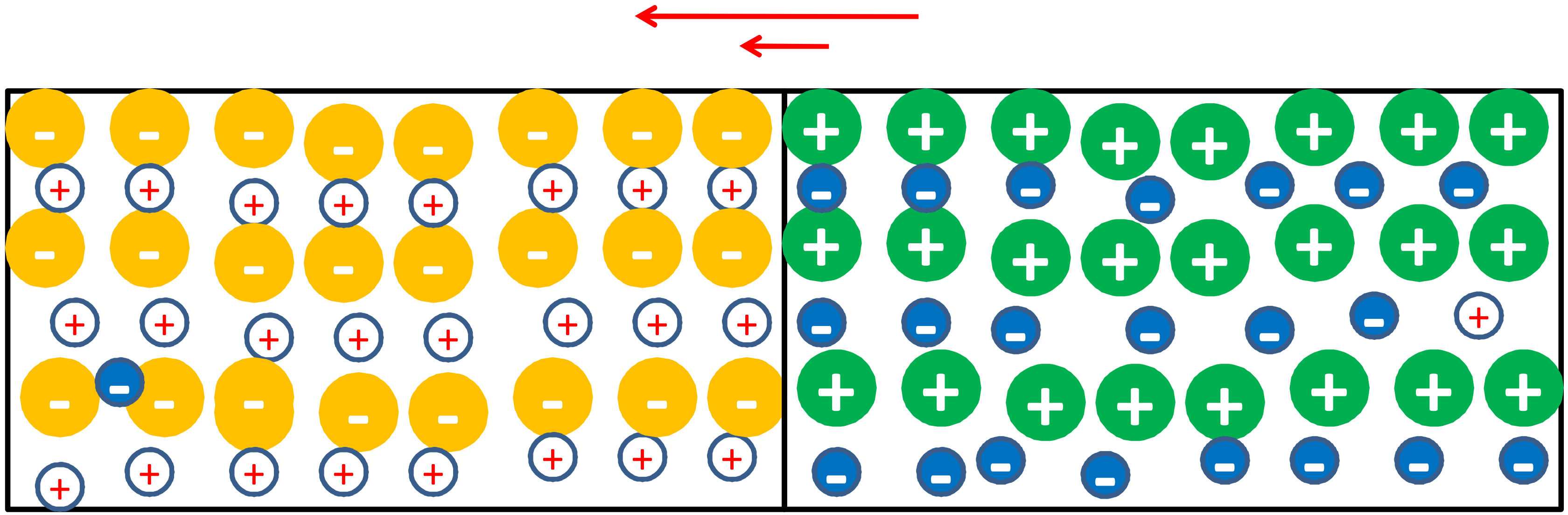


Basic Operation



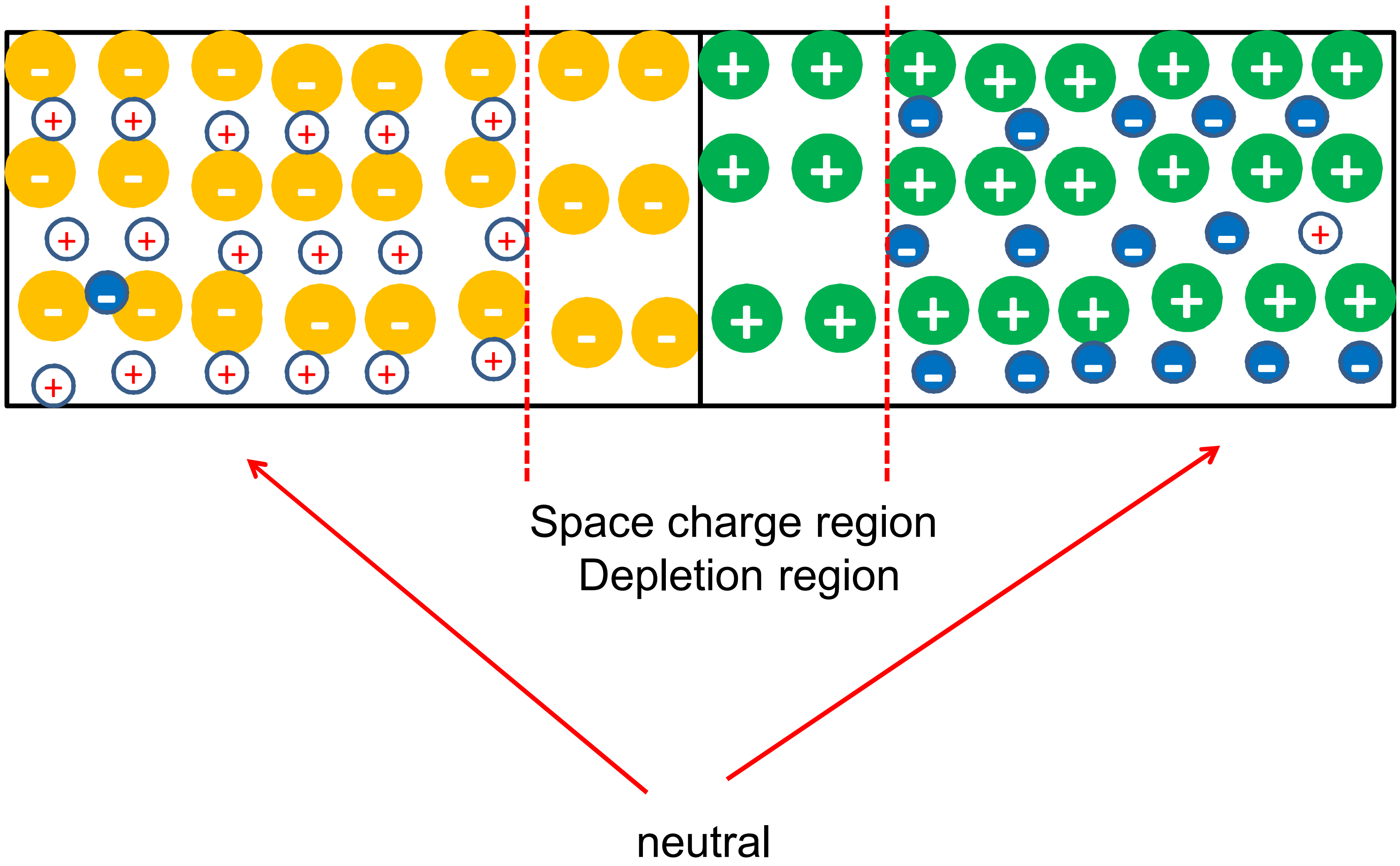
Holes will tend to diffuse from p →n and electrons from n→p

Electric field opposes flow of carriers



Eventually equilibrium is reached and there is no net flow of carriers across the junction

