COMPOSANTS SEMI-CONDUCTEURS

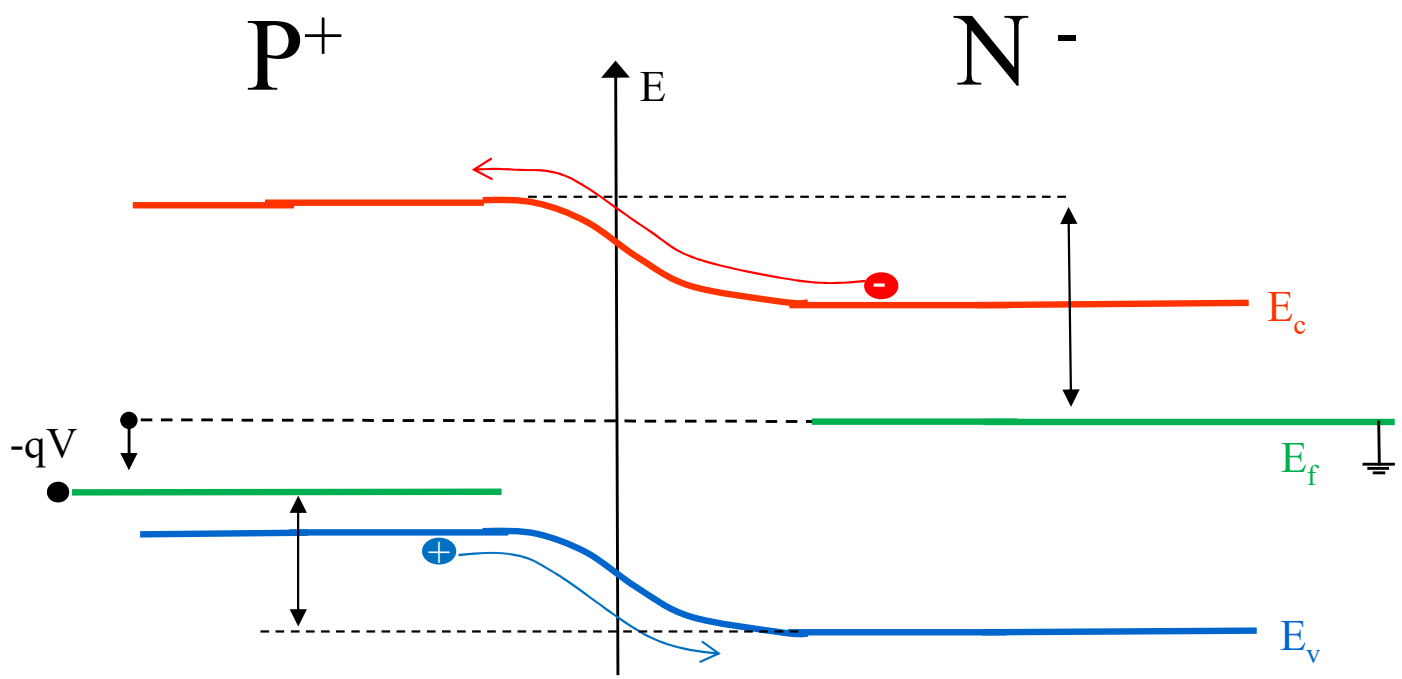
VI) Solutions S6

P.A. Besse

EPFL

Exercice 6.1

Exercice E6.1: diode p^+/n^-, passante



En mode passant, le courant dans la jonction est-il dominé par des électrons ou par des trous ?

Courants dominants dans une diode $P^+ N^-$

Augmentation du dopage P

Courant de trous

$$J_{s,p} \equiv \frac{qD_p}{L_p} \cdot \frac{n_i^2}{N_{D,n}}$$

Courant P

Minoritaires côté N

Constant

Courant d'électrons

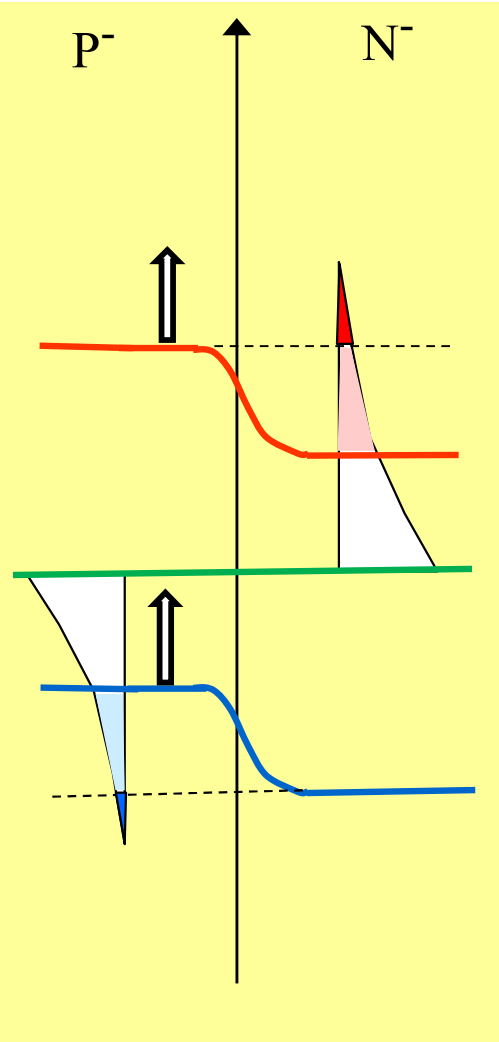
$$J_{s,n} \equiv \frac{qD_n}{L_n} \cdot \frac{n_i^2}{N_{A,p}}$$

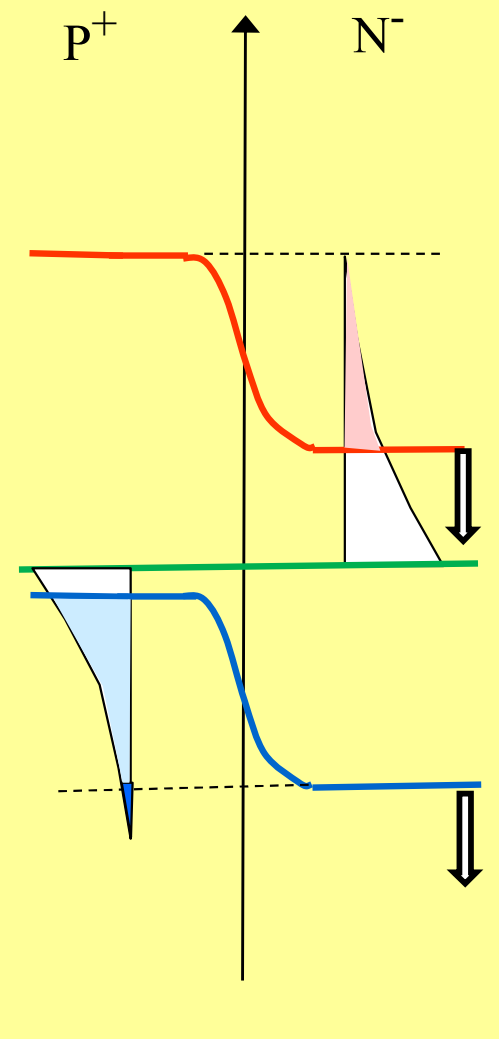
Courant N

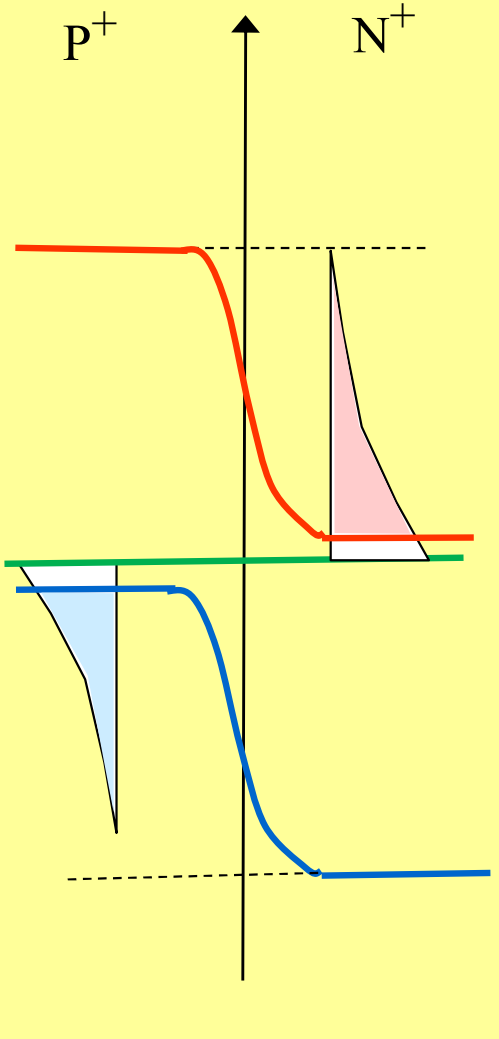
Minoritaires côté P

Diminue

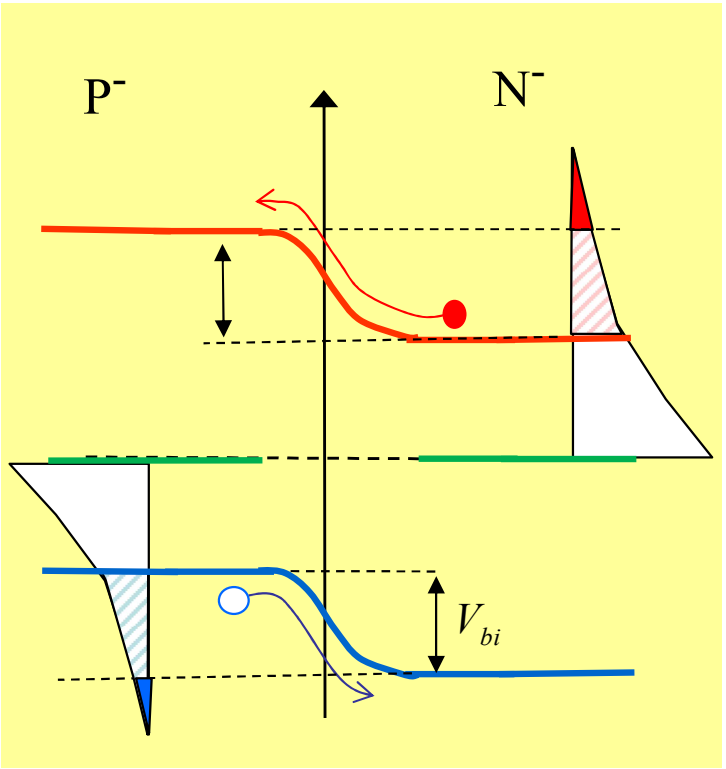
6.1: Diode p^+/n^- «idéale»

