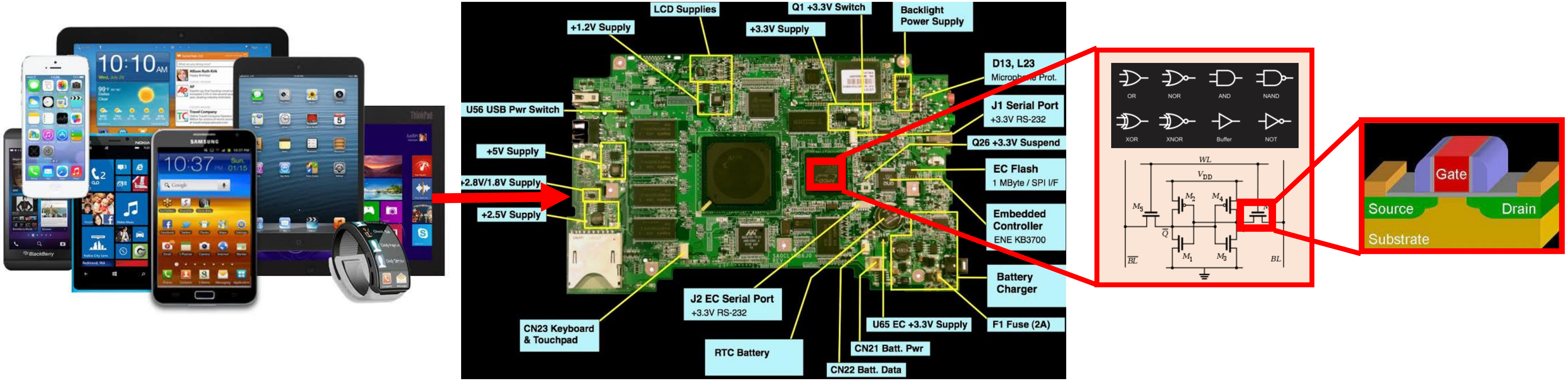

ESC201: INTRODUCTION TO ELECTRONICS

MODULE 4: NON-LINEAR ELEMENTS

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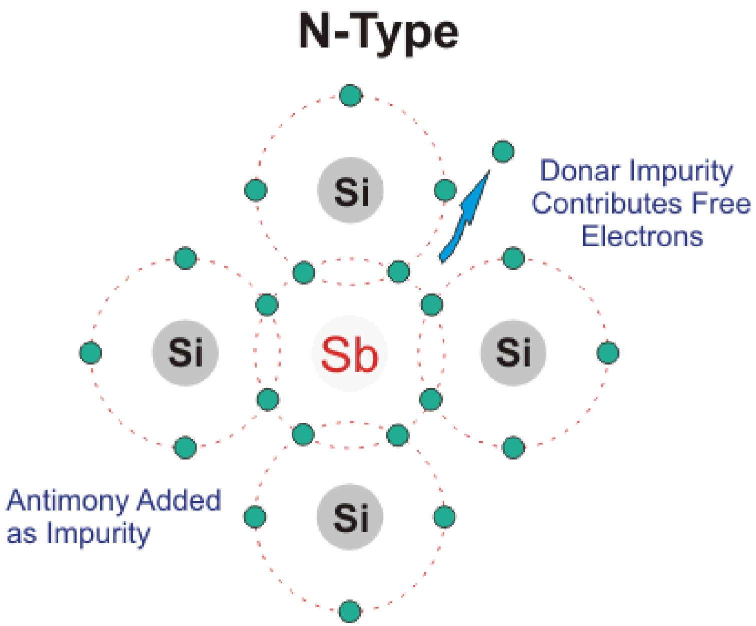
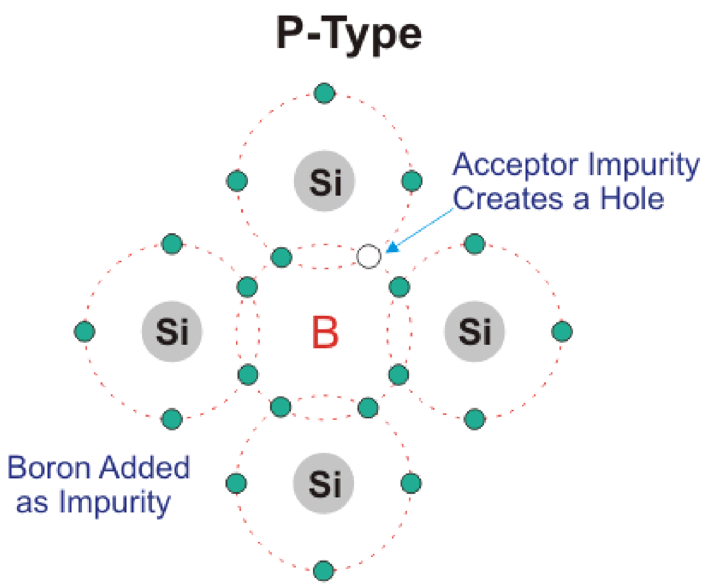
Assistant Professor,
Department of Electrical Engineering,
IIT Kanpur