PN Junction Under Equilibrium



Although small, depletion region has some carriers

$n = 10^{16}$ cm^{-3} ; $p \sim 10^{4}$ cm^{-3}

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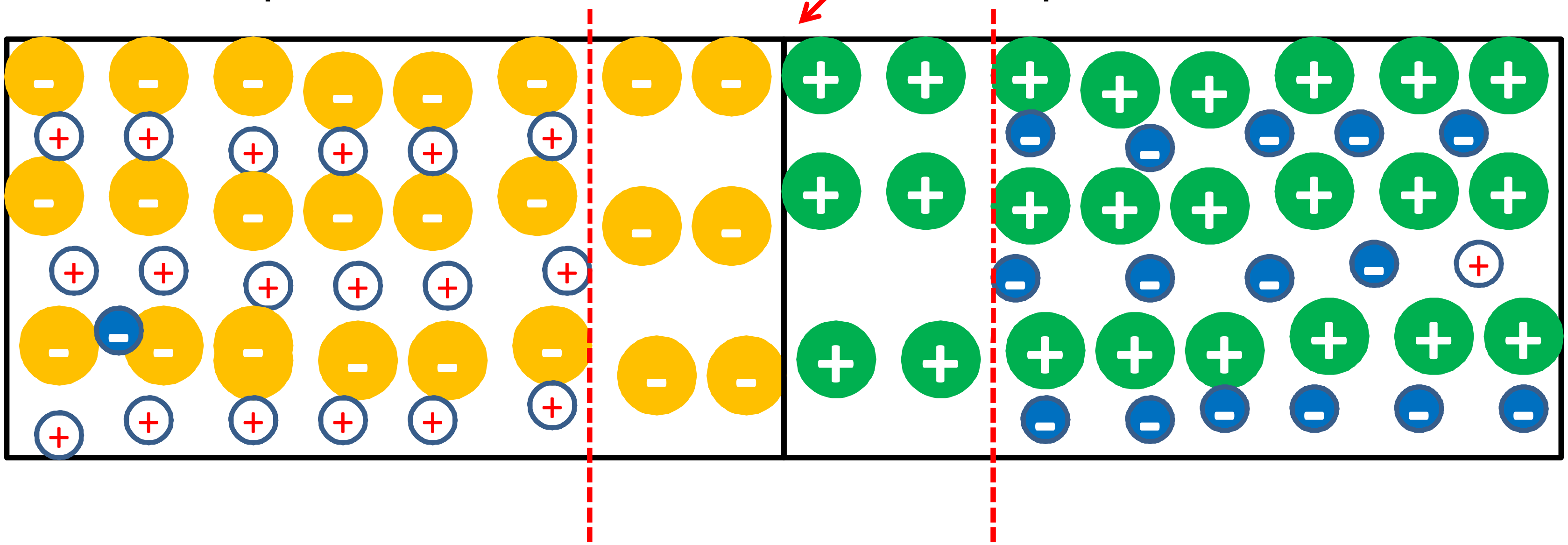
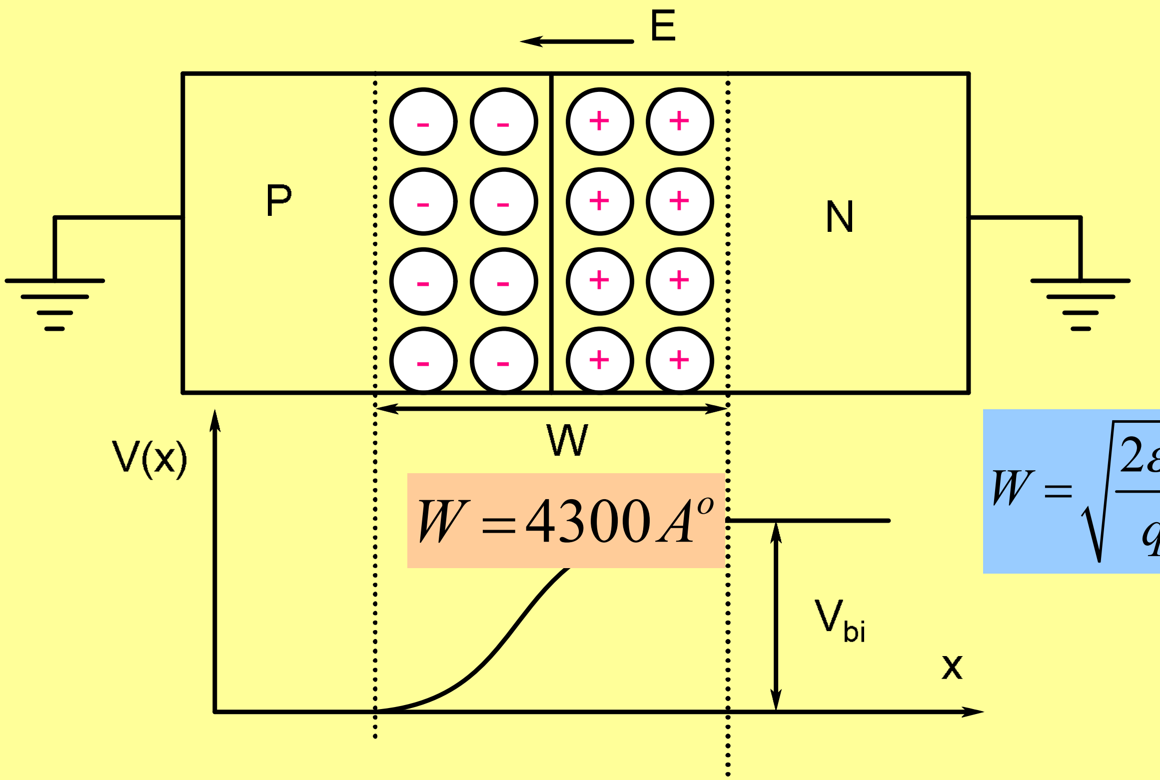