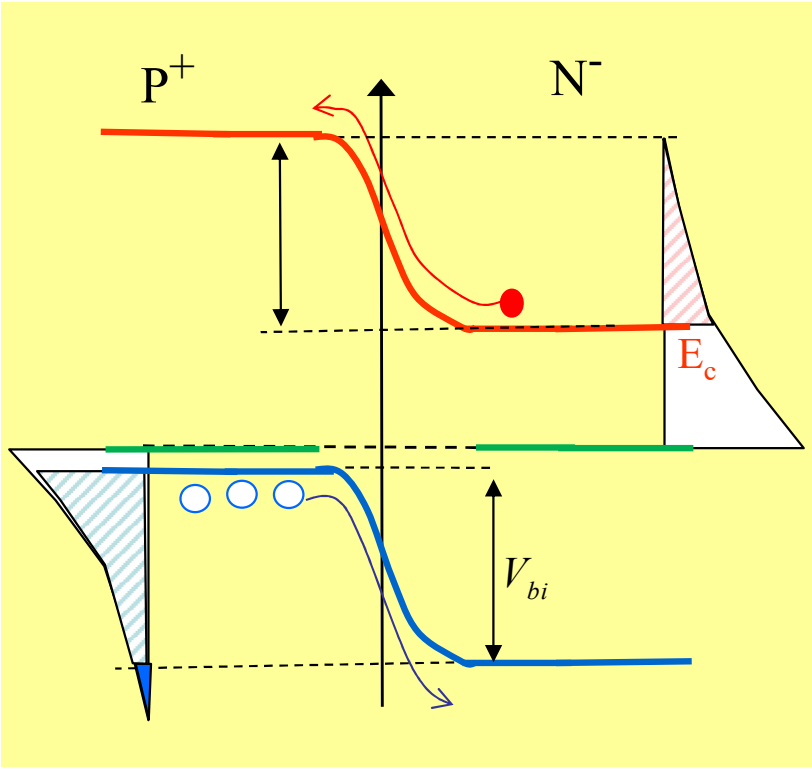






6.1: Diode p^+/n^- «idéale»





$$J_{s,p} \equiv \frac{qD_p}{L_p} \cdot \frac{n_i^2}{N_{D,n}}$$

Constant

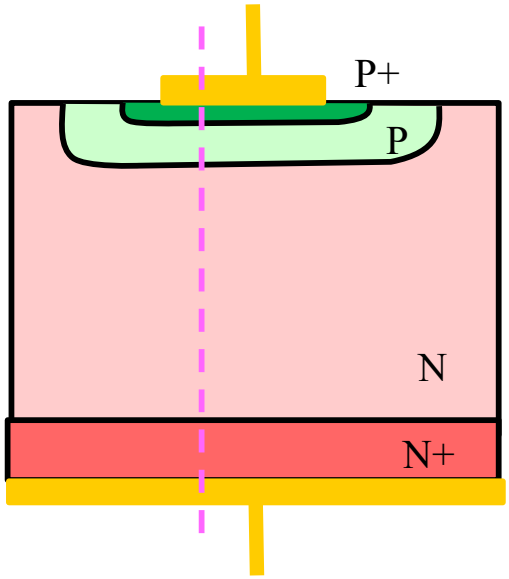
$$J_{s,n} \equiv \frac{qD_n}{L_n} \cdot \frac{n_i^2}{N_{A,p}}$$