Recap

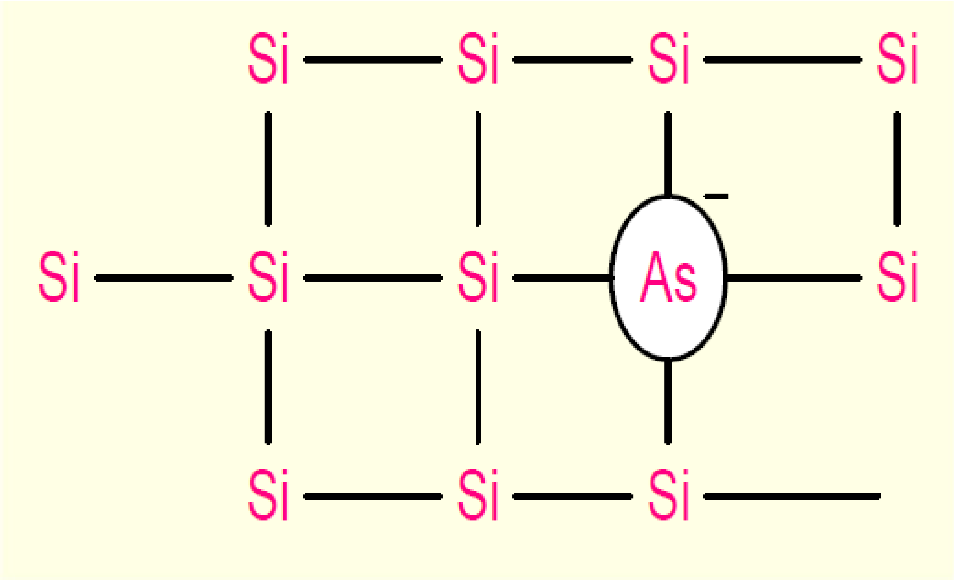
Doping

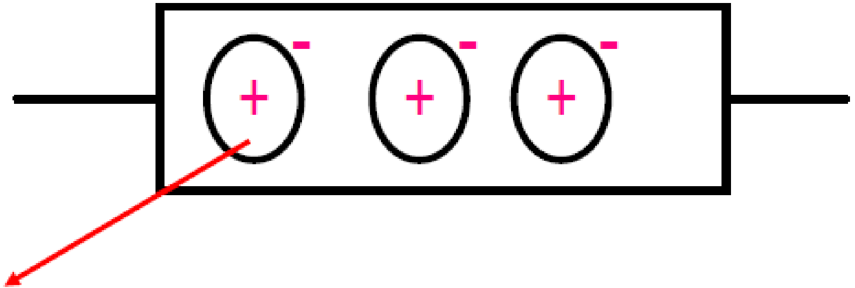




Very small amounts of impurity atoms can cause a drastic change in electrical property of a semiconductor.

