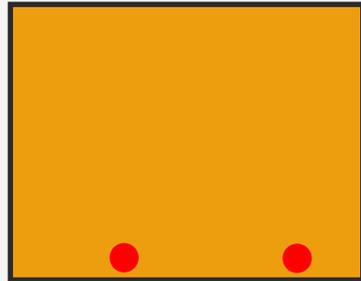


Working Principle of a Semiconductor Based Solar Cell

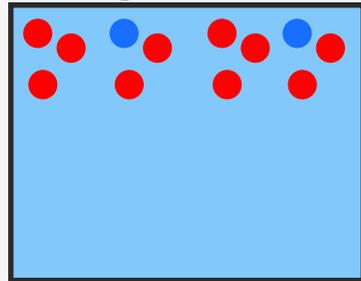
2.4 Charge carrier excitation

Week 2

Arno Smets

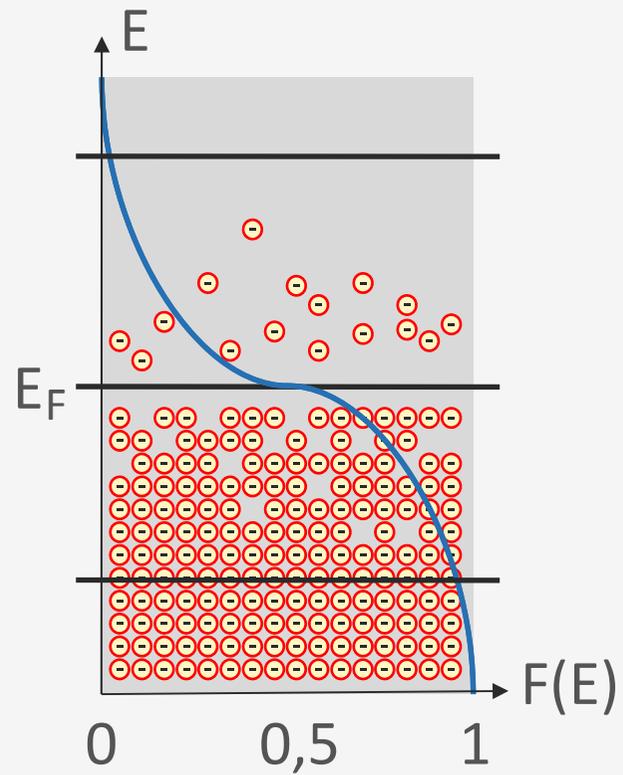