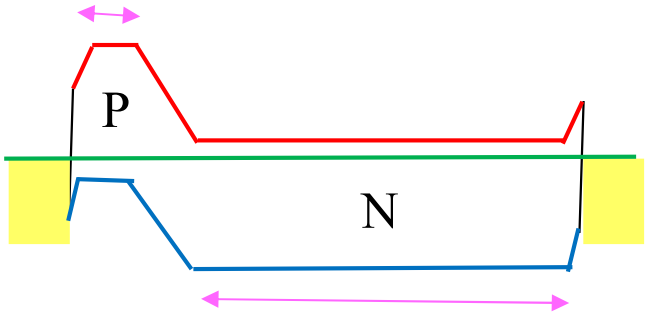
Diminue

Exercice 6.2

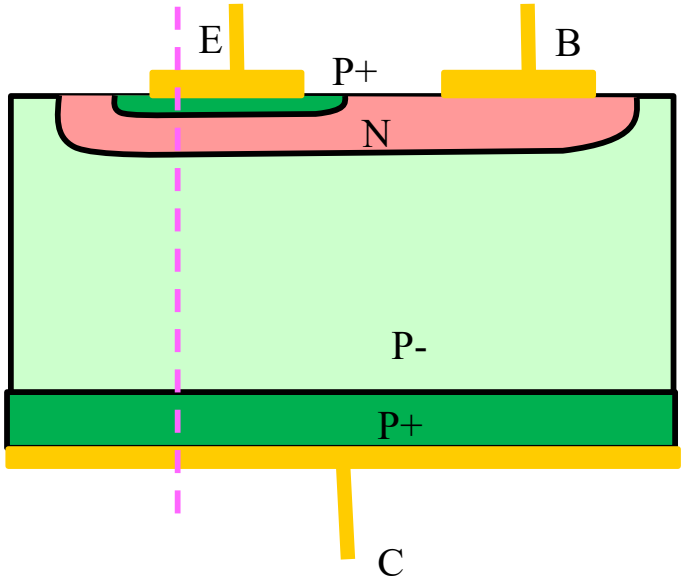
Motivation

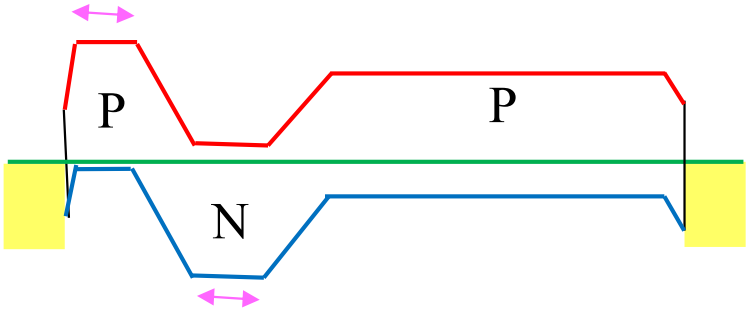
PN diode



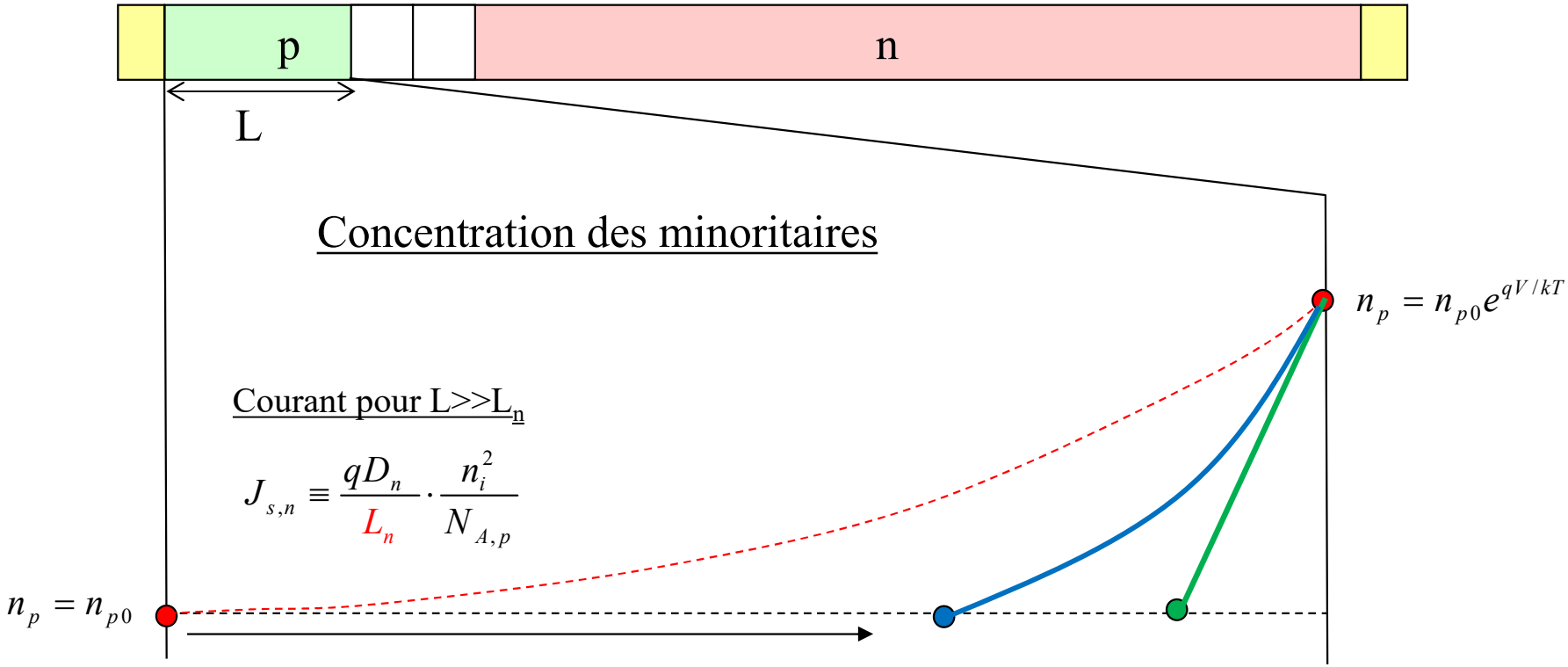


PNP- bipolar transistor





6.2: Jonctions courtes

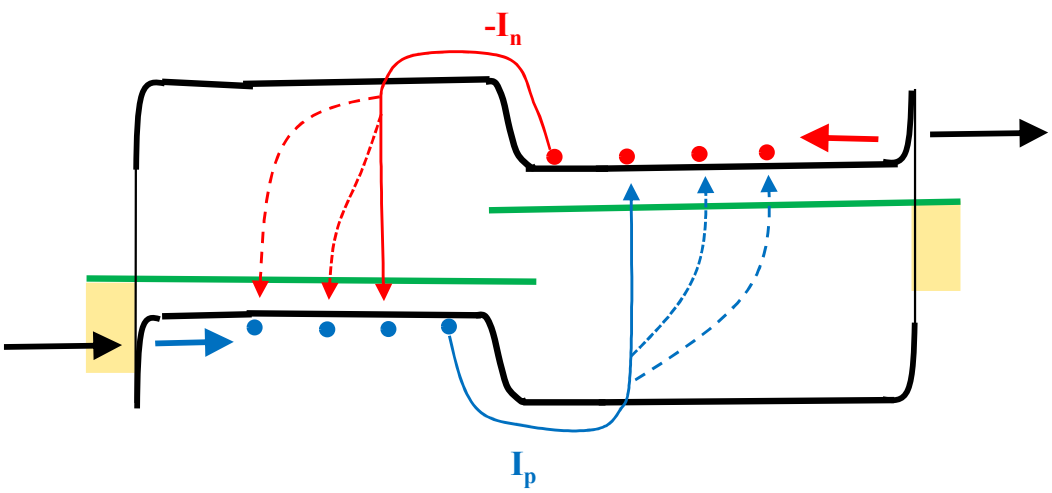


Courant pour L<<L$_n$

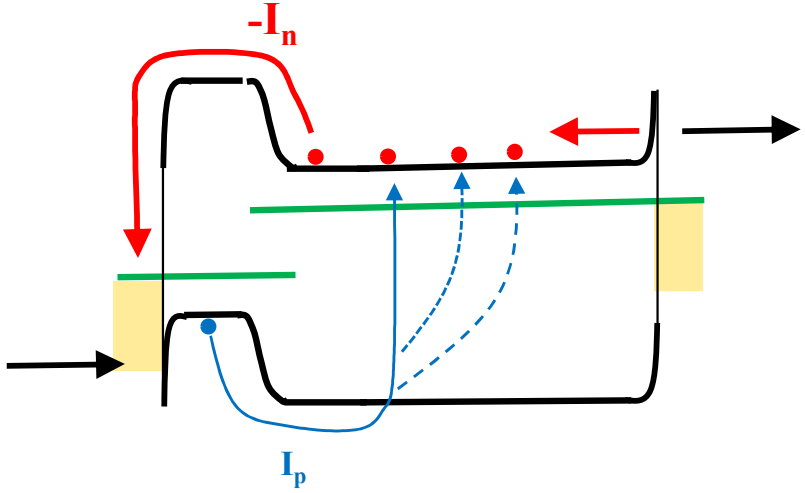
$$J_{s,n} \equiv \frac{qD_n}{L} \cdot \frac{n_i^2}{N_{A,p}}$$

