

COMPOSANTS SEMI-CONDUCTEURS

II) Solutions S2

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Bore: III → accepteur

Phosphore: V → donneur

	(1)	$N_3=1 \times 10^{19} / \text{cm}^3$	P	Bore
	(2)	$N_2=2 \times 10^{16} / \text{cm}^3$	N	Phosphore
(3)		$N_1=6.5 \times 10^{14} / \text{cm}^3$	P	Bore

Exercice 3.1: solution

Le bore (III) est un accepteur (dopant p) dans le silicium

Le phosphore (V) est un donneur (dopant n) dans le silicium

$$3) \quad p_1 = N_{A1} = 6.5 \times 10^{14} \text{ cm}^{-3} \quad n_1 = \frac{n_i^2}{p_1} = \frac{10^{20}}{6.5 \times 10^{14}} \cong 1.5 \times 10^5 \text{ cm}^{-3}$$

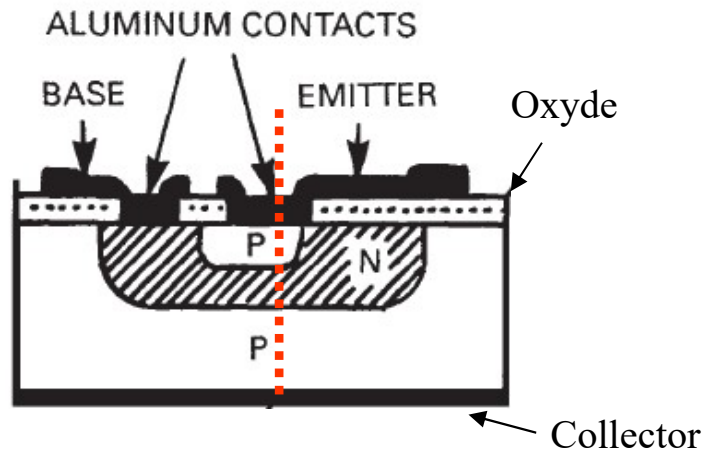
$$2) \quad n_2 = N_2 - N_1 = 2 \times 10^{16} - 6.5 \times 10^{14} \cong 2 \times 10^{16} \text{ cm}^{-3}$$

$$p_2 = \frac{n_i^2}{n_2} = \frac{10^{20}}{2 \times 10^{16}} = 5 \times 10^3 \text{ cm}^{-3}$$

$$1) \quad p_3 = N_3 - (N_2 - N_1) \cong N_3 = 1 \times 10^{19} \text{ cm}^{-3}$$

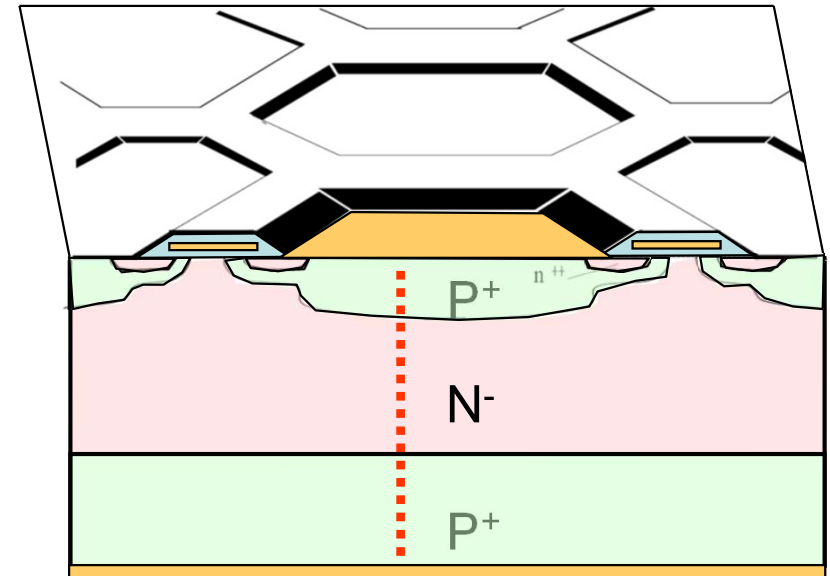
$$n_3 = \frac{n_i^2}{p_3} = \frac{10^{20}}{1 \times 10^{19}} = 10 \text{ cm}^{-3}$$

Transistors bipolaires PNP



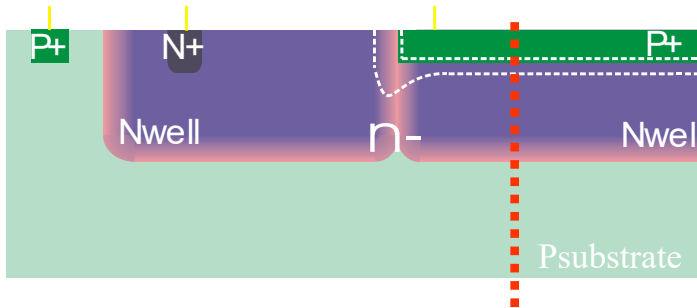
<http://technology-electronic.blogspot.com/2010/07/bipolar-junction-transistors-bjts.html>