**Conduction
band**

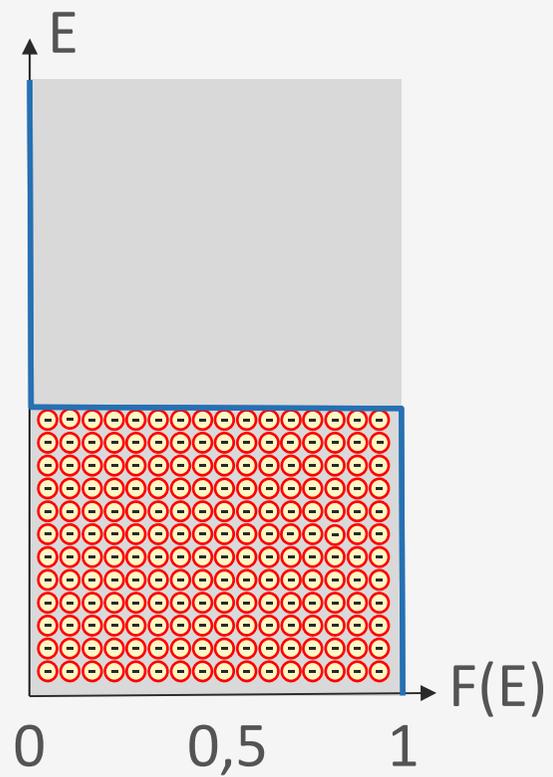


**Valence
band**

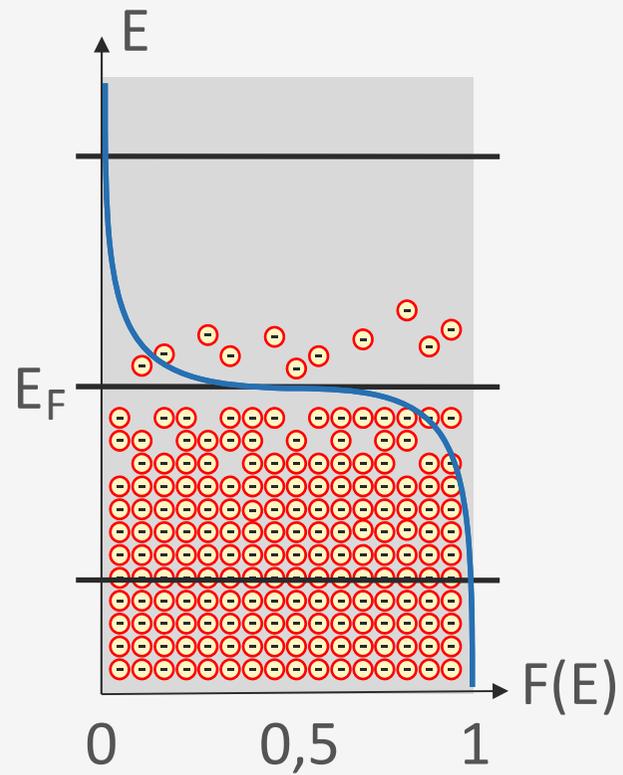
Fermi Level



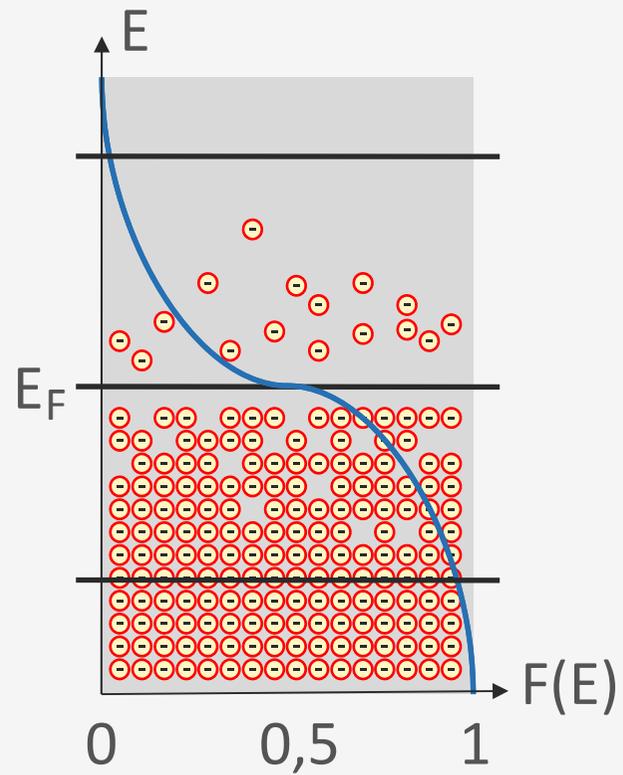
Fermi level



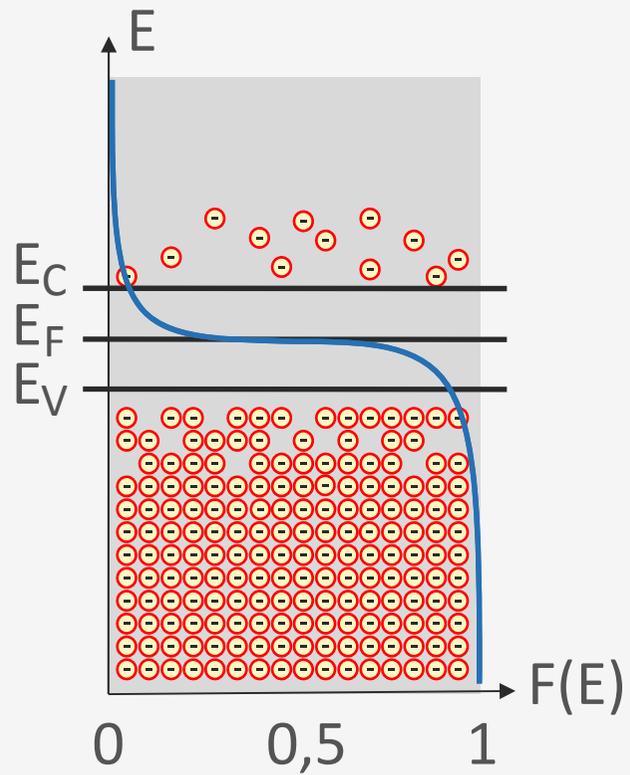