Comparaison avec des diodes passantes

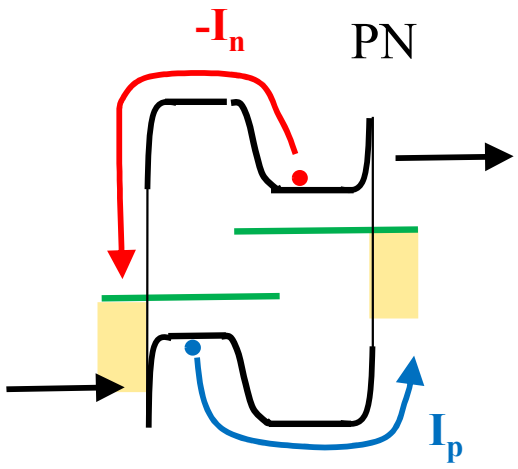
Diode PN longue

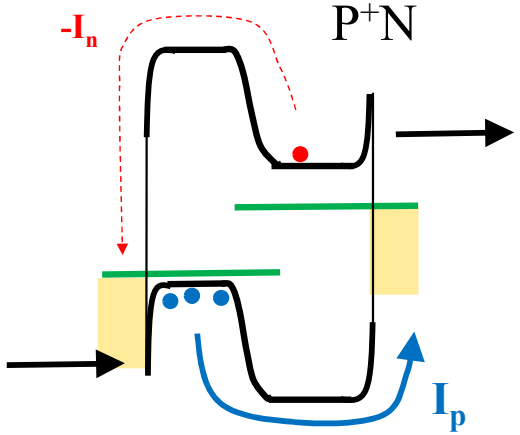


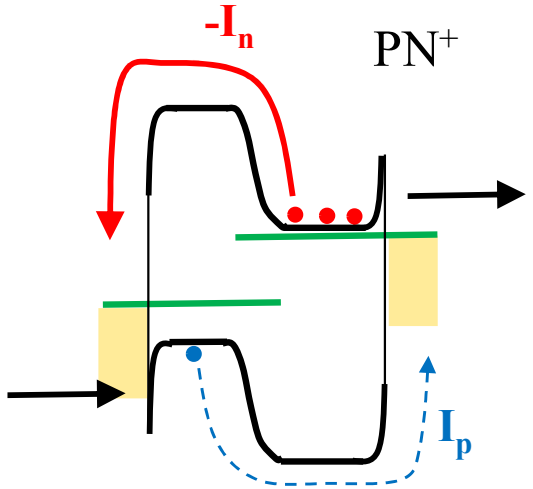
Diode PN courte sur un côté



Diode PN courte sur deux côtés

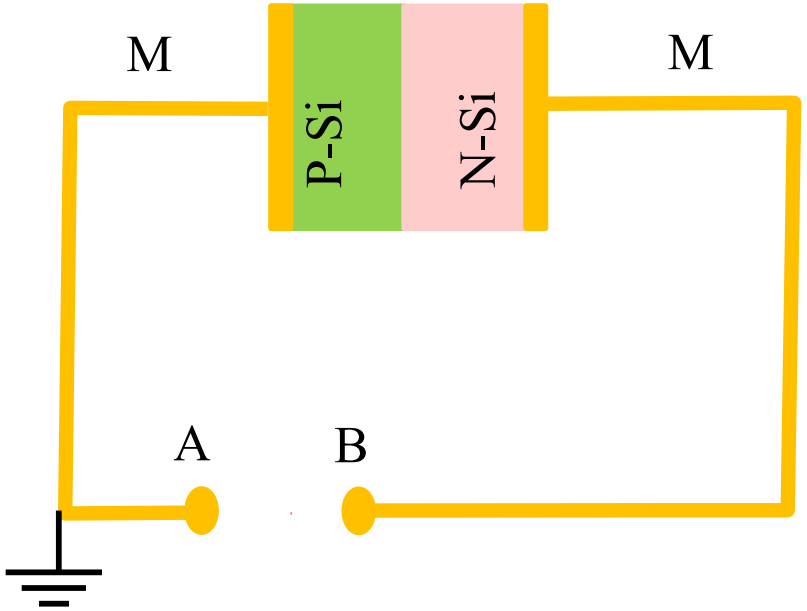


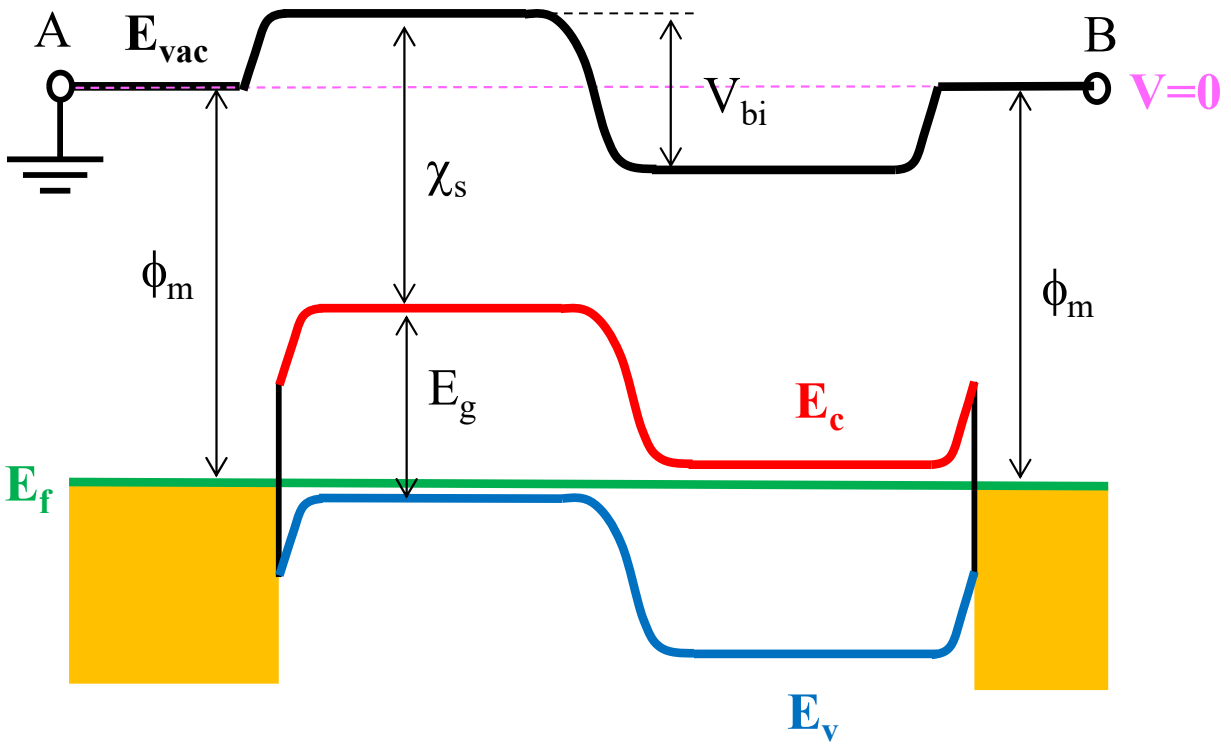




Exercice 6.3

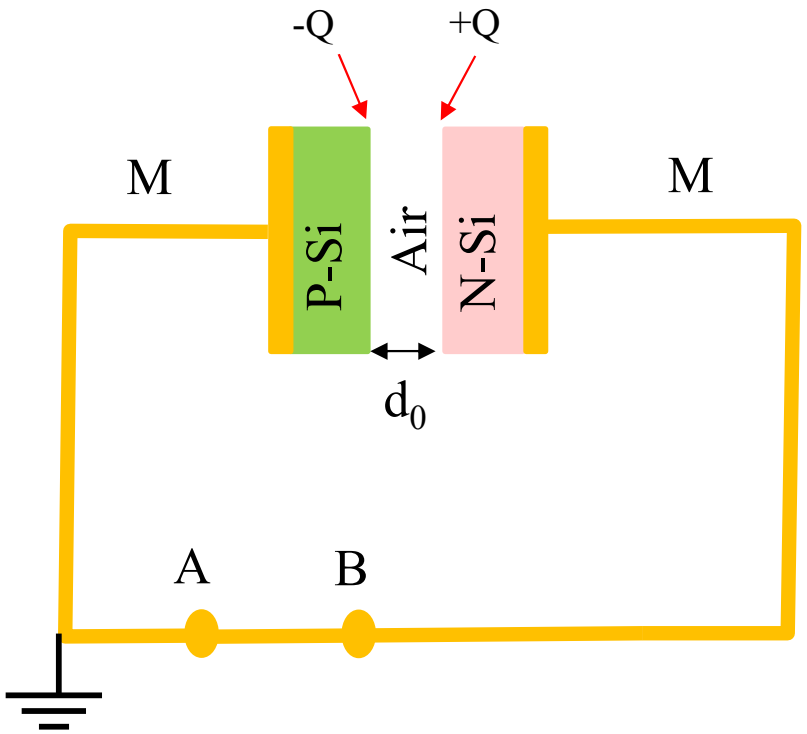
Exercice E6.3: Tension de built-in (1)





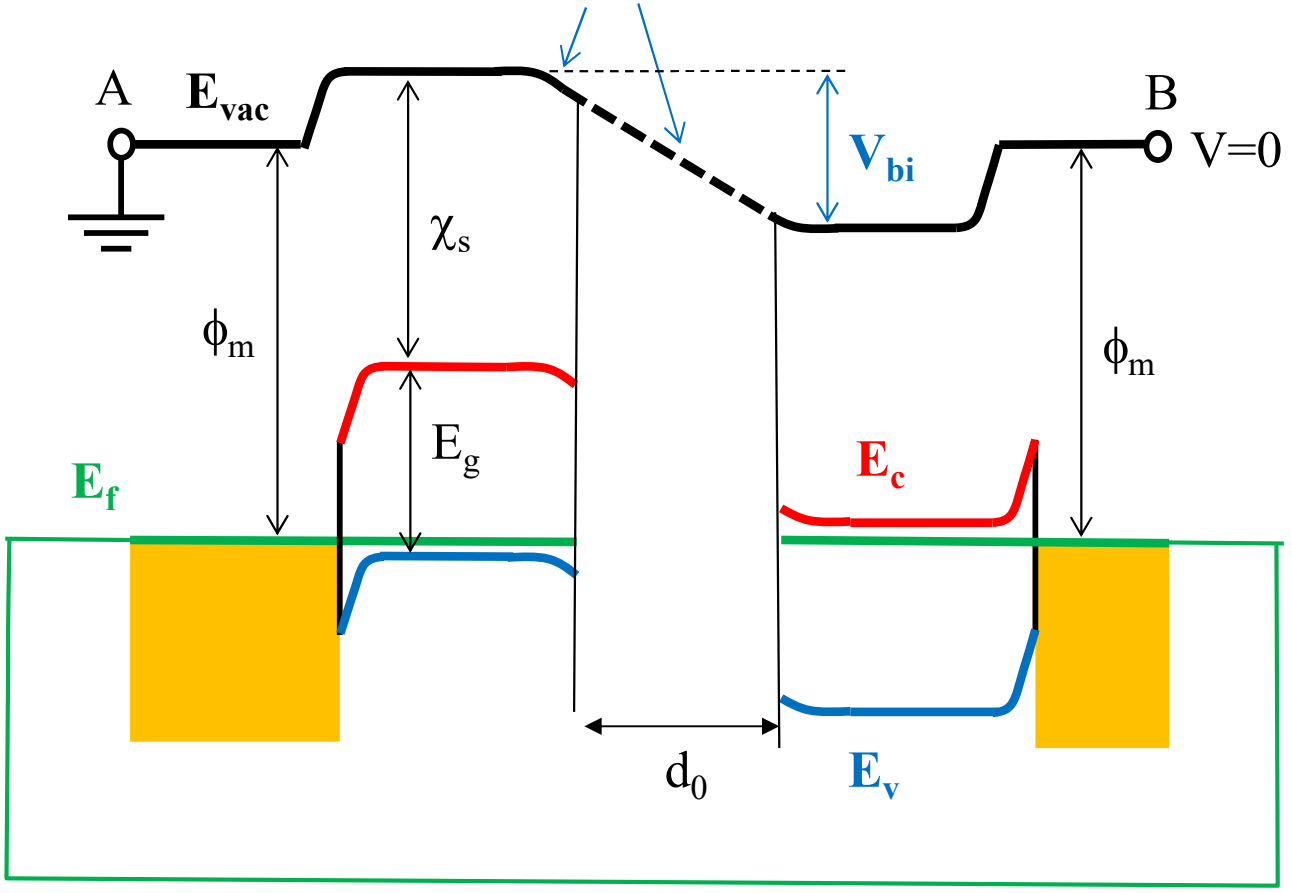
$$\phi_m = \chi_s + \frac{E_g}{2}$$

Exercice E6.3: Tension de built-in (2)

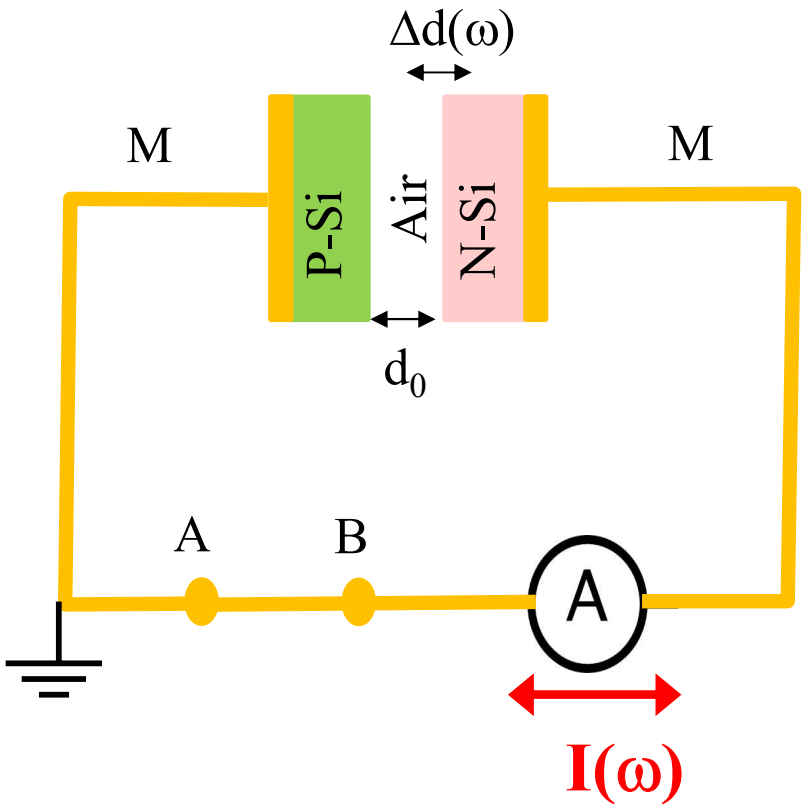


Si d_0 augmente:

- V_{bi} reste constant
- La courbure (donc les charges) diminuent
- Le champ électrique diminue



Exercice E6.3: Tension de built-in (3)



- La tension est constante sur la capa (= V_{bi})
- Les charges varient avec la distance Δd(ω)