Space charge region
Depletion region

Built-in Potential V_{bi}



$$W = \sqrt{\frac{2\varepsilon_s}{q} \times \left(\frac{1}{N_A} + \frac{1}{N_D}\right) \times V_{bi}}$$

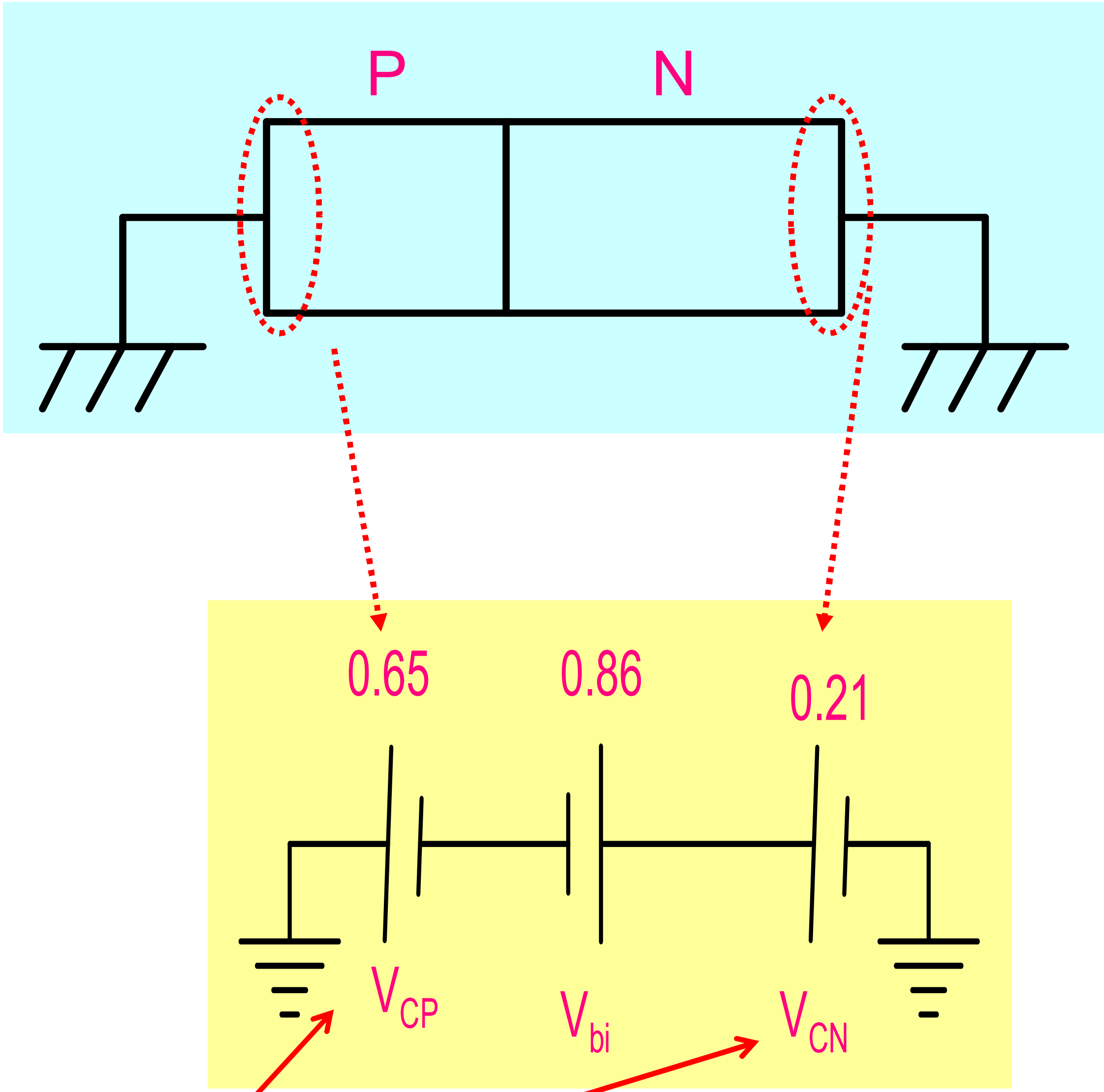
$$V_{bi} = \frac{k\,T}{q} \ln\left[\frac{N_A N_D}{n_i^{\,2}}\right]$$