Fermi Level



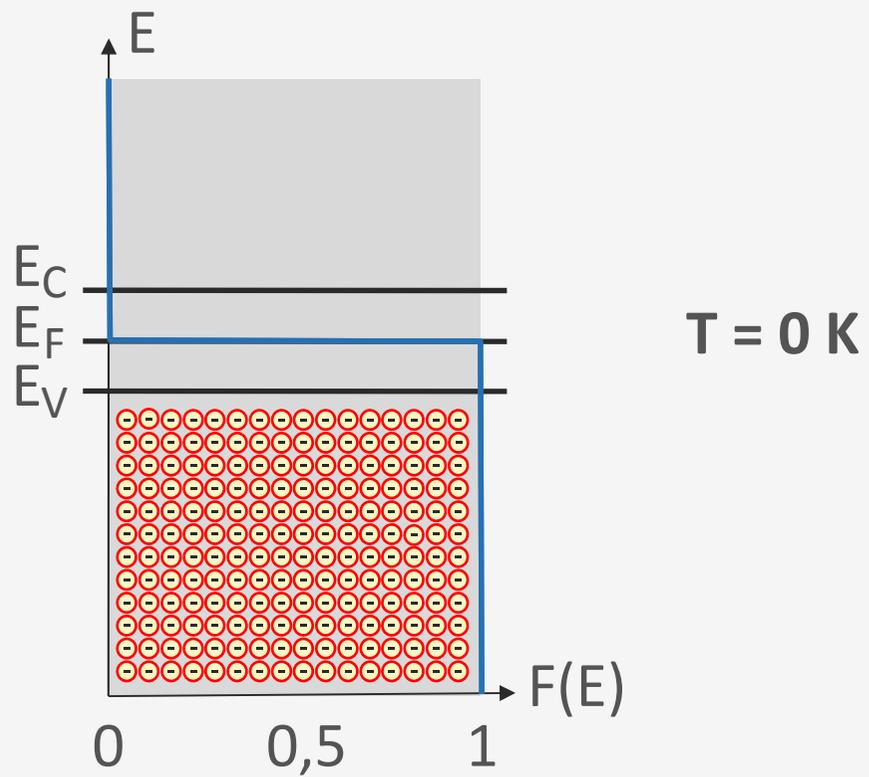
Fermi Level



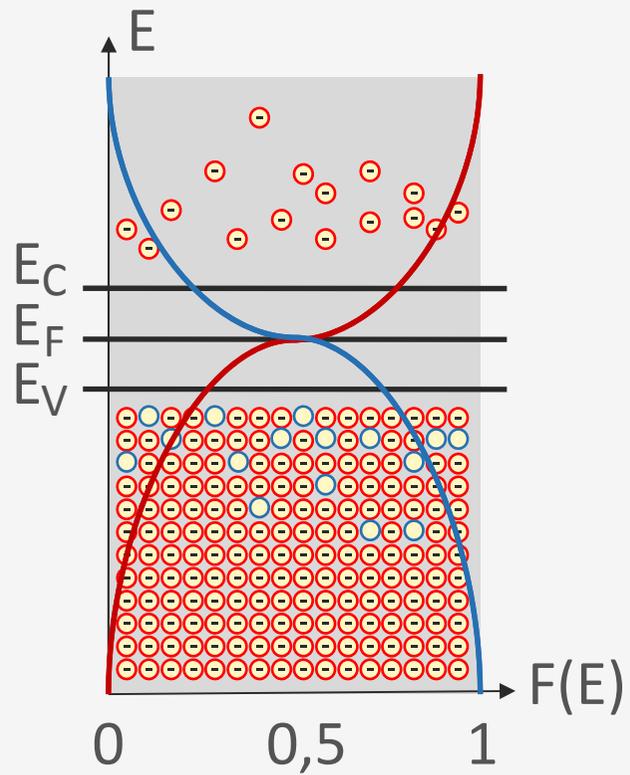
Fermi Level

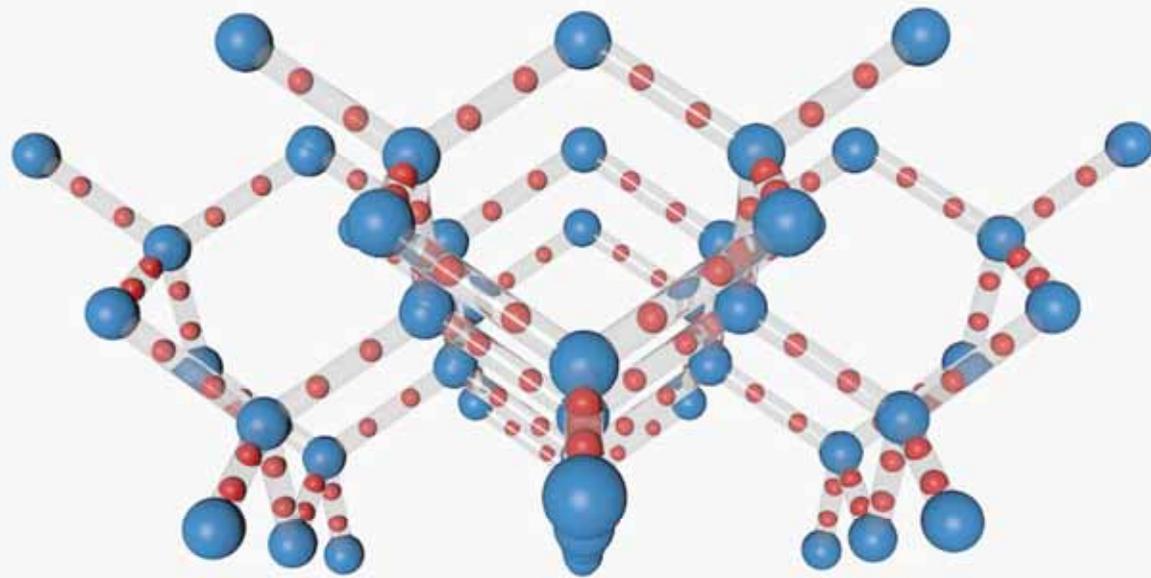


Fermi level

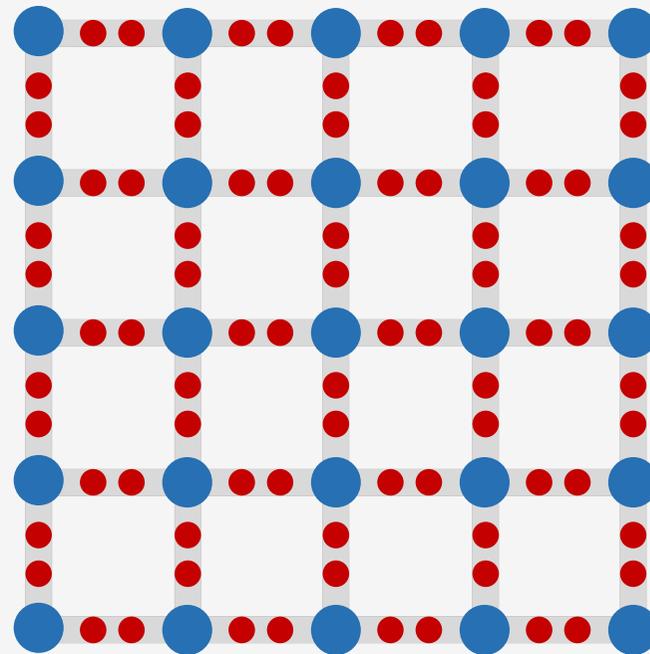