N-type semiconductor





Positively charged donor atoms

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

$$In\ equilibrium: \quad n \times p = n_i^2$$

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

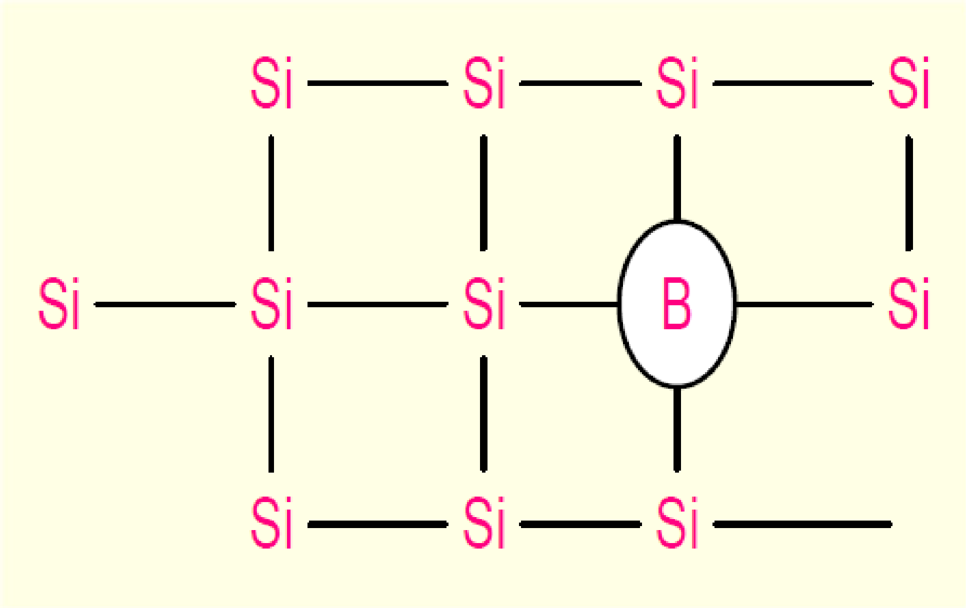
$$N_D = 10^{16}\mathrm{cm}^{-3}$$

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

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

$$n >> p$$

P-type Semiconductor

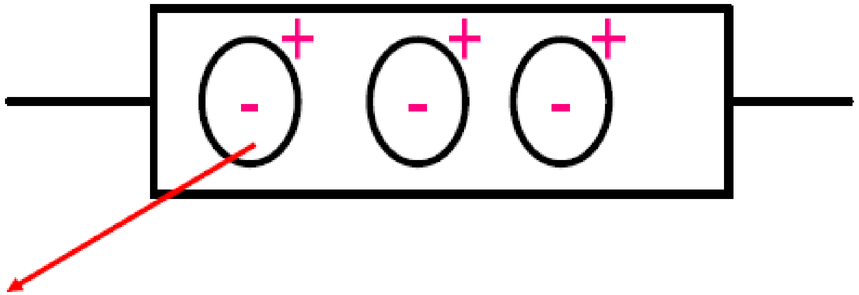


$$N_A + e^- \longrightarrow N_A^- + h^+$$

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