Isolated Gate Bipolar Transistor (IGBT)
 =
Darlington avec un MOSFET et un BJT

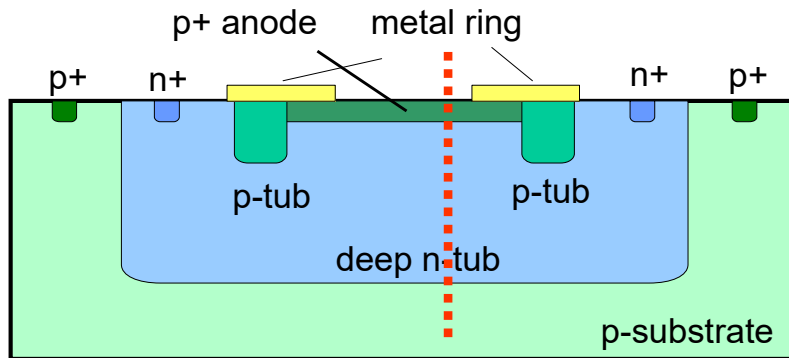


Omar Elmazria: thèse Uni Metz

Single photon avalanche detector (SPAD)

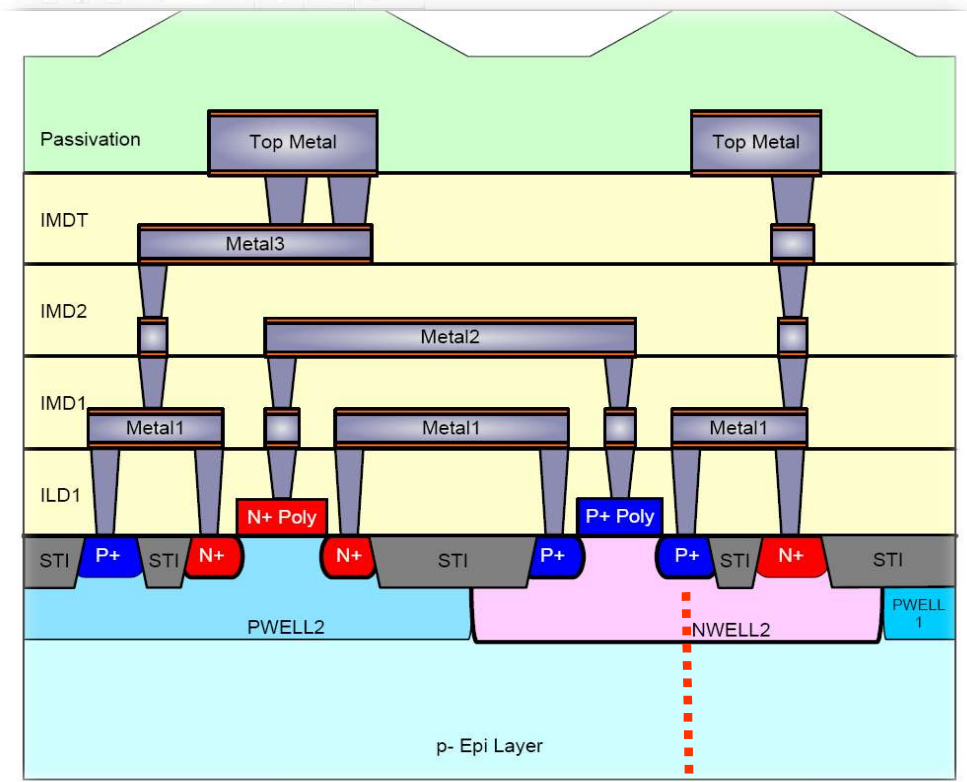


A. Rochas et al., IEEE Transactions Electron Devices, 49 (2002) 387-394.