Fermi Level

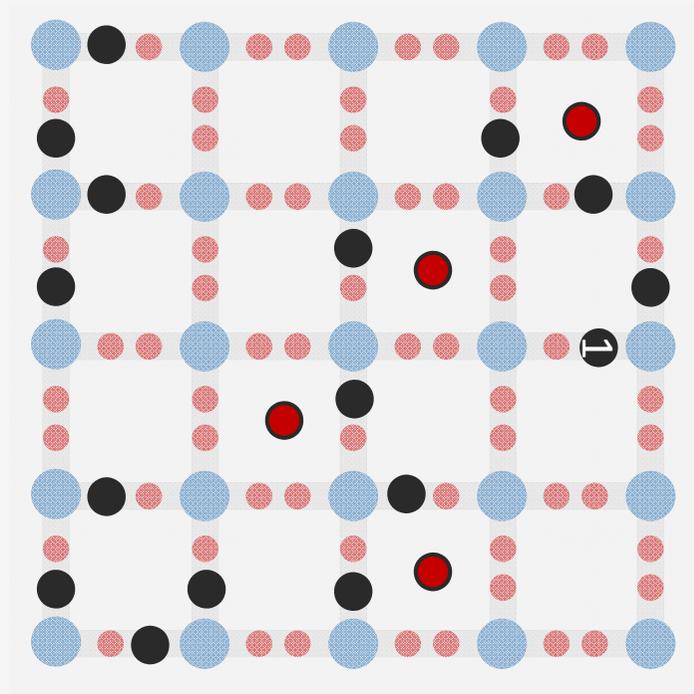




Silicon Structure representation in 2D



Silicon Structure

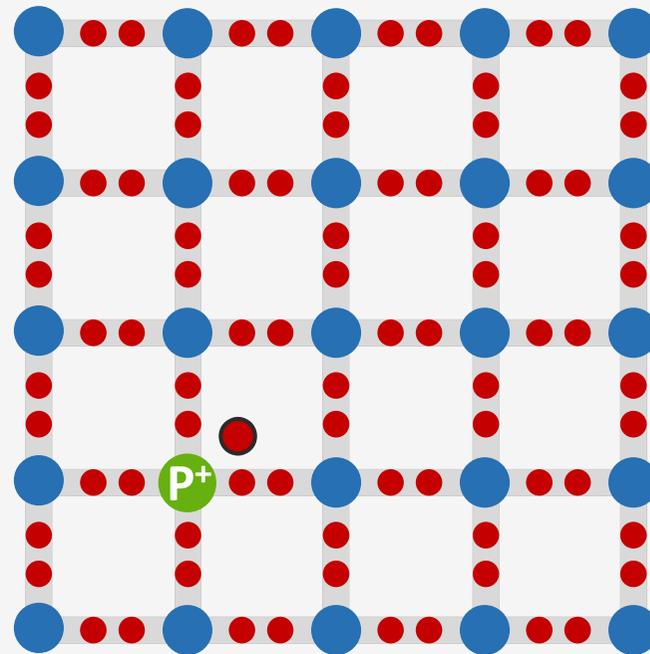


- „Free“ electron
- Hole
(bond missing
valence electron)