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

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

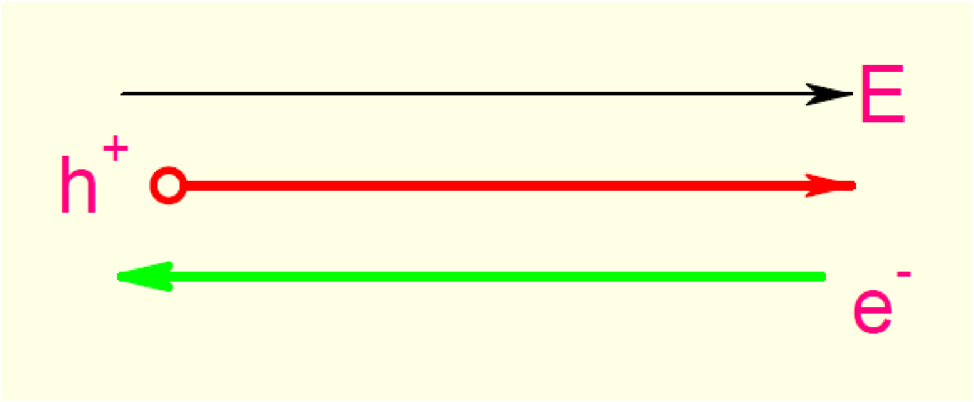


Negatively charged acceptor atoms

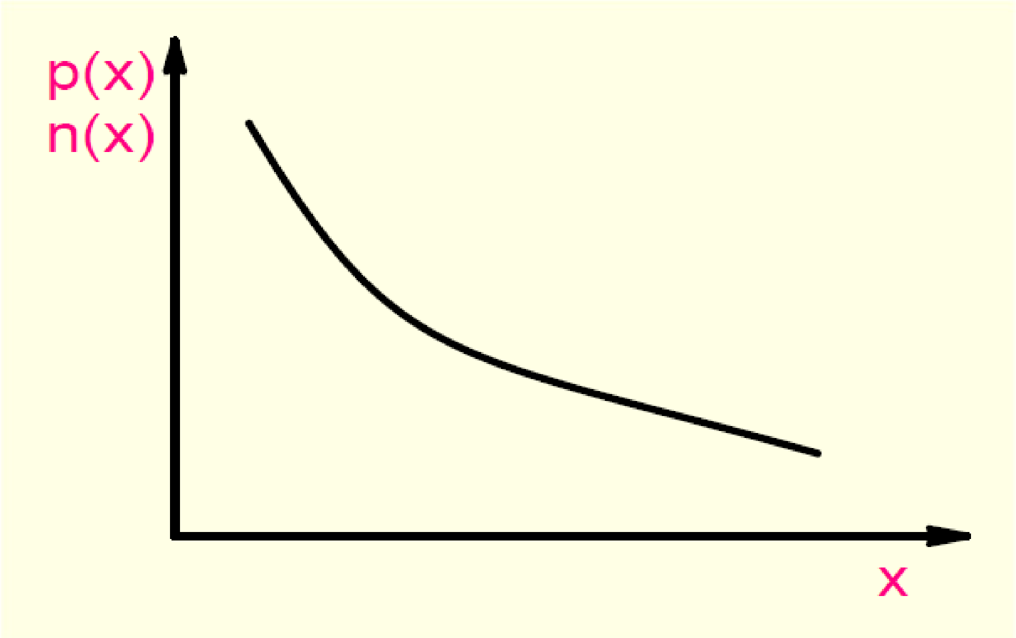
$$p >> n$$

Current Flow

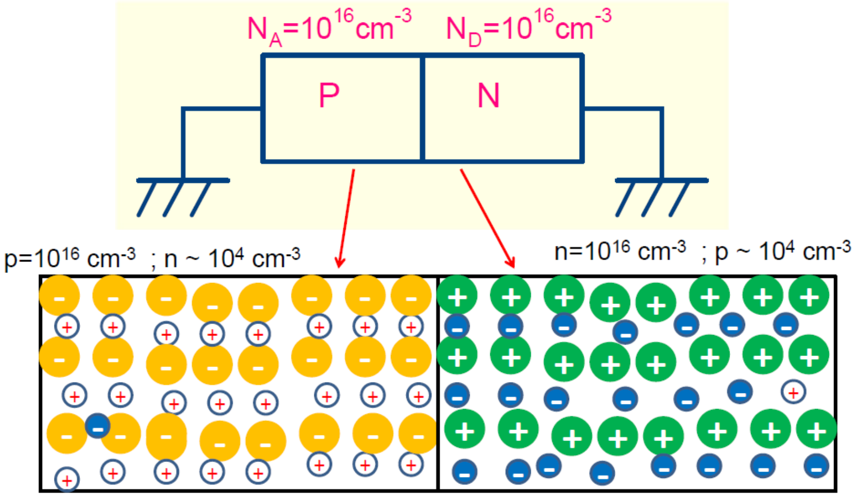
Drift current due to Electric field

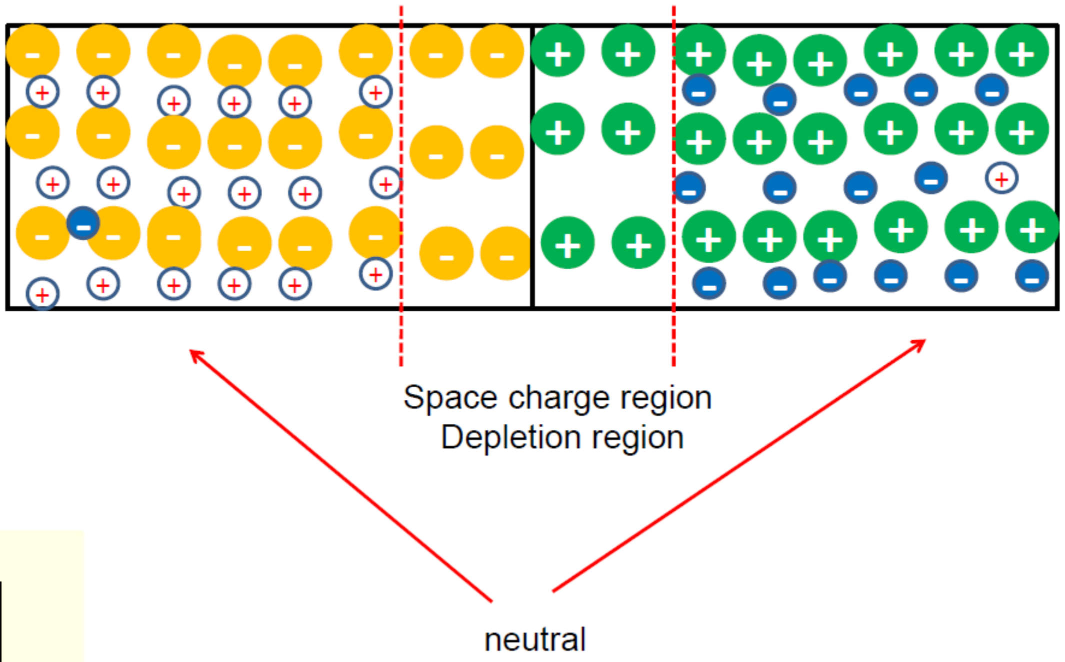


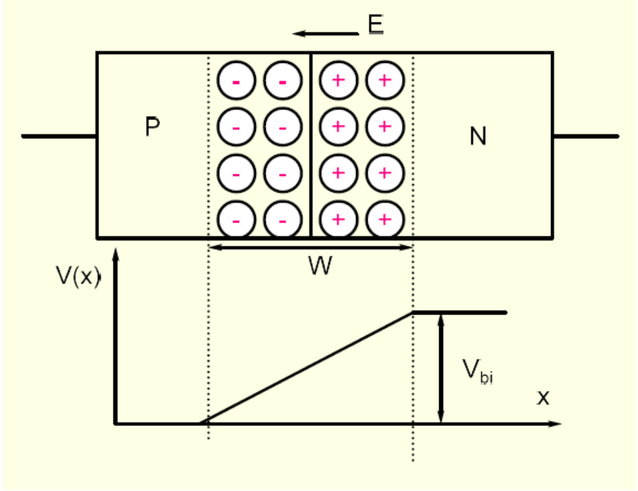
Diffusion to concentration gradient



pn junction diode







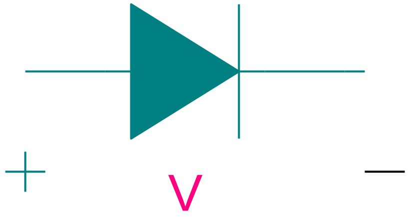
$$V_{bi} = \frac{kT}{q}\ln\left[\frac{N_A N_D}{n_i^2}\right]$$