⇩

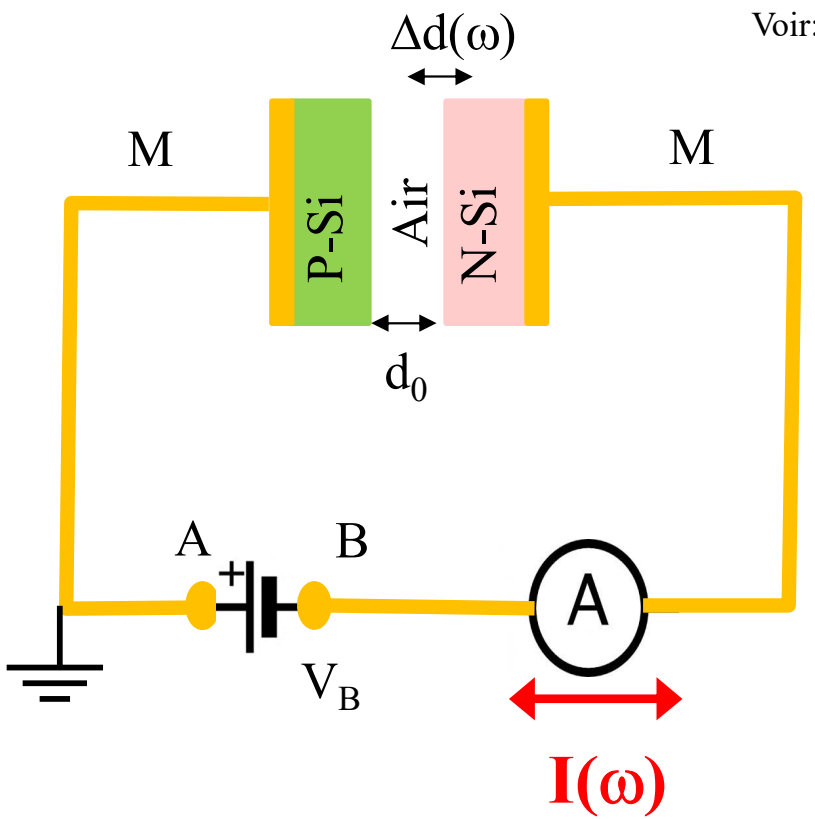
Il faut apporter et extraire périodiquement ces charges

→ Cela génère un courant dans l'ampèremètre

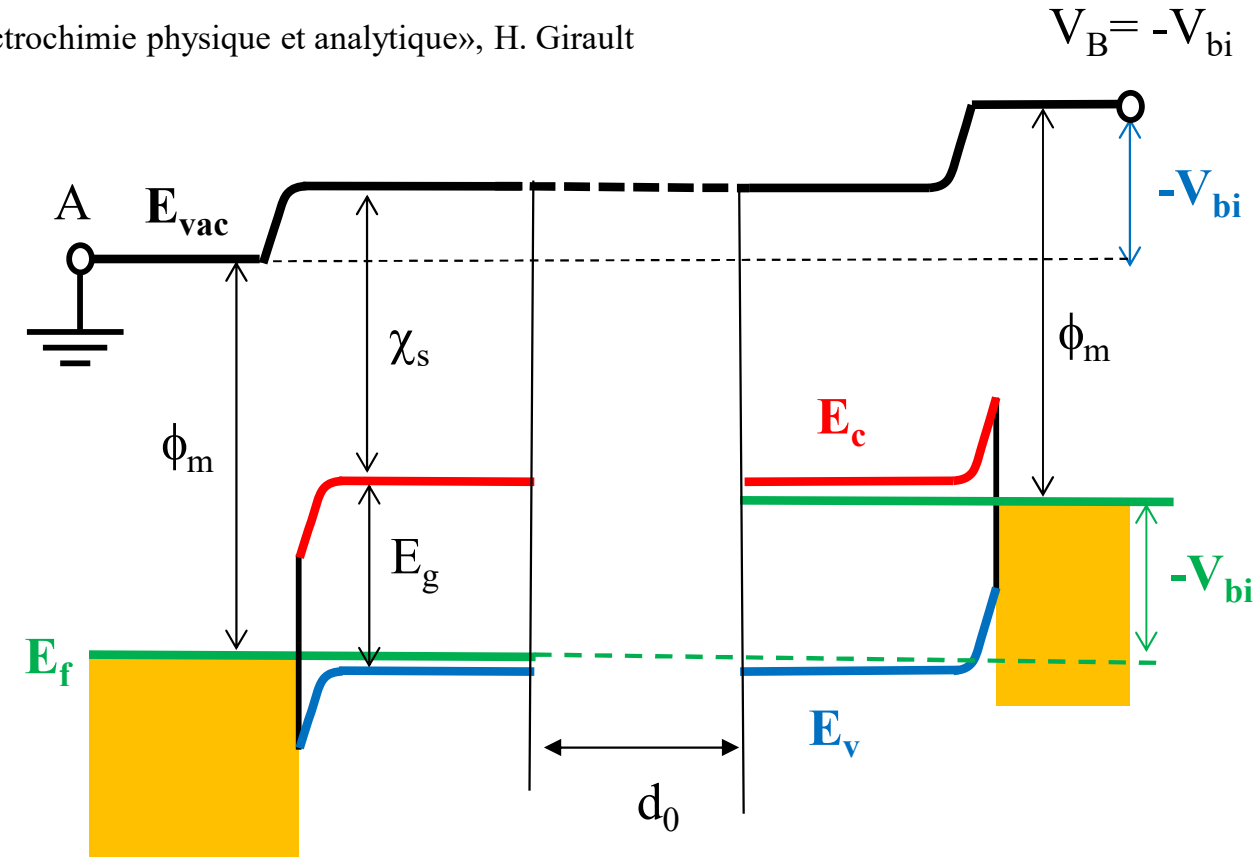
$$I = \frac{\partial Q}{\partial t} = \frac{\partial}{\partial t}\left(C \cdot V_{bi}\right)$$

$$I = \frac{\partial C}{\partial t} \cdot V_{bi}$$

Exercice E6.3: Tension de built-in (4)



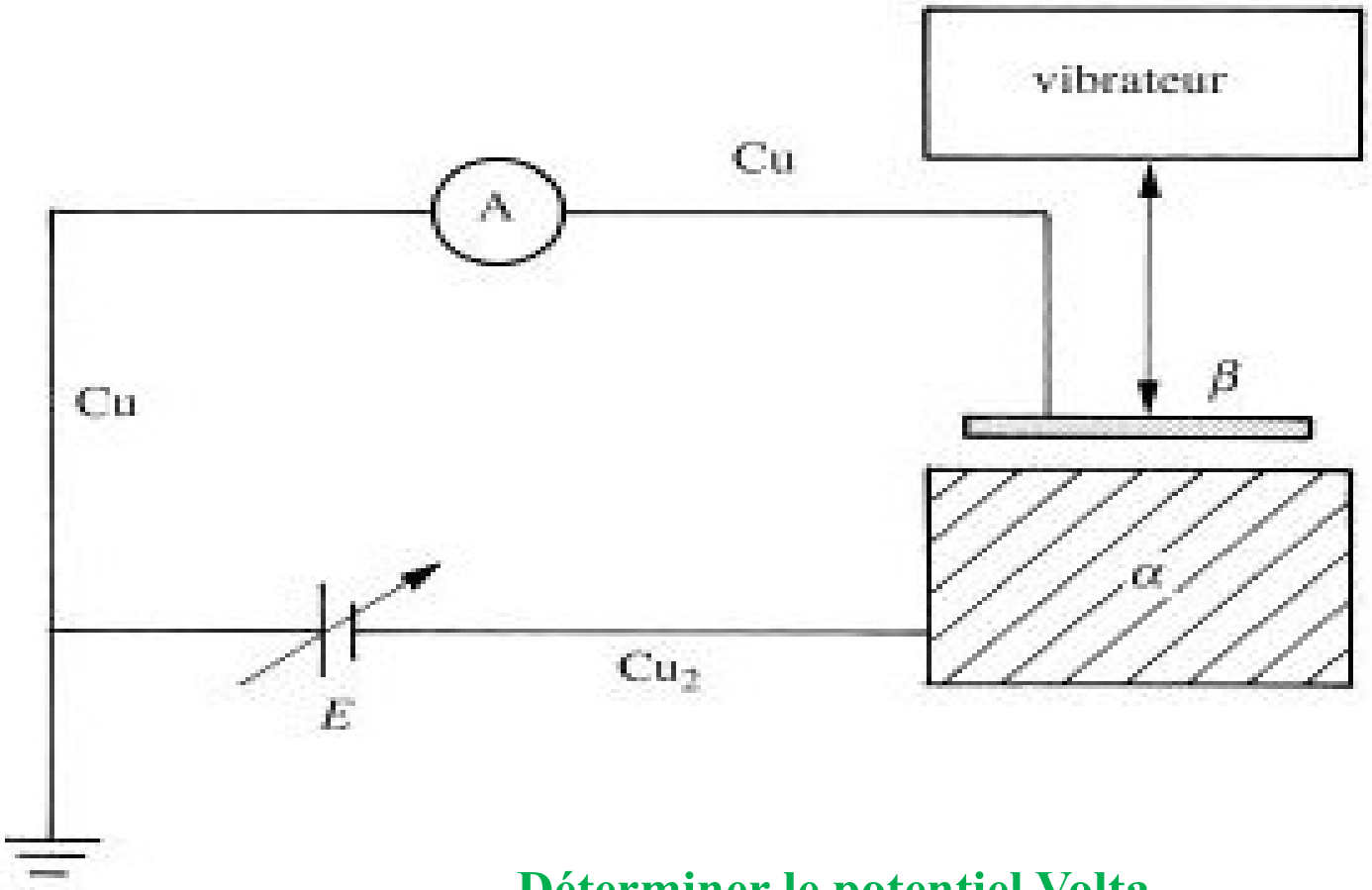
Voir: «Electrochimie physique et analytique», H. Girault



$$I = \frac{\partial C}{\partial t} \cdot (V_{bi} + V_B)$$

Il n'y a pas de tension, donc pas de charge sur la capacité, le courant disparait
En déterminant la tension externe V_B qui annule le courant, on mesure V_{bi}.