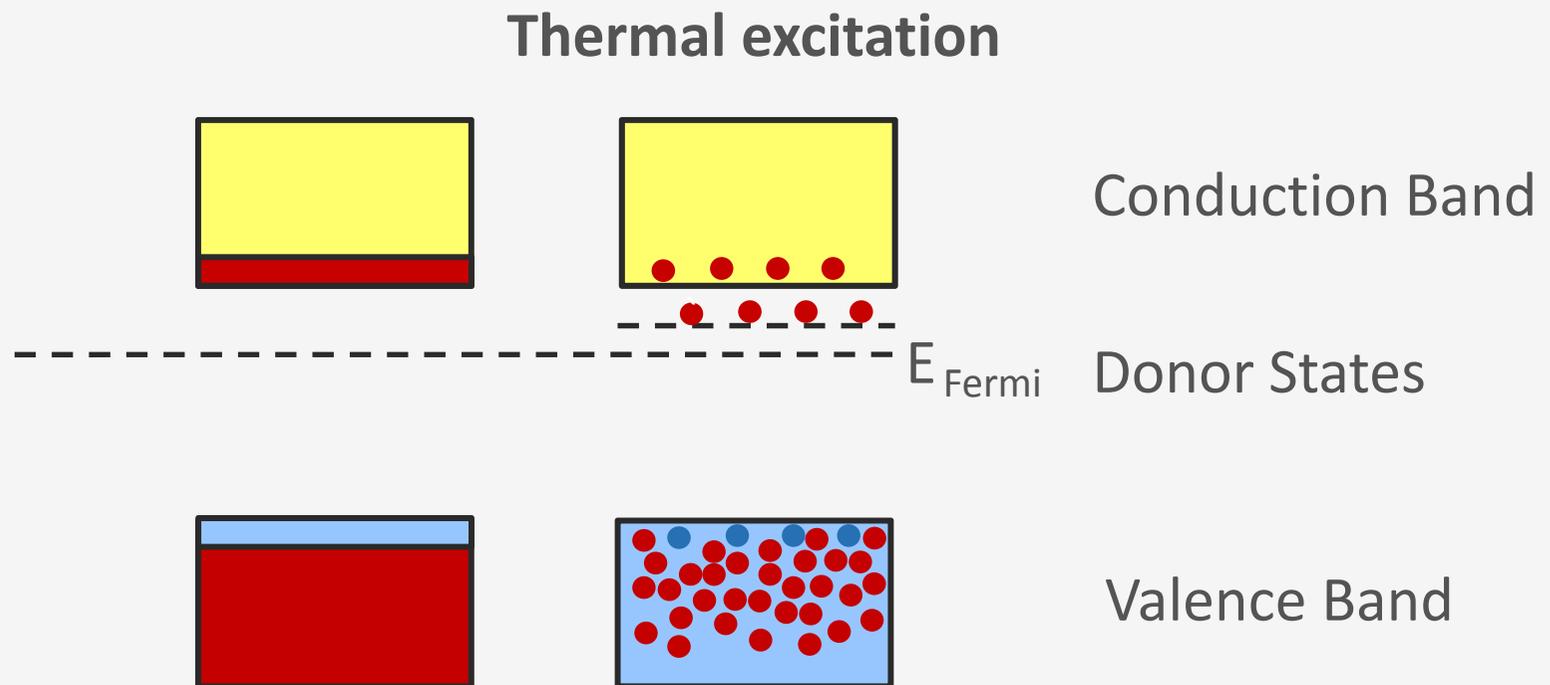
Semiconductor Materials

			P IIIA	I IVA	N VA			VIIIA 2 He 4.0026
		5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180	
		13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.065	17 Cl 35.453	18 Ar 39.948	
IB	IIB							
29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.798	
47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29	
79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po [209]	85 At [210]	86 Rn [222]	