A. Rochas et al, sent for publication in Review of Scientific Instruments.

Procédé CMOS standard



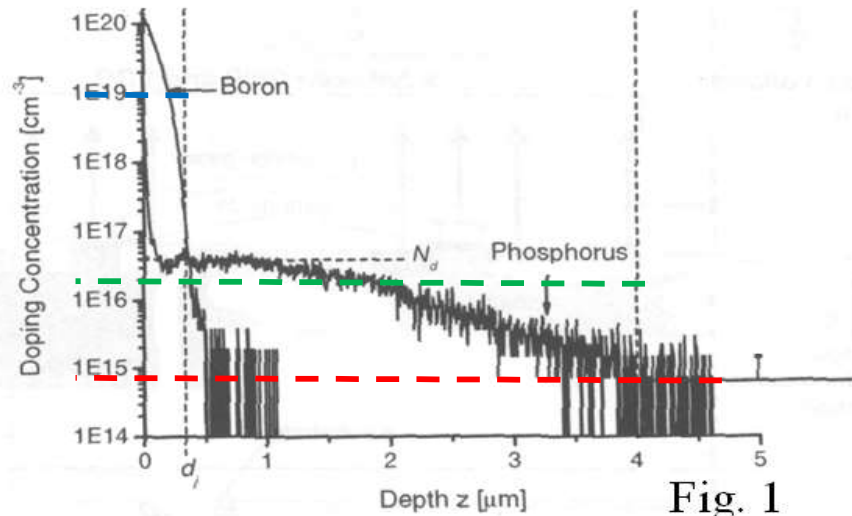


Fig. 1

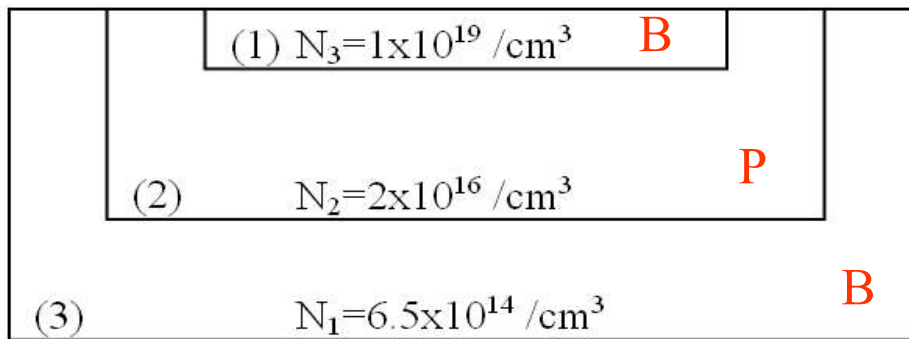
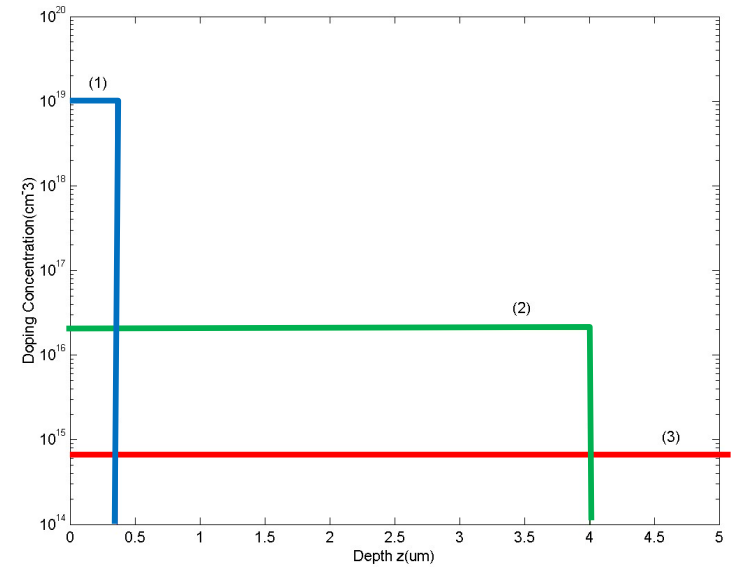
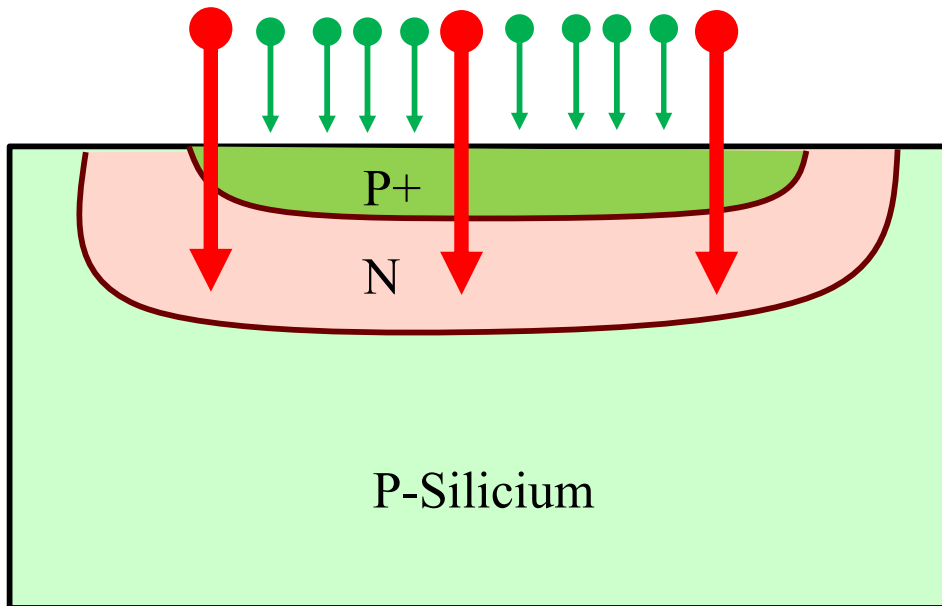