Exercice E6.3: Kelvin Probe

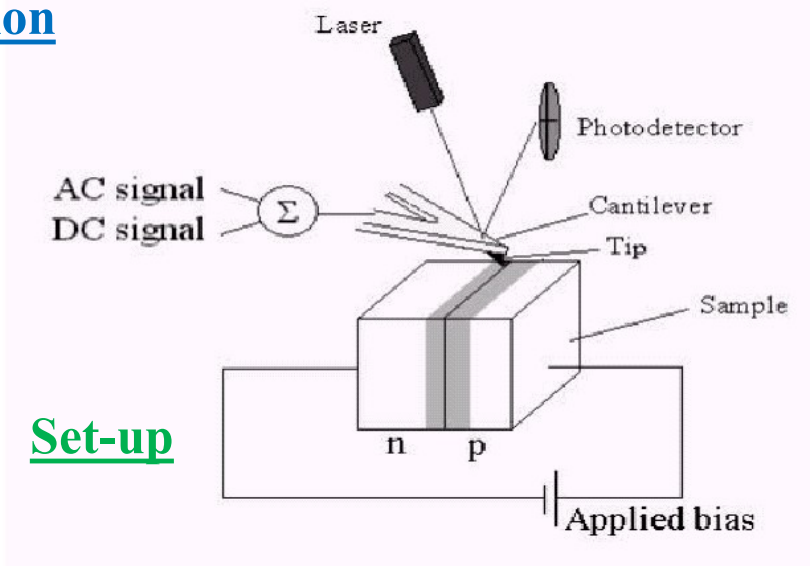


Déterminer le potentiel Volta

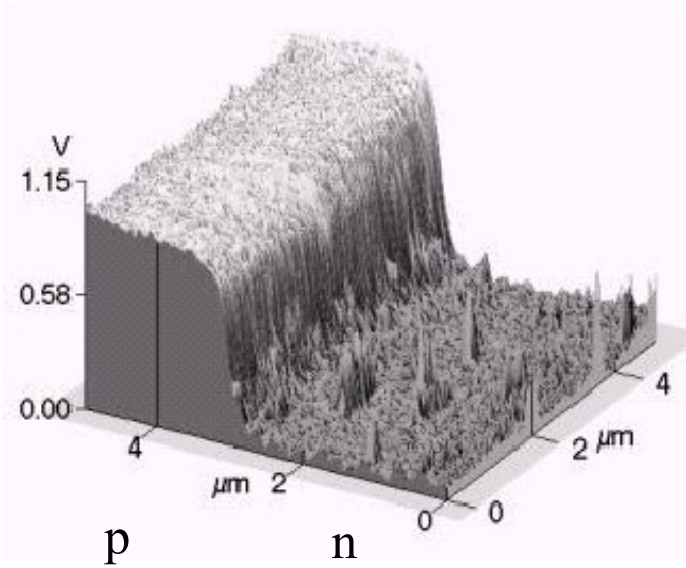
Hubert Girault, «Electrochimie physique et analytique», PPUR, p. 32-33

Kelvin Probe Force Microscopy (KPFM)

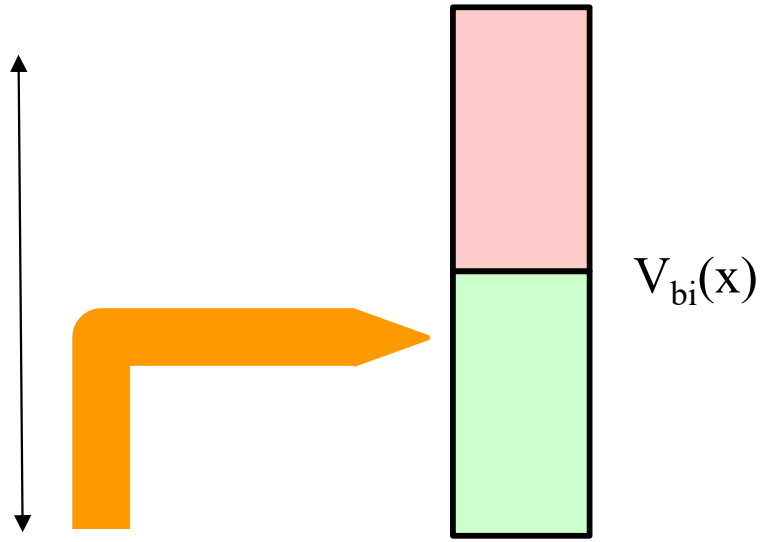
PN-junction



Set-up



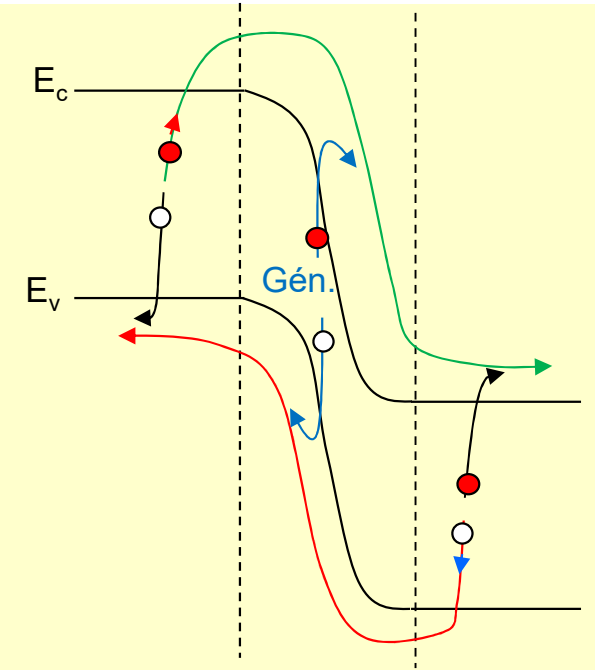
Y. Rosenwaks et al., «Nanoscale electronic measurements of semiconductors using kelvin probe force microscopy" in Scanning Probe Microscopy: Characterization, Nanofabrication and Device Application of Functional Materials, Kluwer Academic Publishers



Courants dans une diode PN Non-idéale

Diode pn: Courants de diffusion de minoritaires et courants de génération-recombinaison

Diode bloquante



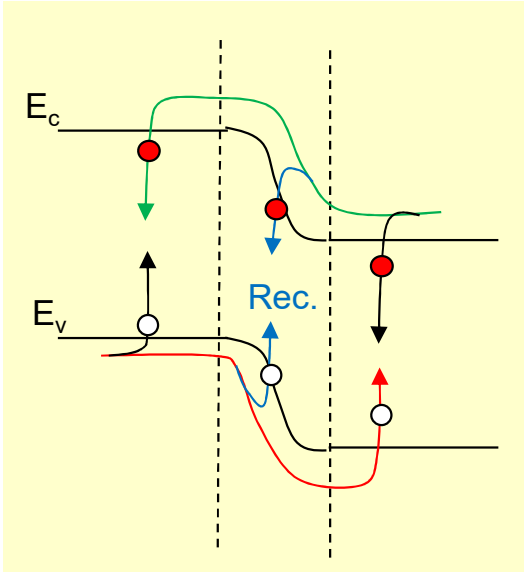
DIODE IDEALE:
Courants des zones de diffusion :
Extraction et injection de minoritaires

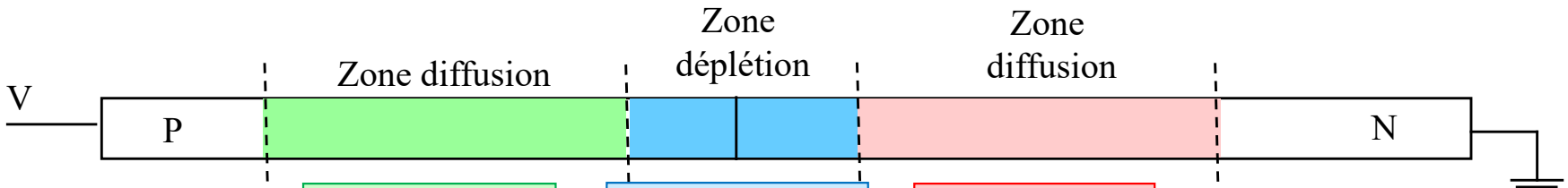
$$J_{ideal} = (J_{sn} + J_{sp}) \cdot (e^{qV/kT} - 1)$$

Génération-recombinaison
(dans la zone de déplétion)

$$J_{gr} = J_{s,gr} \cdot (e^{qV/2kT} - 1)$$

Diode passante





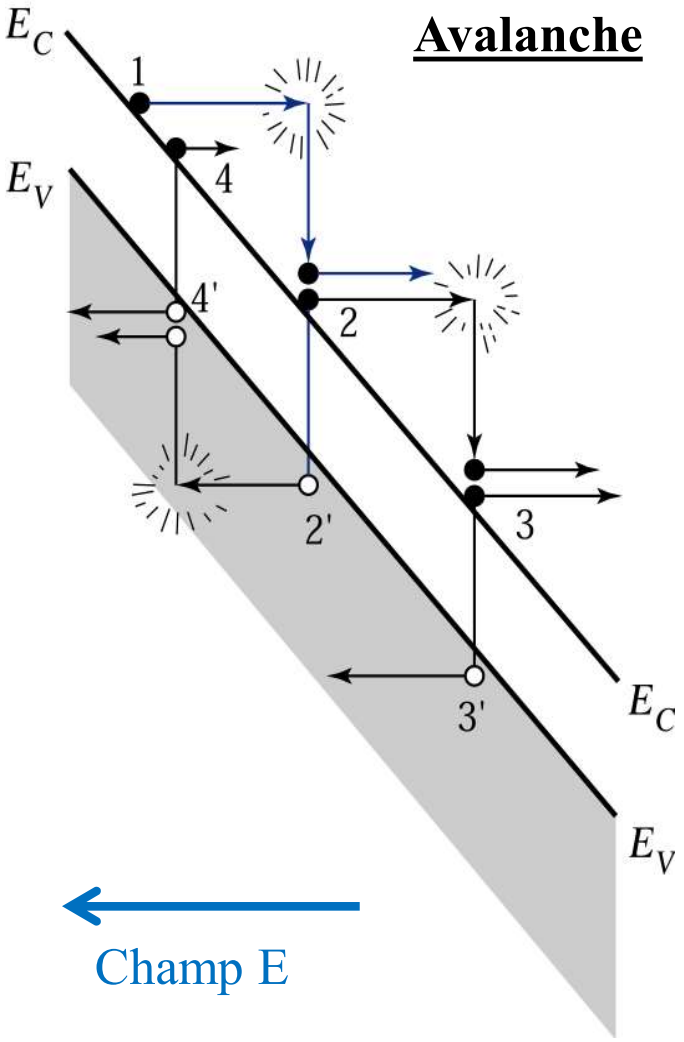
$$J_n \equiv q \cdot \int_{-\infty}^{-x_p} U_{th}(x)dx$$