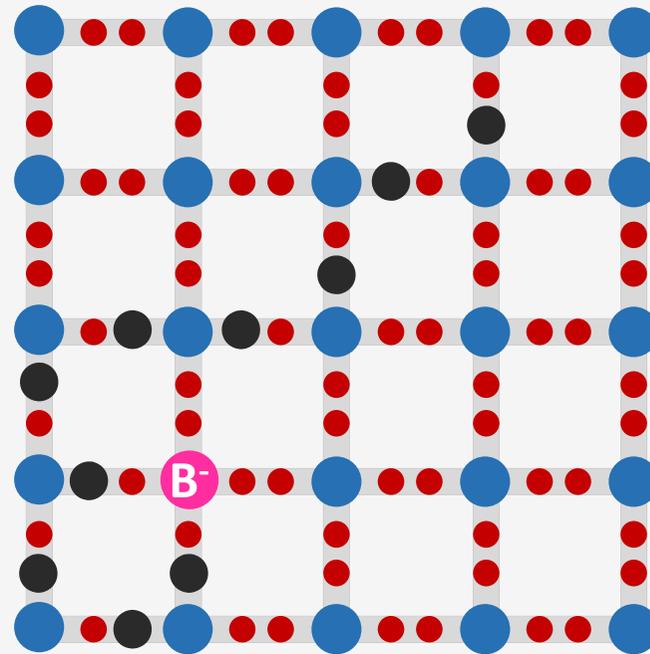
n-Doping



Energy band diagram of n-doped Silicon

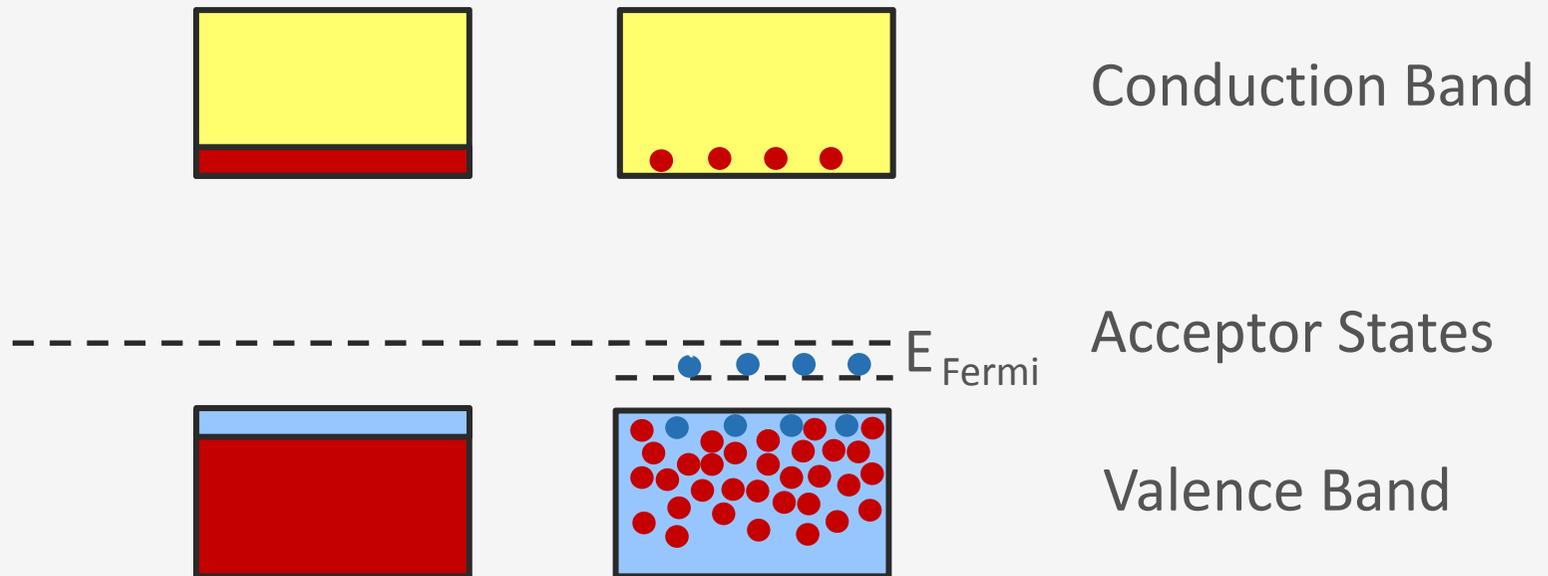


p-Doping



Energy band diagram of p-doped Silicon

Thermal excitation



Typical Concentrations:

$$\frac{\text{Majority Carriers}}{\text{Minority Carriers}} = \frac{10^{16} \text{ cm}^{-3}}{10^4 \text{ cm}^{-3}}$$

Si density in c-Si is $5 \times 10^{22} \text{ cm}^{-3}$

Law of Mass Action

$$\left. \begin{array}{l} n = \text{electron carrier concentration} \\ p = \text{hole carrier concentration} \end{array} \right\} n \cdot p = 1,21 \times 10^{20} \text{ cm}^{-6}$$

$$\text{Intrinsic material } n = p = n_{\text{intrinsic}} = 1,1 \times 10^{10} \text{ cm}^{-3}$$