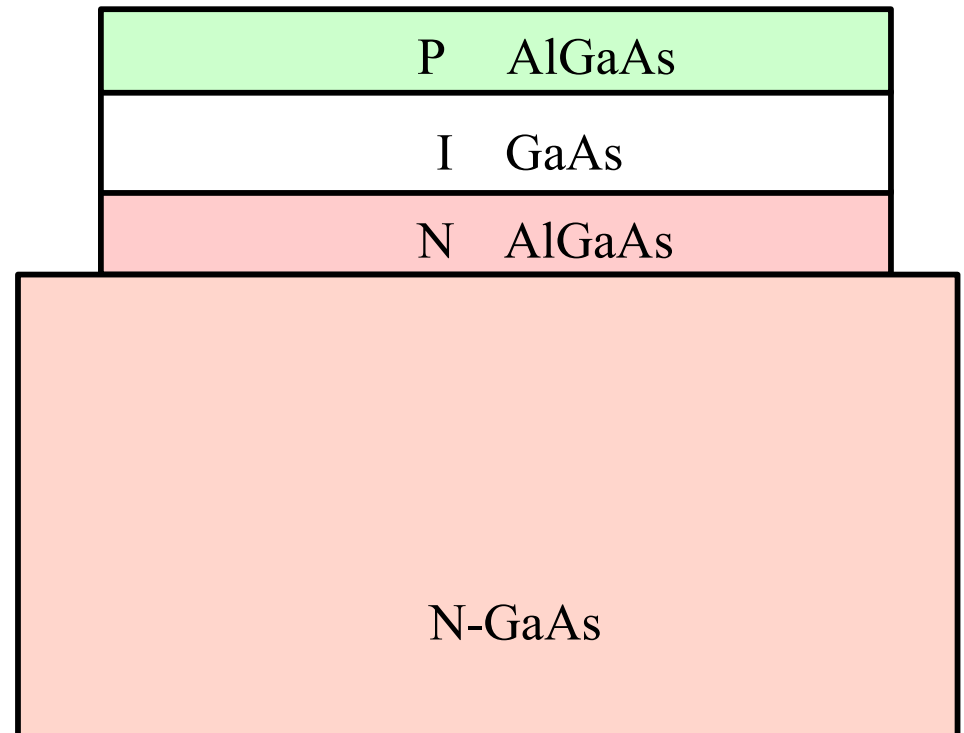
Fig. 2



Dopage par implantation



Dopage par épitaxie



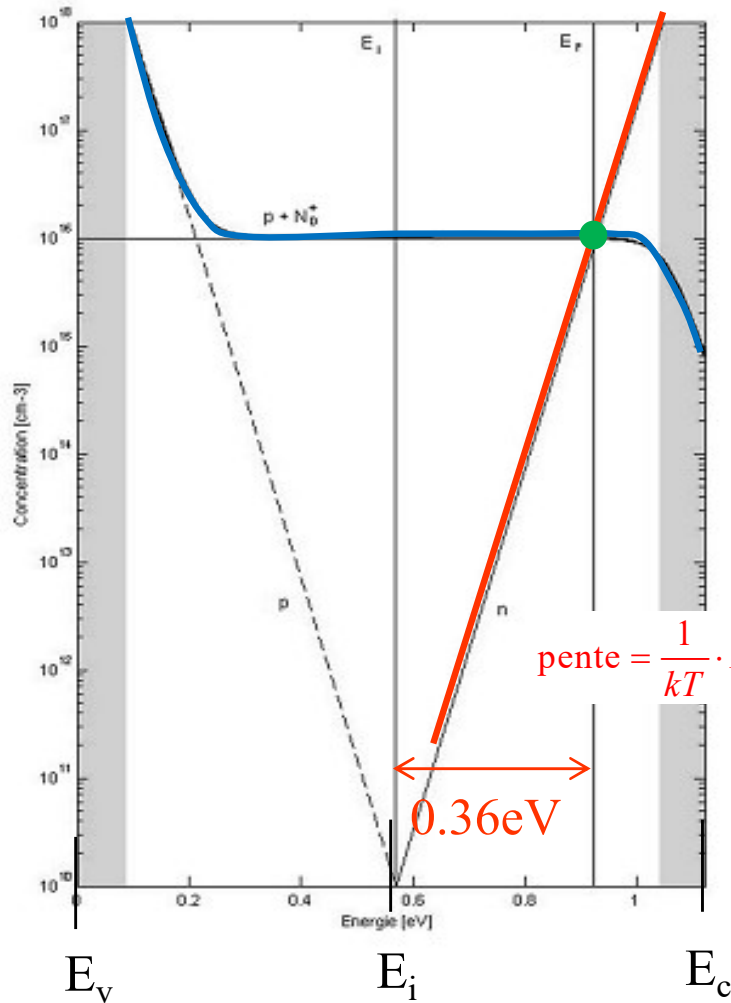


- 1) *Trouvez le niveau de Fermi d'un silicium dopé avec 10^{16} cm^{-3} atomes de phosphore à 300 K .*

- 2) *Le même matériau est chauffé à 600 K.
Calculez la concentration de porteurs intrinsèques à cette température.
Quel est maintenant le niveau de Fermi ?
Supposez le bangap et les masses effectives constants en température .*

- 3) *Si l'échantillon est refroidi à la température de l'azote liquide (77 K),
quelle hypothèse faut-il reconsidérer ?
(Pour information, l'énergie d'ionisation du phosphore est $E_D = E_C - 0.045 \text{ eV}$).*