$$J_{gr} \equiv q \cdot \int_{-x_p}^{x_n} U_{th}(x)dx$$

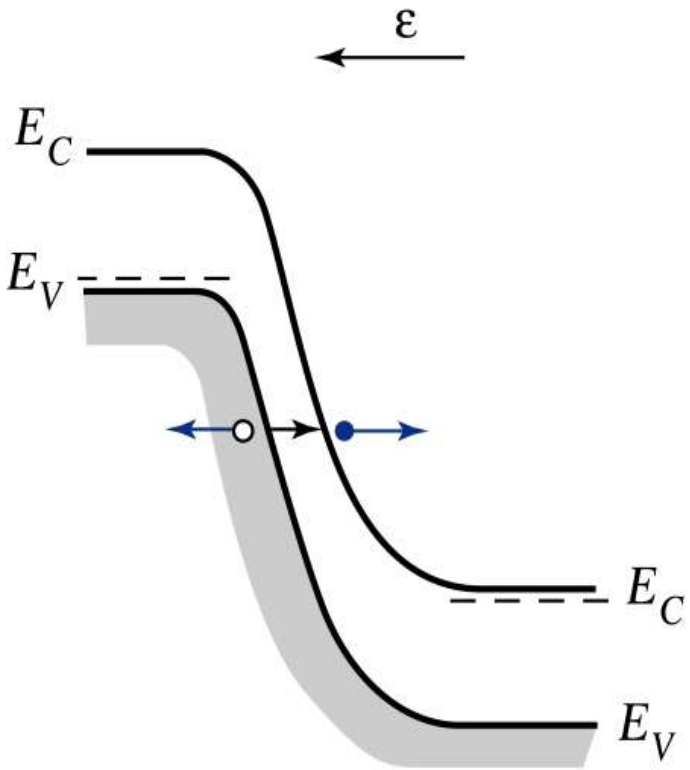
$$J_p \equiv q \cdot \int_{x_n}^{\infty} U_{th}(x)dx$$

Breakdown

Avalanche



S. Sze « *Semiconductor devices* »

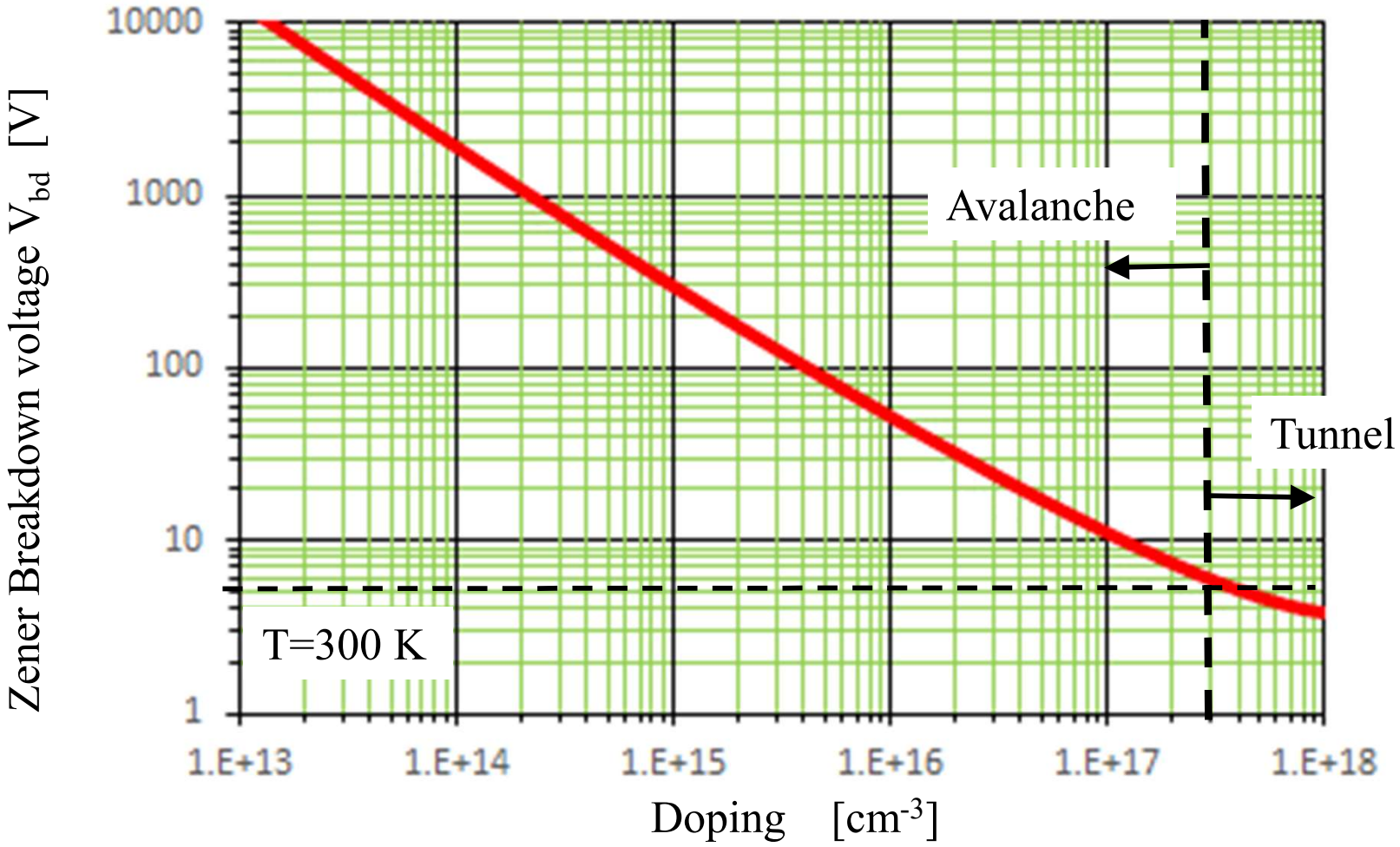


Effet « Band-to-band tunneling »
(Zener effect)

Breakdown: diode Zener

Insipré de:
http://ecee.colorado.edu/~bart/book/breakdown.htm

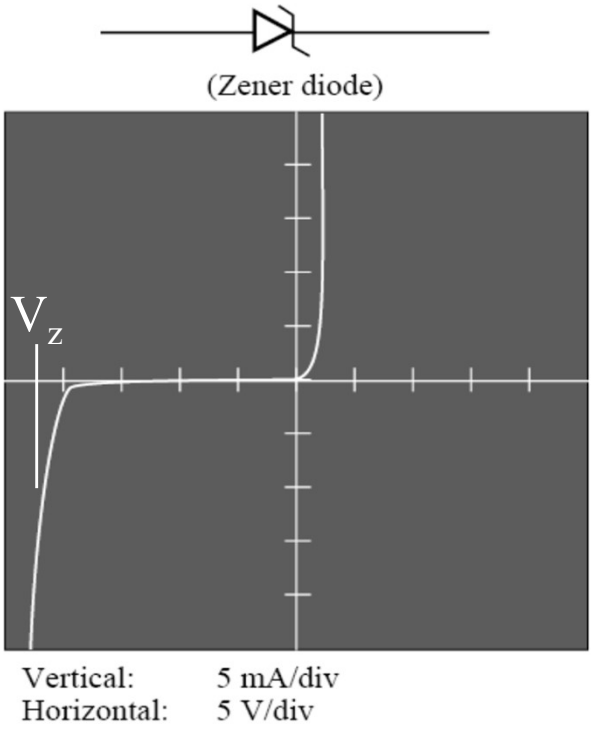
One-sided abrupt silicon PN diode



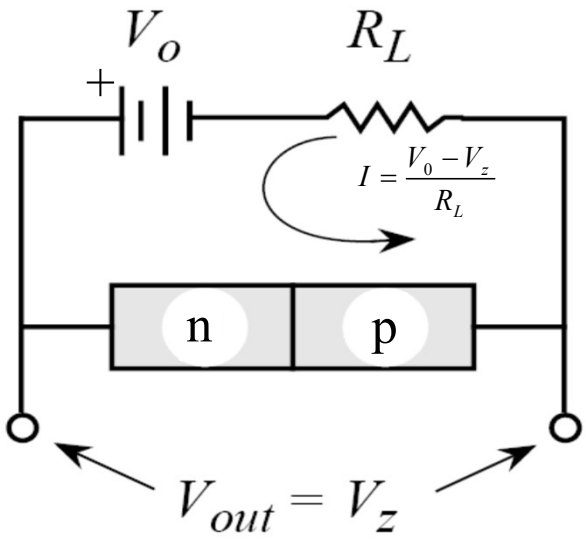
L'effet tunnel demande des dopages très élevés

Diodes Zener

Diode Zener: basse tension de claquage par effet tunnel ou avalanche
(typique: V_{bd} entre -3 et -50 V)