Doping: At Room Temperature:

$$n_0 p_0 = (n_{\text{intrinsic}})^2$$

n-type doping

$$n_0 = N_D$$

$$p_0 = \frac{(n_{\text{intrinsic}})^2}{n_0}$$

p-type doping

$$p_0 = N_A$$

$$n_0 = \frac{(n_{\text{intrinsic}})^2}{p_0}$$

Example

n-type doping

$$n_0 = N_D$$

$$p_0 = \frac{(n_{\text{intrinsic}})^2}{n_0}$$

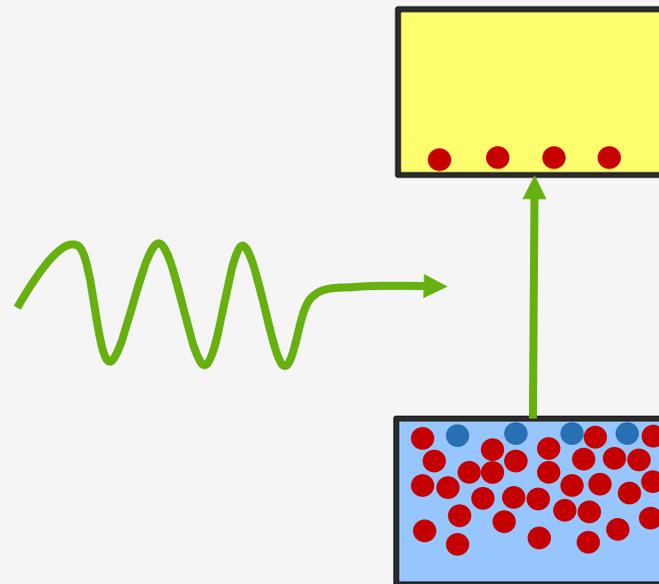
n-type doping example

$$n_0 = N_D = 10^{16} \text{ cm}^{-3}$$

$$p_0 = \frac{1,21 \times 10^{20}}{10^{16}} = 1,21 \times 10^4 \text{ cm}^{-3}$$

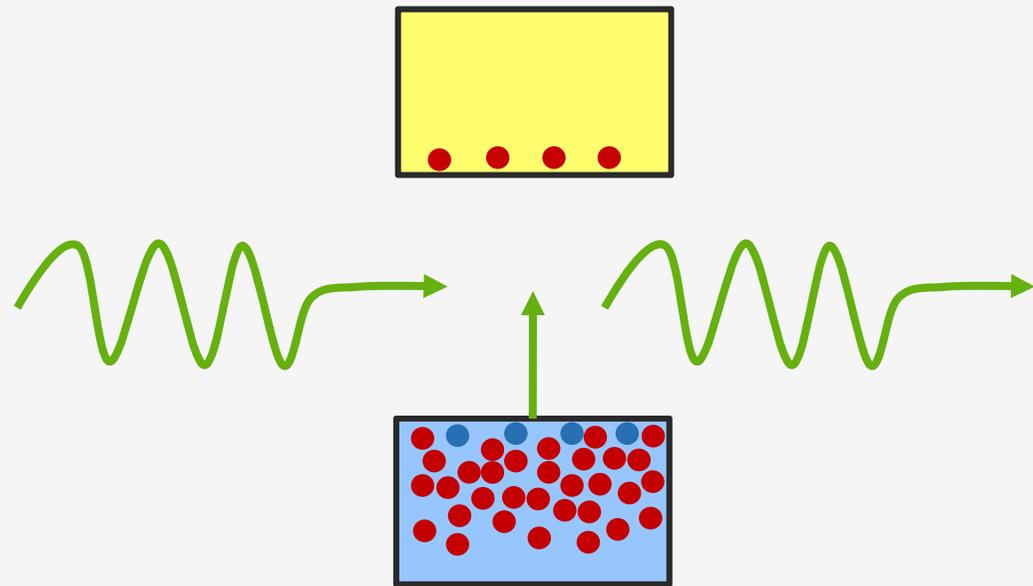
Light Absorption *scenario 1*

$$E_{ph} = E_G:$$



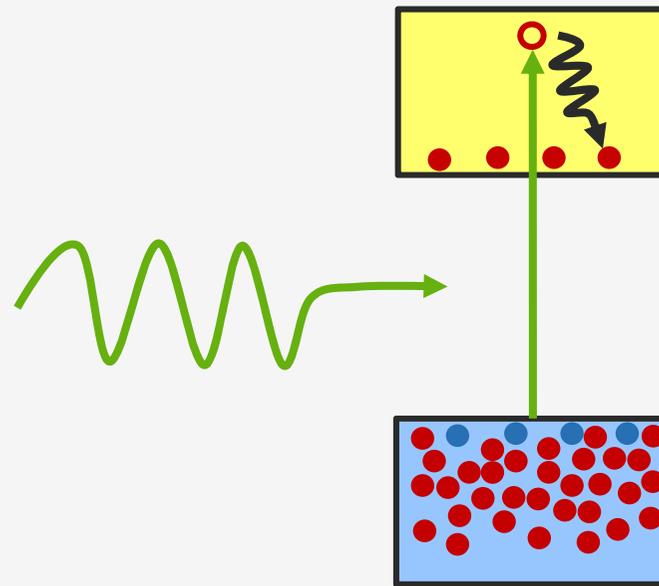