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



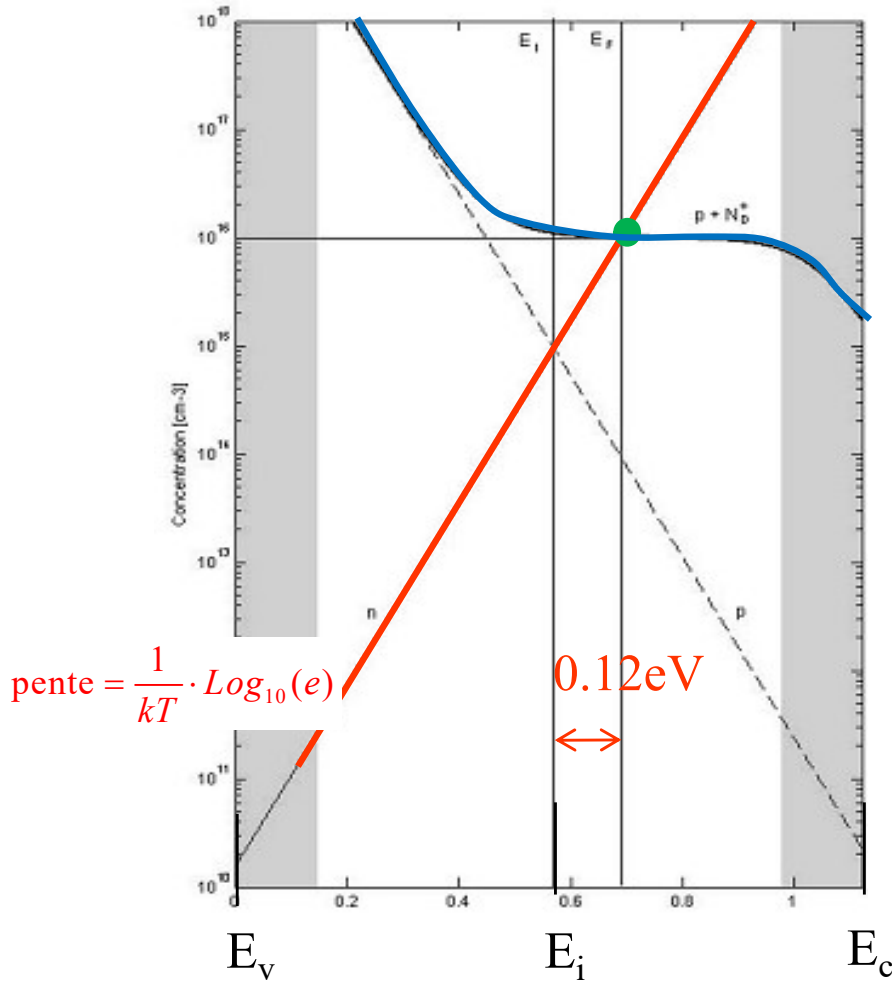
a) 300K

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

$$E_F - E_i = kT \ln(N_D / n_i) = 0.36eV$$

$$\text{pente} = \frac{1}{kT} \cdot \text{Log}_{10}(e)$$

0.36eV



b) 600K: calcul de n_i

$$N_C = 2 \left(\frac{m_{dos,n}^* k_B T}{2\pi \hbar^2} \right)^{3/2} = 7.9 \times 10^{19}$$