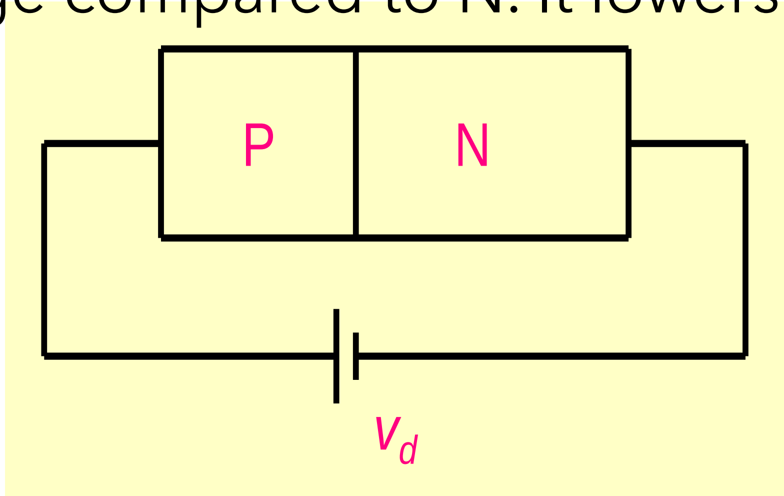
$N_A = N_D = 10^{16}$ cm^{-3}, T = 300°K

V_{bi} = 0.86 V

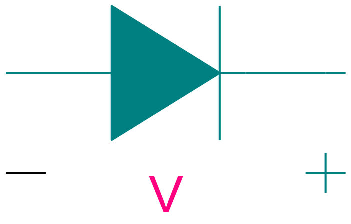
Forward and Reverse Bias

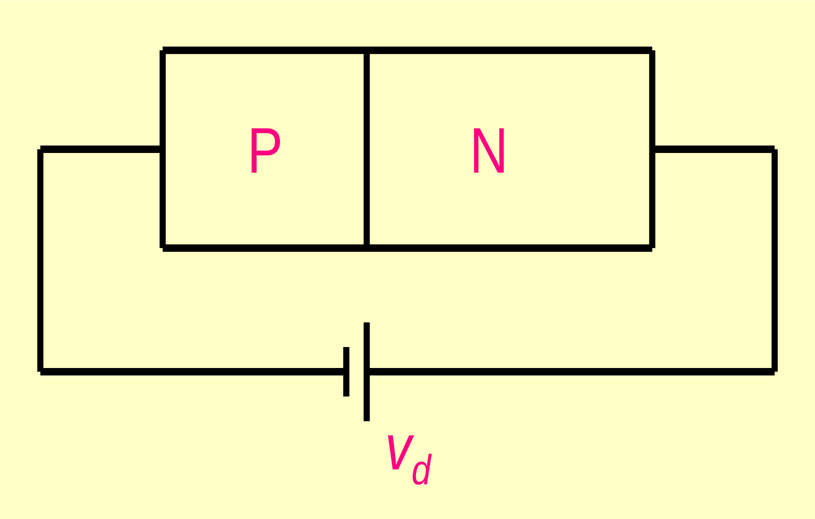
Forward Bias: P is biased at a higher voltage compared to N. It lowers the built-in potential and allows current to flow.



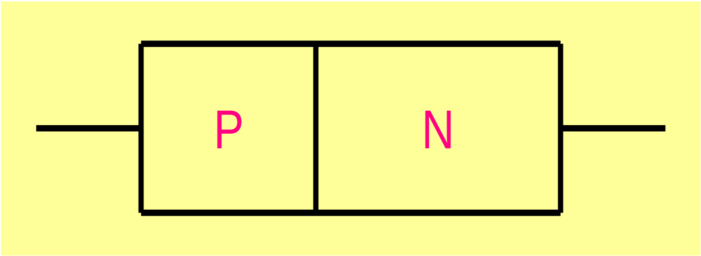


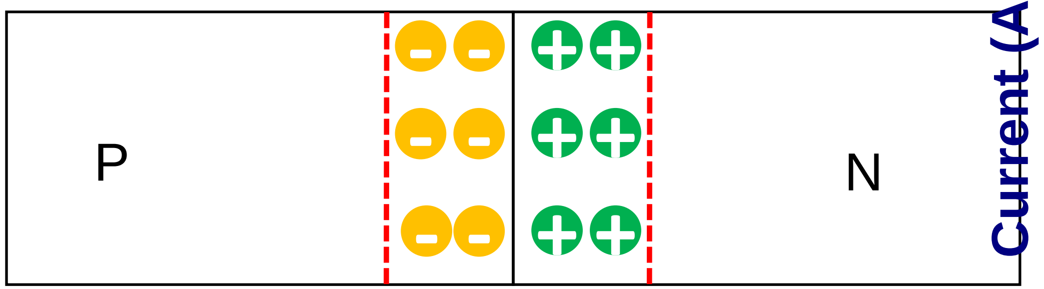
Reverse Bias: N is biased at a higher voltage compared to P. This increases built-in potential and very little current flows.