$N_A = N_D = 10^{16}\ cm^{-3}$, $T = 300°K$

$V_{bi} = 0.86\ V$

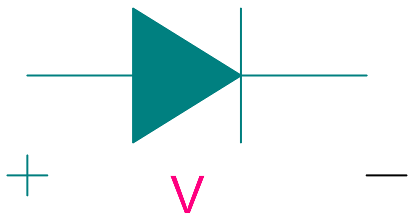
Anytime you put two different materials into contact, a potential develops between them.

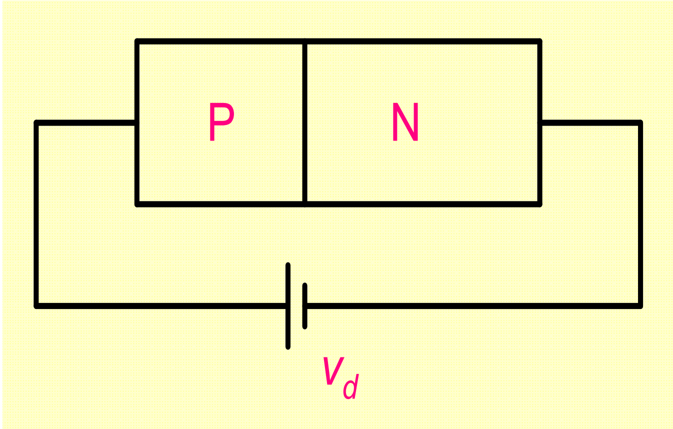