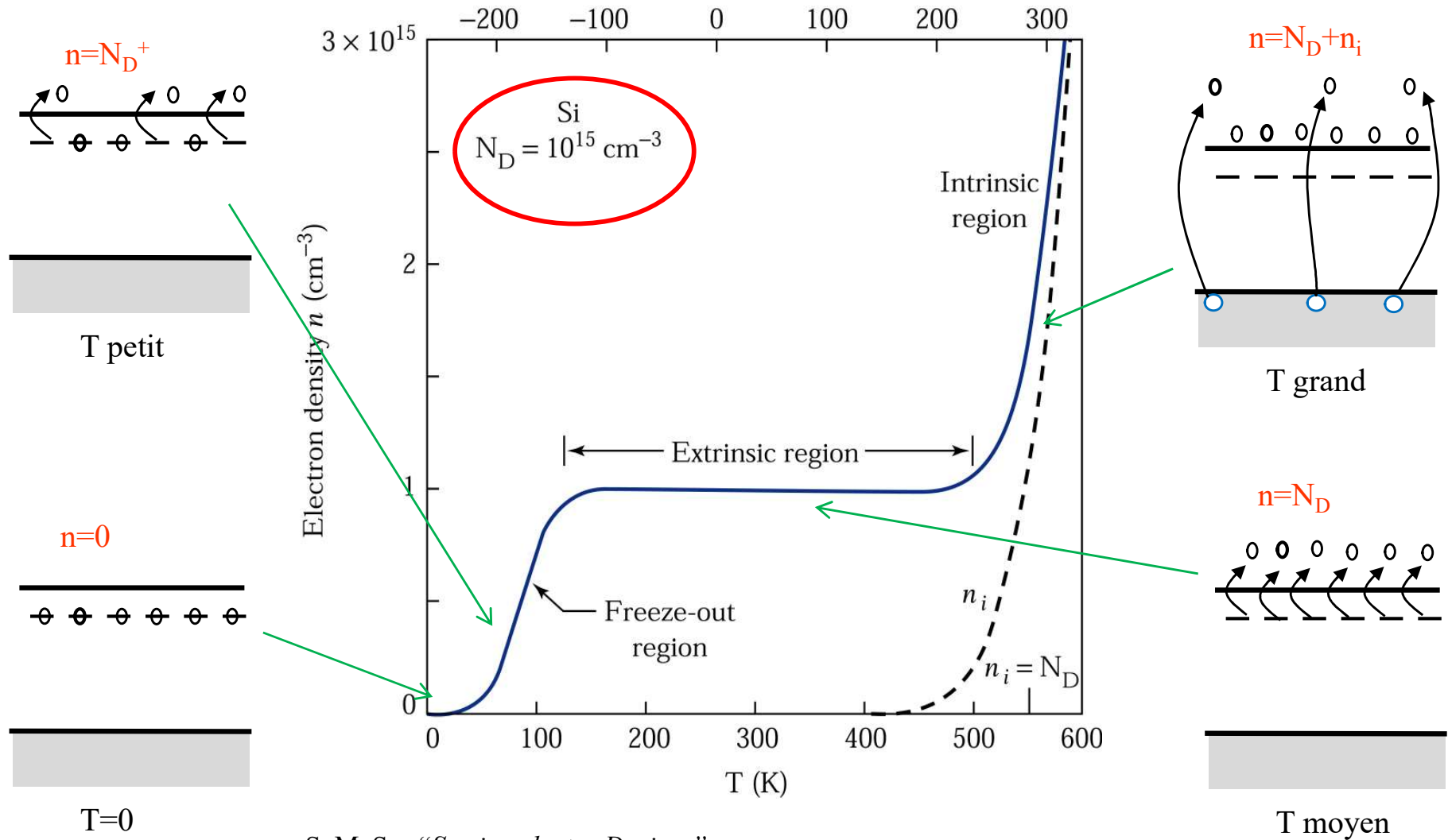
$$N_V = 2 \left(\frac{m_{dos,p}^* k_B T}{2\pi \hbar^2} \right)^{3/2} = 2.9 \times 10^{19}$$

$$n_i = \sqrt{N_C N_V} \exp\left(\frac{-E_g}{2k_B T}\right) = 9.4 \times 10^{14}$$

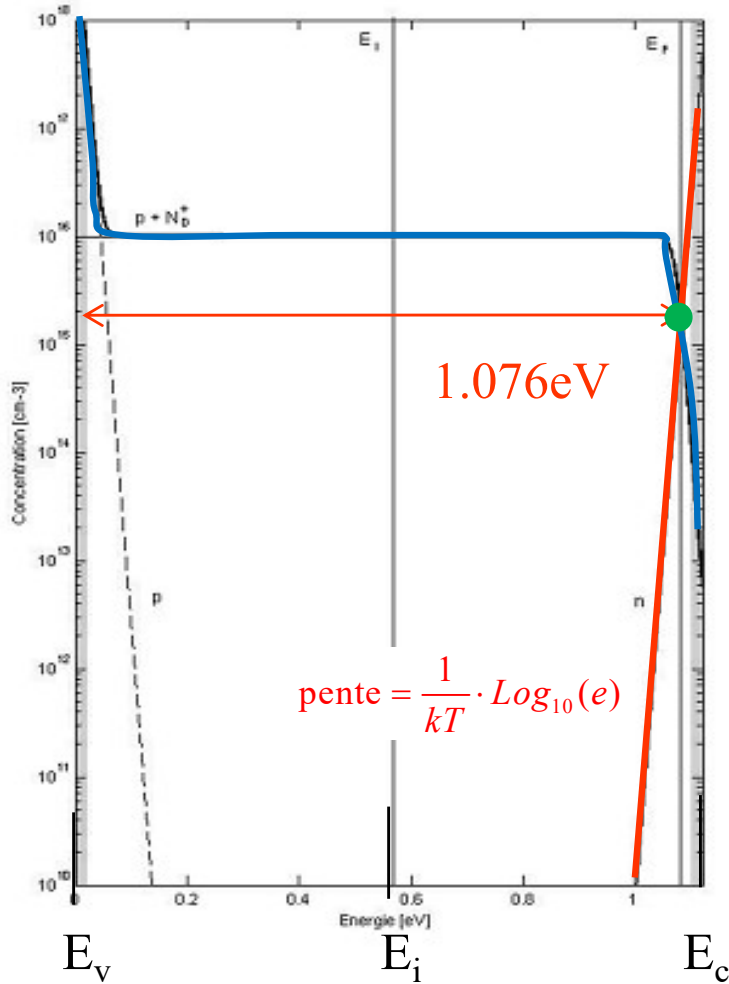
Calcul de E_f

$$E_F - E_i = kT \ln(N_D / n_i) = 0.12\text{eV}$$

Concentration et température



S. M. Sze "Semiconductor Devices"



c) 77K: calcul de n_i

$$N_C = 2 \left(\frac{m_{dos,n}^* k_B T}{2\pi \hbar^2} \right)^{3/2} = 3.66 \times 10^{18} \quad [cm^{-3}]$$

$$N_V = 2 \left(\frac{m_{dos,p}^* k_B T}{2\pi \hbar^2} \right)^{3/2} = 1.33 \times 10^{18} \quad [cm^{-3}]$$

$$n_i = \sqrt{N_C N_V} \exp\left(\frac{-E_g}{2k_B T}\right) = 4.8 \times 10^{-19} \quad [cm^{-3}]$$