Light Absorption *scenario 2*

$$E_{ph} < E_G:$$



Light Absorption *scenario 3*

$$E_{ph} > E_G:$$



Light Absorbption in doped material

before light absorption:

Majority Carriers

Minority Carriers

=

10^{16} cm^{-3}

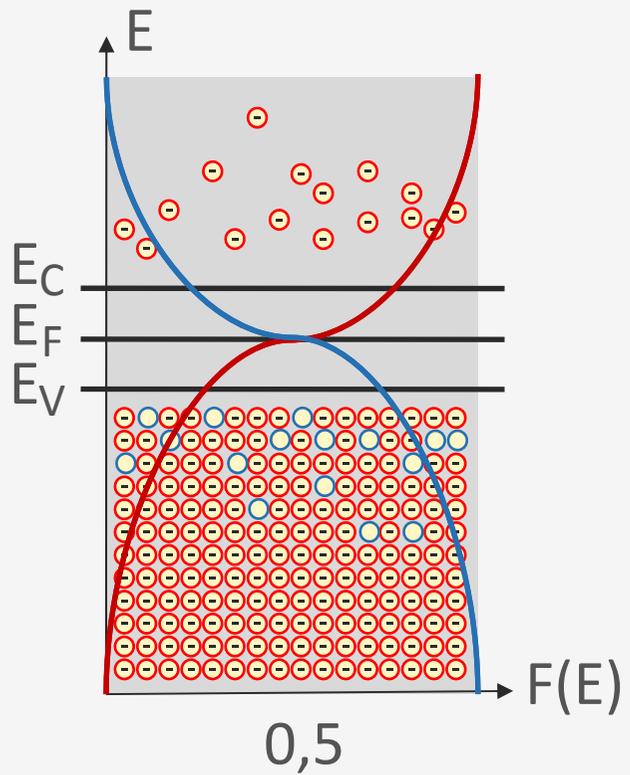
10^4 cm^{-3}

Light Absorbption in doped material

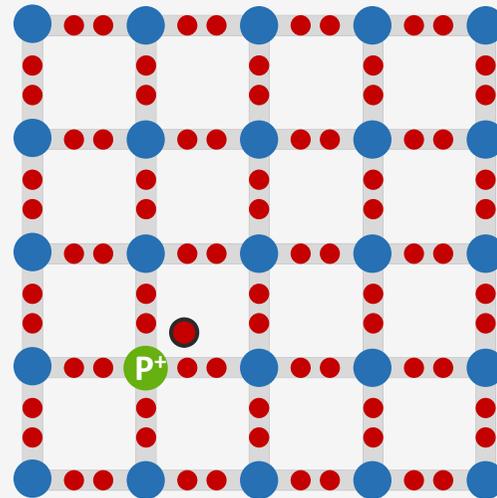
10¹¹ now electron-hole pairs:

$$\frac{\text{Majority Carriers}}{\text{Minority Carriers}} = \frac{10^{16} + \cancel{10^{11}} \text{ cm}^{-3}}{\cancel{10^4} + 10^{11} \text{ cm}^{-3}}$$

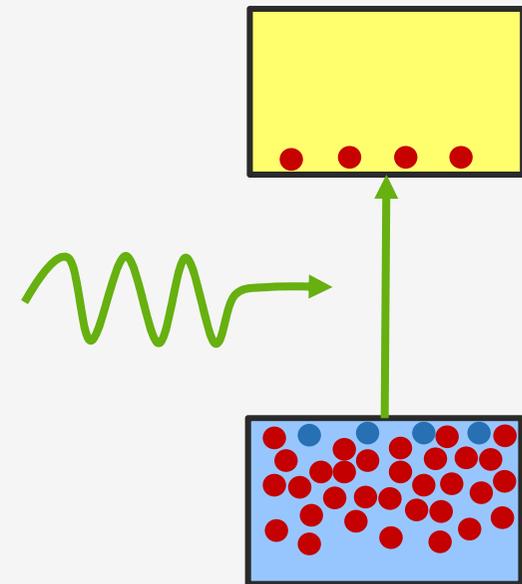
Temperature



Doping



Light



Thank you for your attention!