Built-in Potential



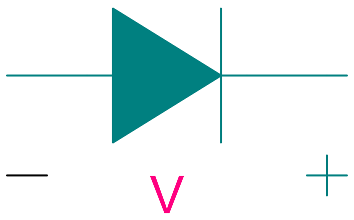
Contact potential

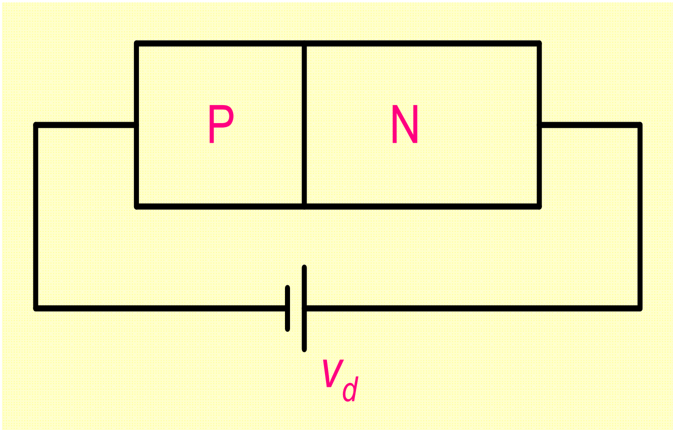
Forward and Reverse Bias



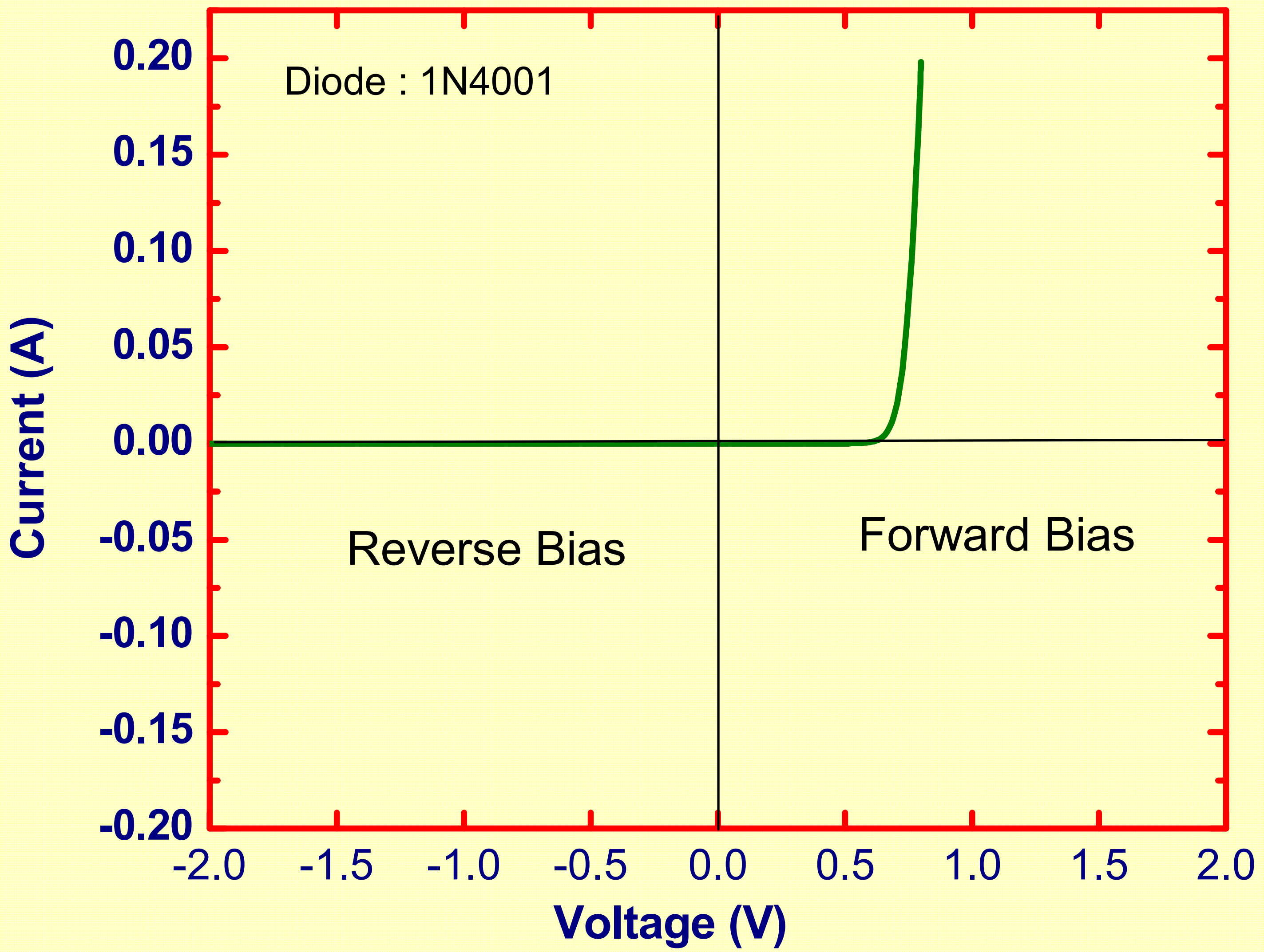