Condition de neutralité: $n = N_D^+$

Condition de neutralité: $n=N_D^+$

$$n = n_i \exp\left(\frac{E_F - E_i}{k_B T}\right) = N_D^+ = N_D \left(1 - \frac{1}{1 + \frac{1}{2} \exp\left(\frac{E_D - E_F}{k_B T}\right)}\right)$$

$$E_F = 1.076 \text{ eV}$$

avec $2E_i = E_g = E_c = 1.12 \text{ eV}$

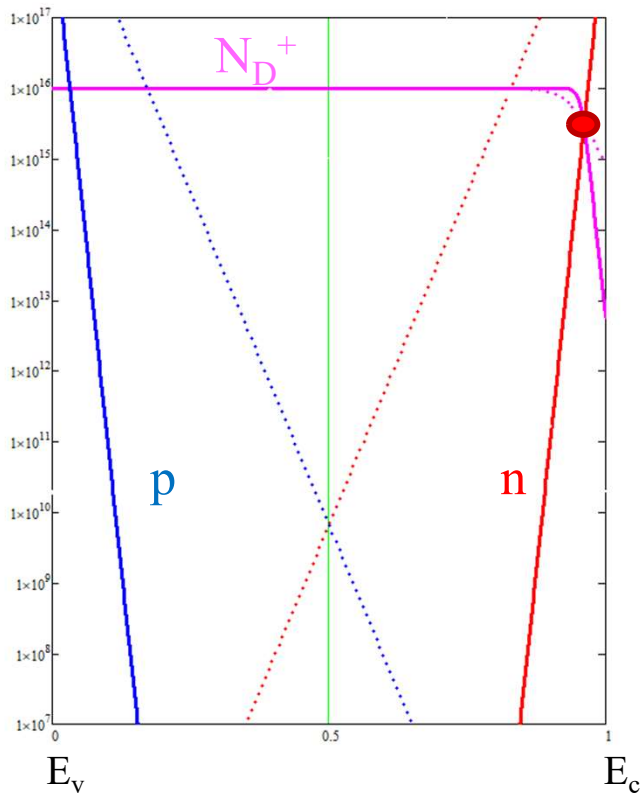
$$E_C - E_F = 44 \text{ meV}$$

$$E_C - E_D = 45 \text{ meV}$$

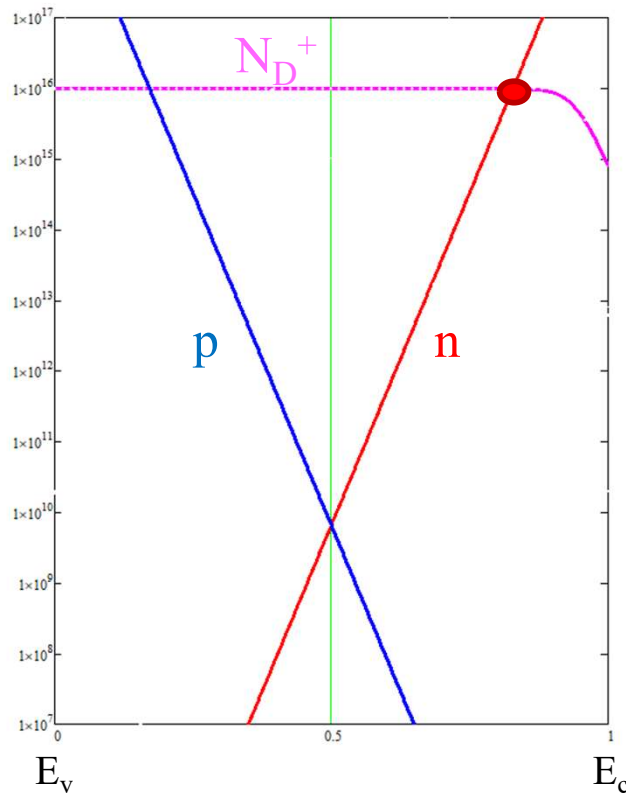
$$N_D^+ = 3 \times 10^{15} \text{ cm}^{-3}$$