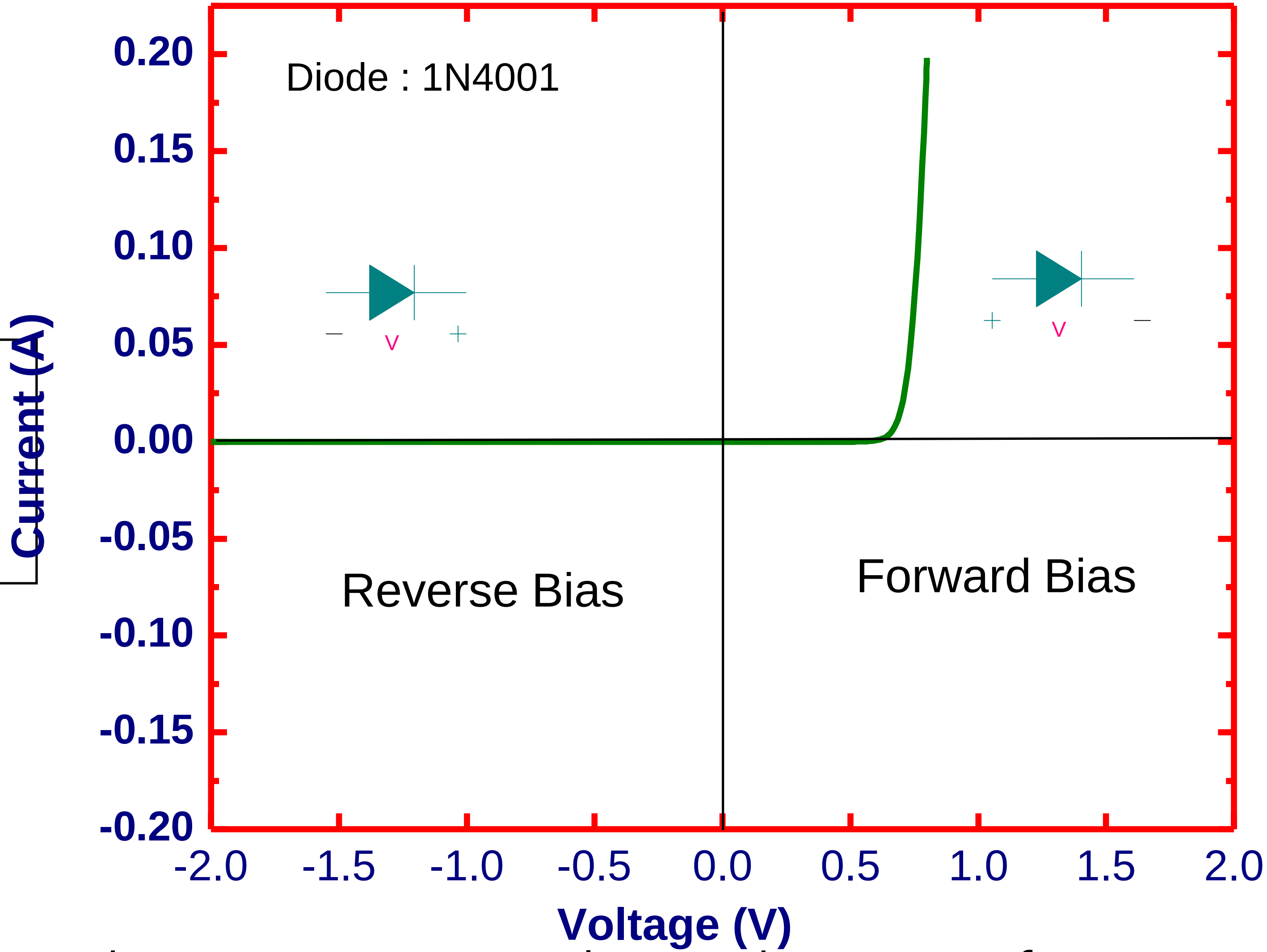




p-n junction diode

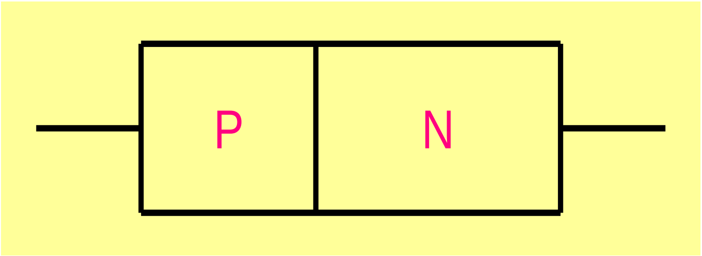


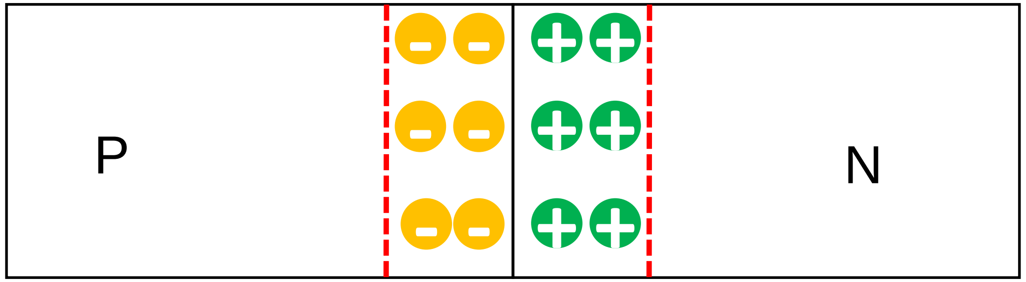


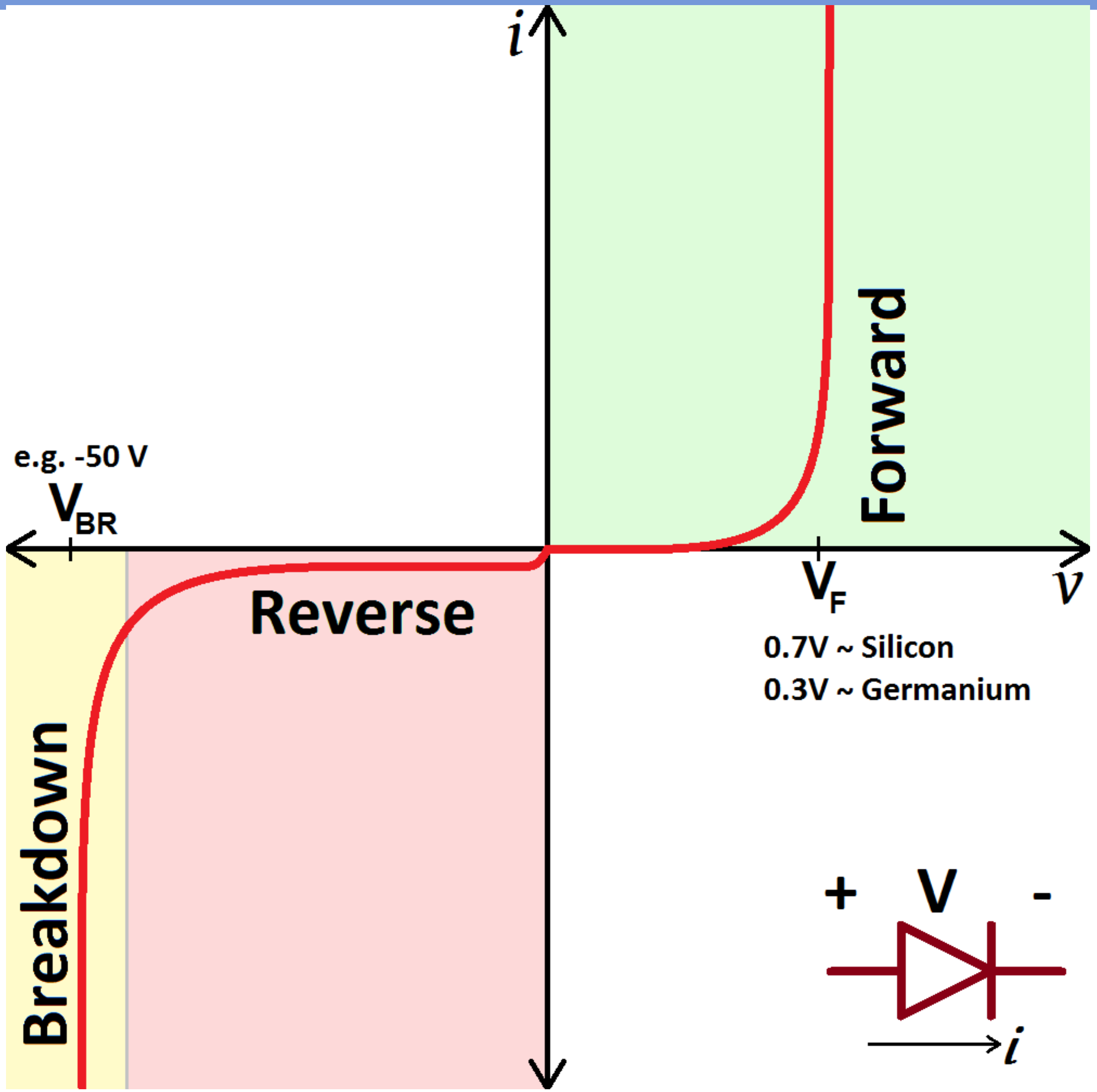