Forward Bias: P is biased at a higher voltage compared to N



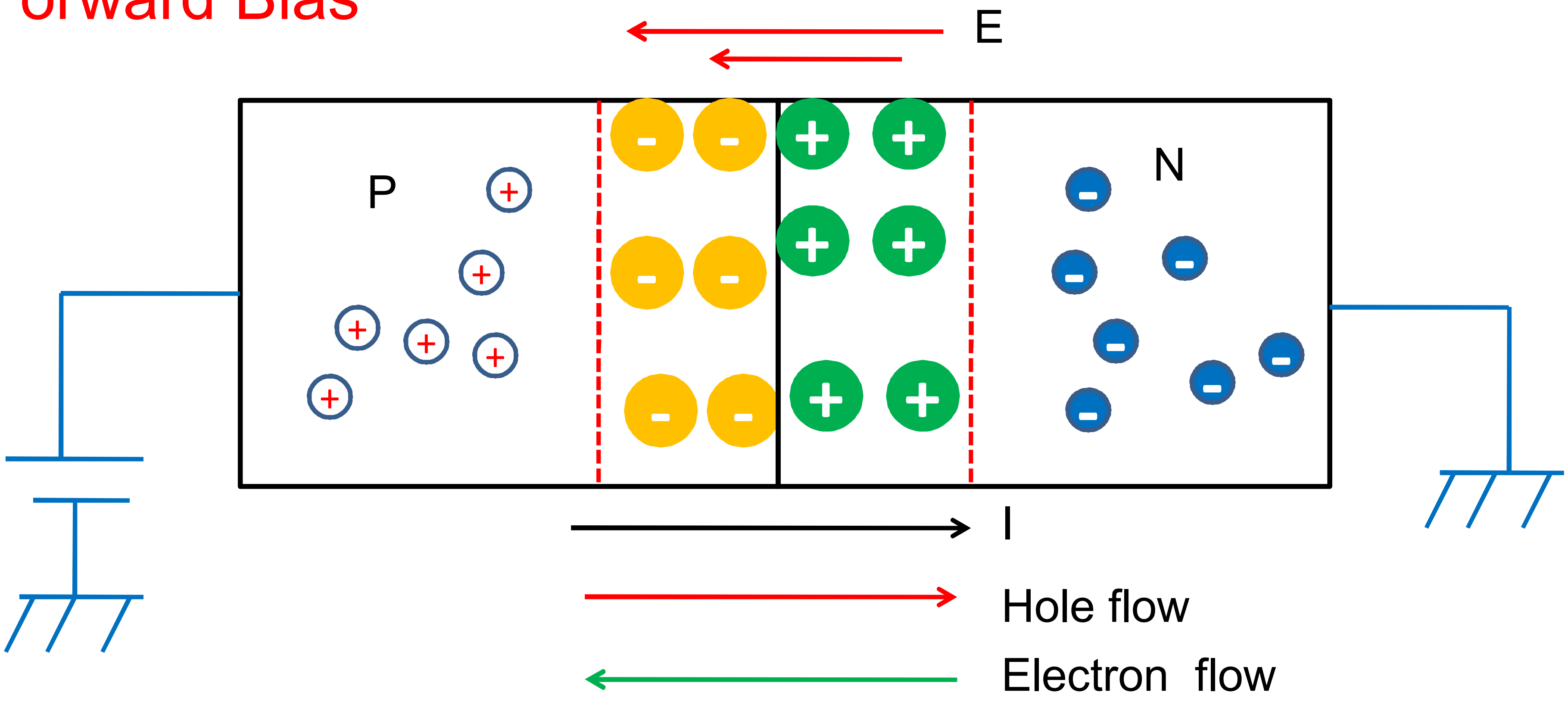


Reverse Bias: N is biased at a higher voltage compared to P

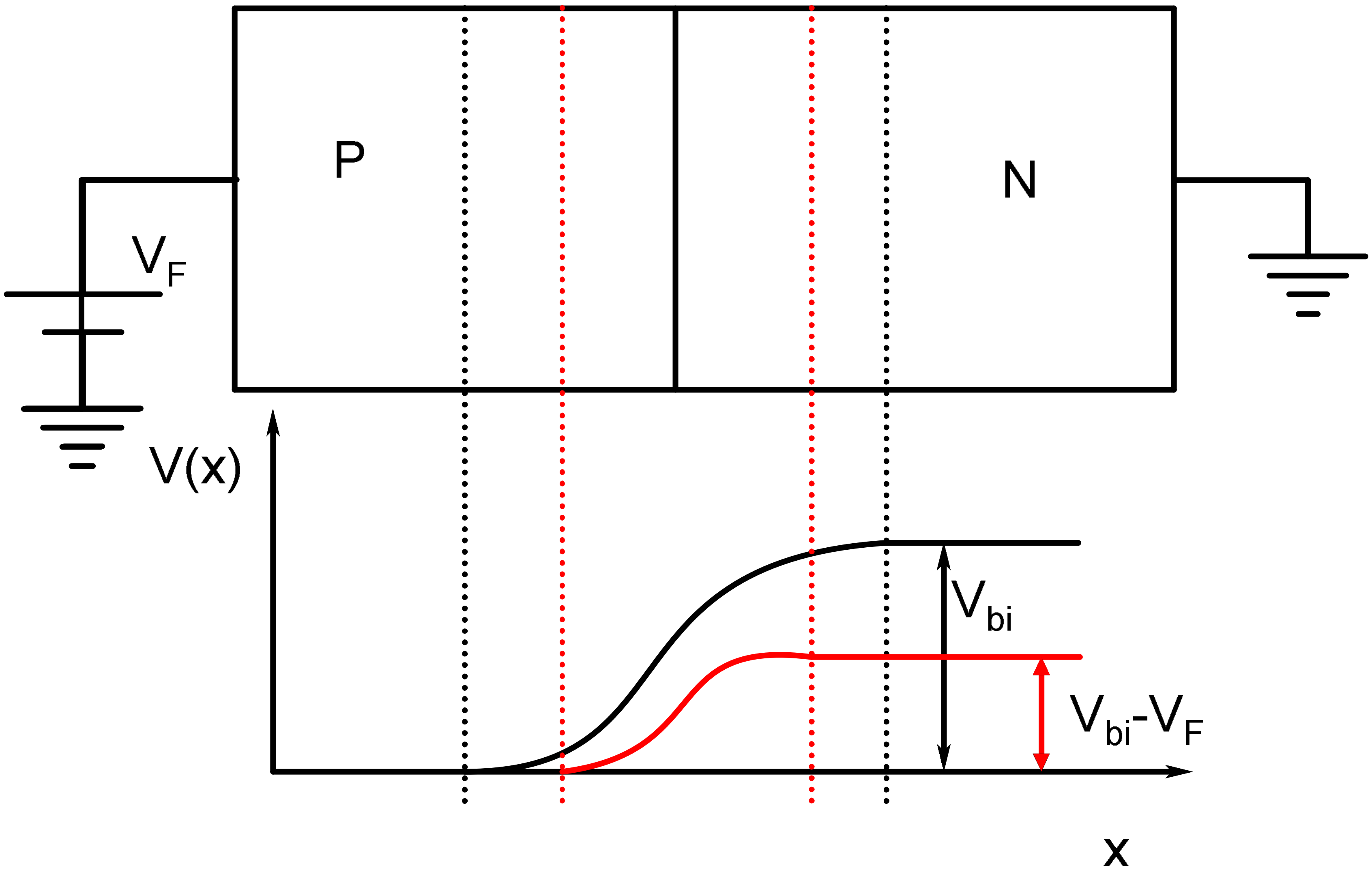


The p-n junction conducts significant current in the forward-bias region.

Forward Bias



Application of forward bias lowers the built-in potential and allows holes and electrons to cross the junction and result in current flow



P
N
V_F
V(x)
V_bi
V_bi-V_F
x