$$\frac{N_D^+}{N_D} = 30\%$$

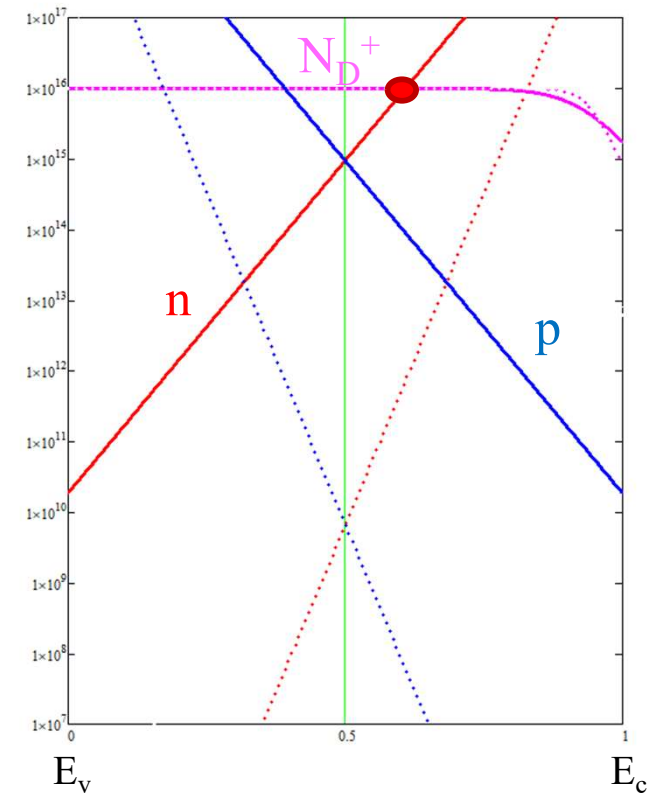
77 K



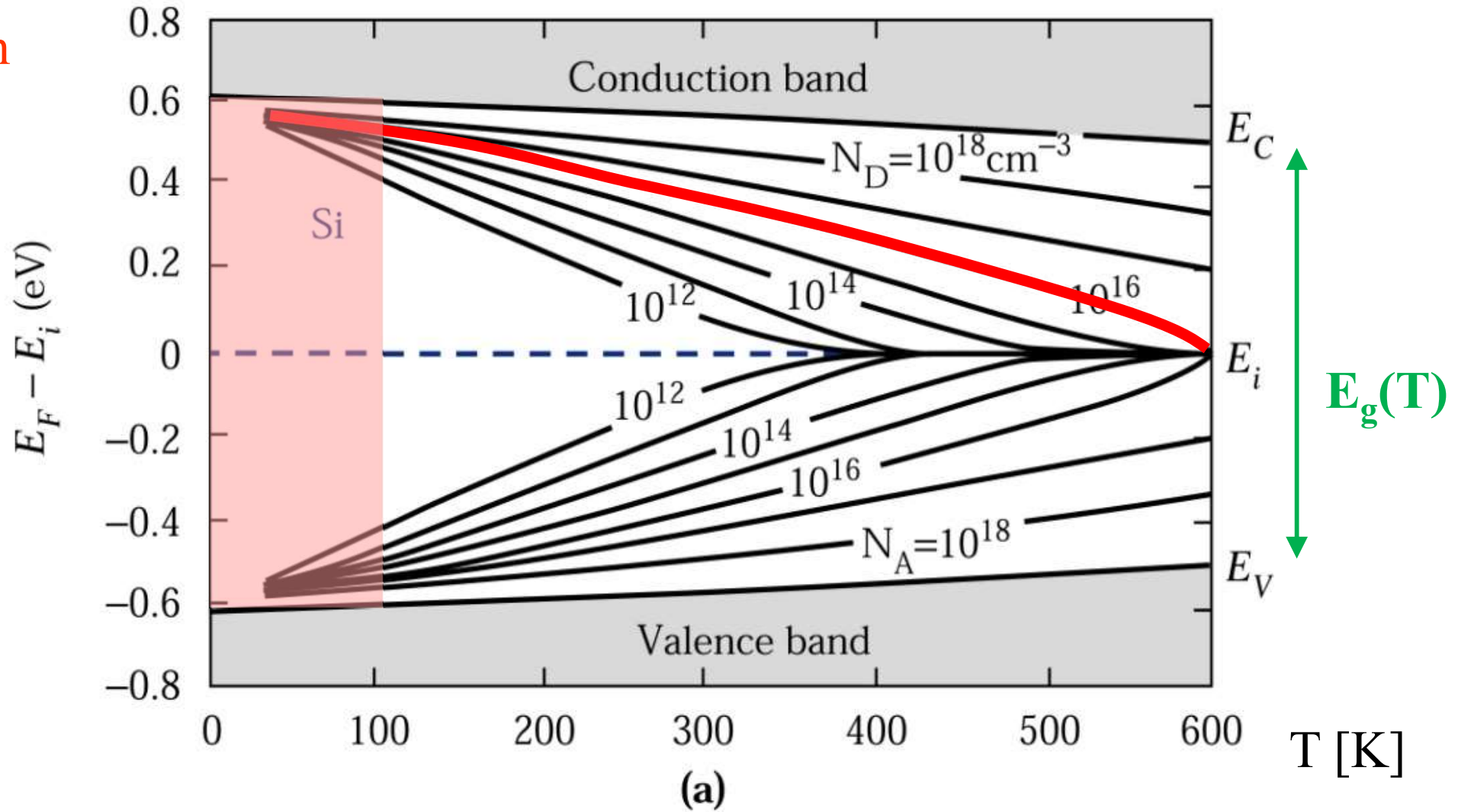
300 K



600 K



Silicium



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