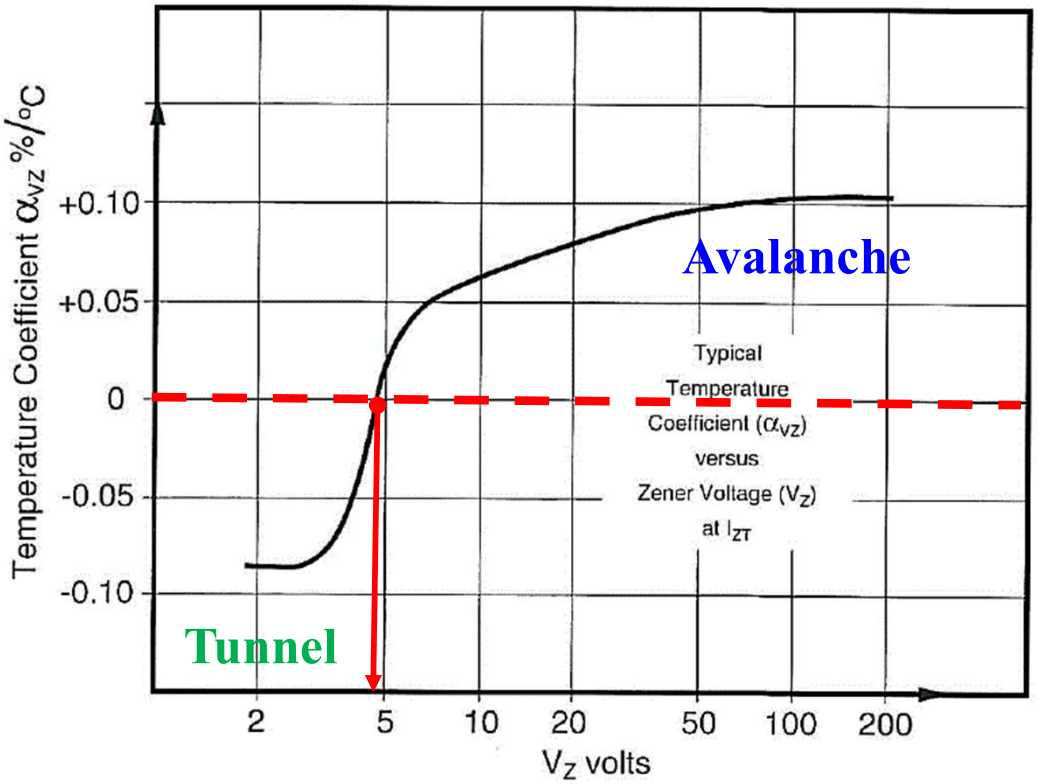


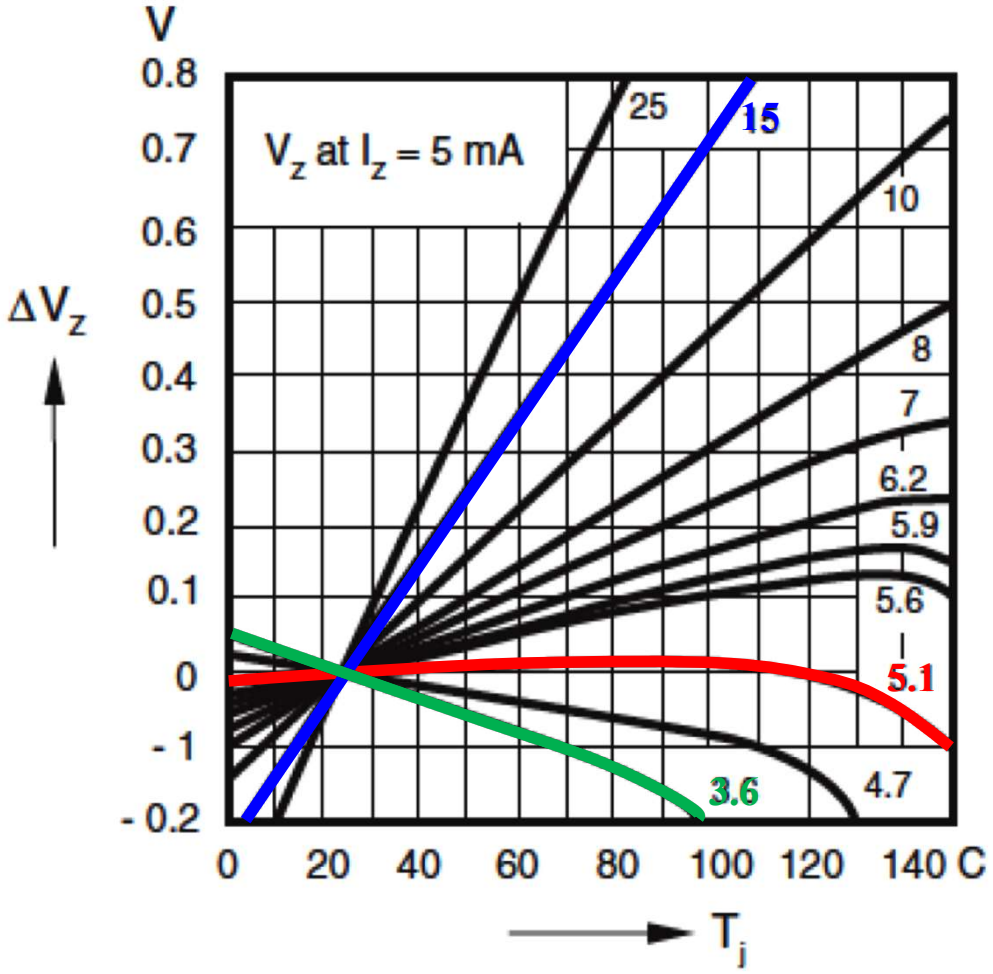
Régulateur de tension



Inspiré de J. Singh, « semiconductor devices: basic principles »

Breakdown et température





$$\Delta V_Z = \alpha_{VZ} \cdot V_Z \cdot \Delta T$$

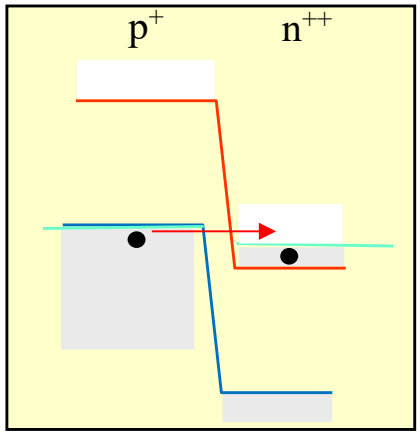
K. Walters, M. Clark, «Zener voltage regulation with temperature» Micro-notes N'.203

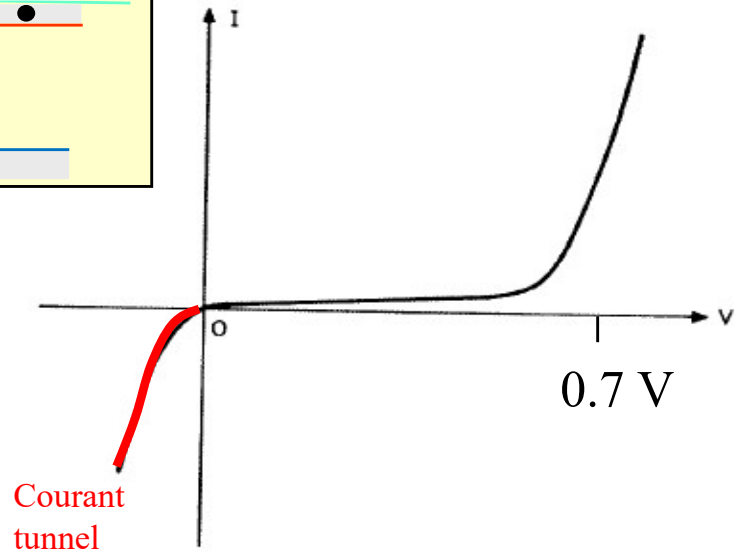
http://www.farnell.com/datasheets/2311149.pdf

Diode backward et tunnel: caractéristique I(V)

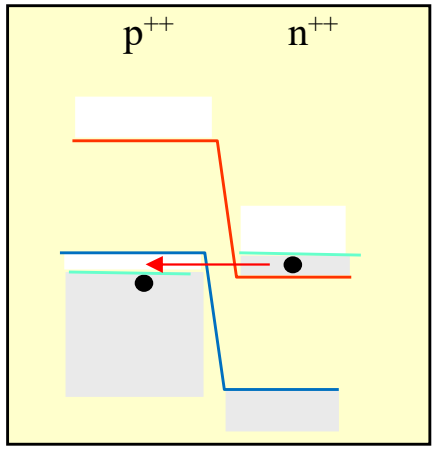
L. Esaki, prix Nobel de physique 1973

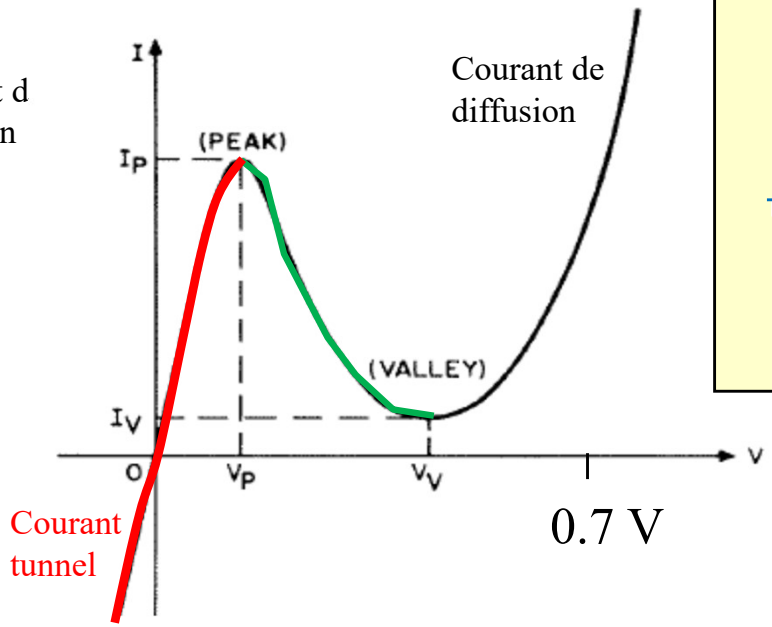
Diode backward





Diode tunnel





Tension de breakdown plus faible que tension passante.

S. Sze, « physics of semiconductor devices »

Courbe I(V) et dopage