The p-n junction only conducts significant current in the forward-bias region.

Breakdown

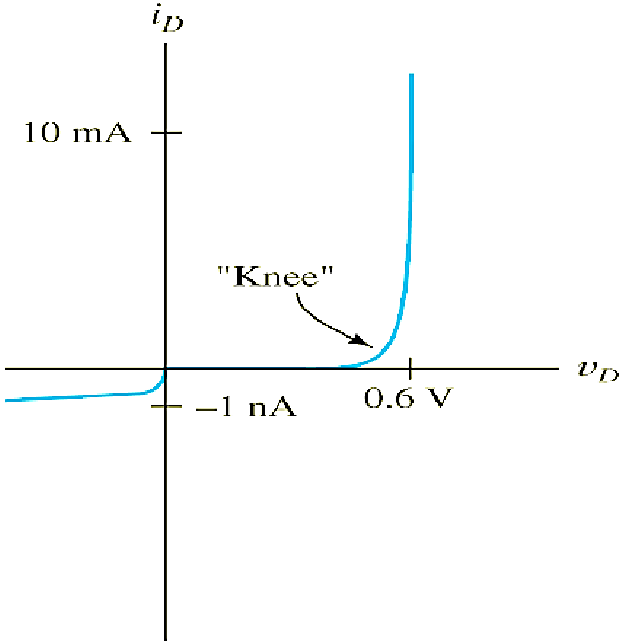

P
N


P
N


i
e.g. -50 V
V_{BR}
Forward
Reverse
Breakdown
V_F
v
0.7V ~ Silicon
0.3V ~ Germanium
+ V -
i

I-V Characteristics- Nonlinear Behavior

Let us ignore breakdown region, assuming that our circuit does not generate large negative voltages



applied voltage $= v_D$

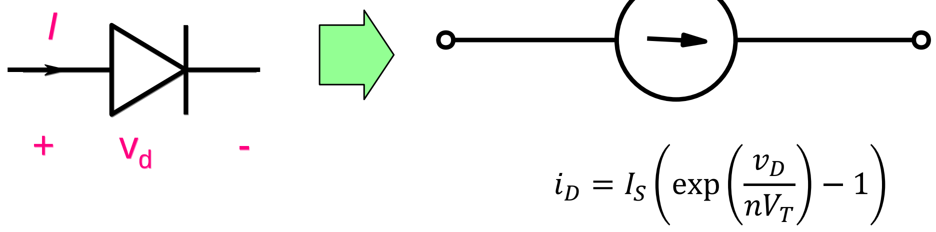
diode current:

$$i_D = I_S\left(\exp\left(\frac{v_D}{nV_T}\right) - 1\right)$$

I_S : Reverse saturation current

n: ideality factor (= 1 for ideal diodes)

$$V_T = \frac{kT}{q} \approx 26mV \text{ at T } = 300\text{K}$$



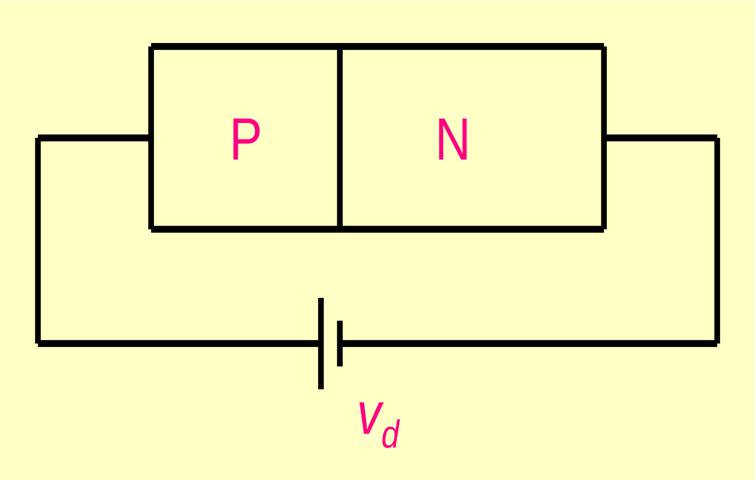
How to analyze circuits containing diodes?

Forward Bias

$$I_D = I_S\left(\exp\left(\frac{v_D}{V_T}\right) - 1\right)$$

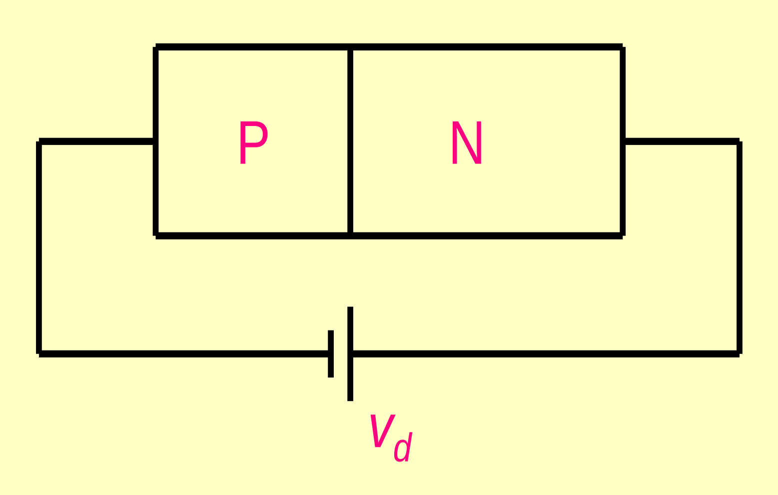
$$v_d >> V_T = 26mV$$

$$i_D \approx I_S \times \exp\left(\frac{v_d}{V_T}\right)$$



Reverse Bias

$$I_D = I_S\left(\exp\left(\frac{v_D}{V_T}\right) - 1\right)$$



$$v_d = -v_R \qquad |v_R| >> V_T$$

$$i_D = I_S\left(\exp\left(-\frac{v_R}{V_T}\right) - 1\right) \approx -I_S$$