

# COMPOSANTS SEMI-CONDUCTEURS

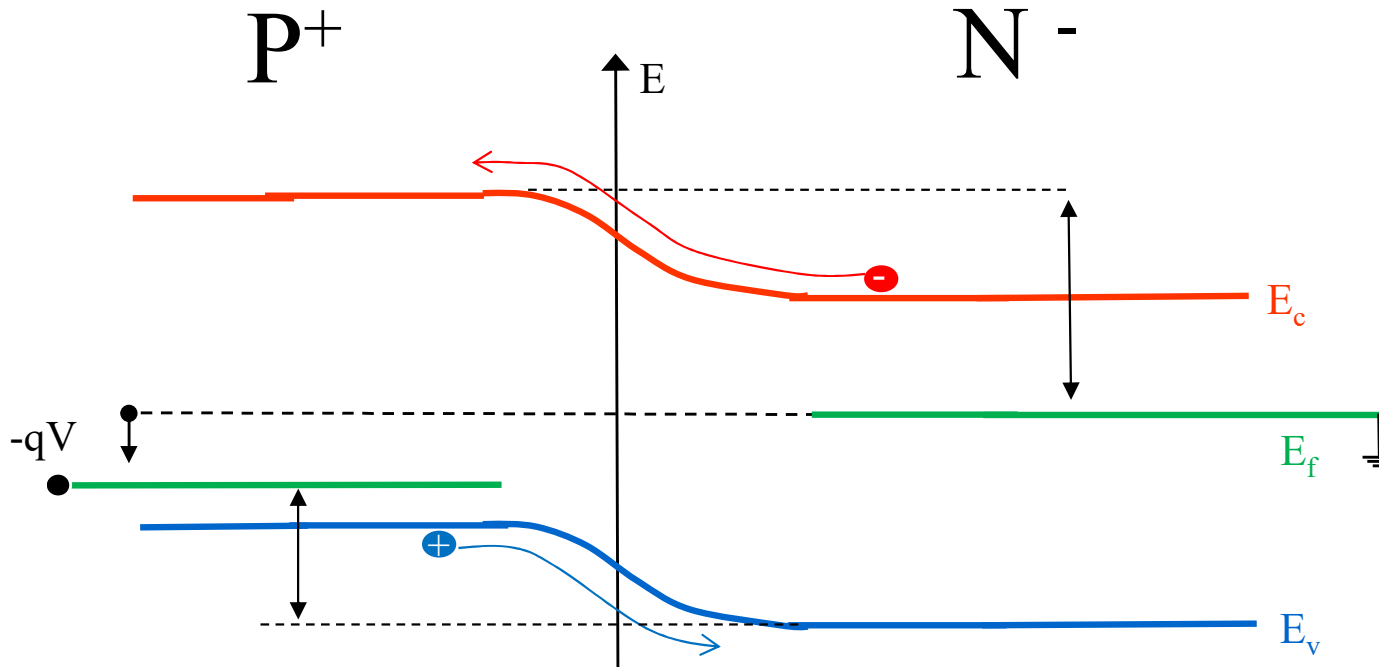
## VI) Solutions S6

P.A. Besse

EPFL

# Exercice 6.1

# Exercice E6.1: diode p<sup>+</sup>/n<sup>-</sup>, passante



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

## Augmentation du dopage P


Courant de trous

Courant d'électrons

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

Courant P

Minoritaires  
côté N

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


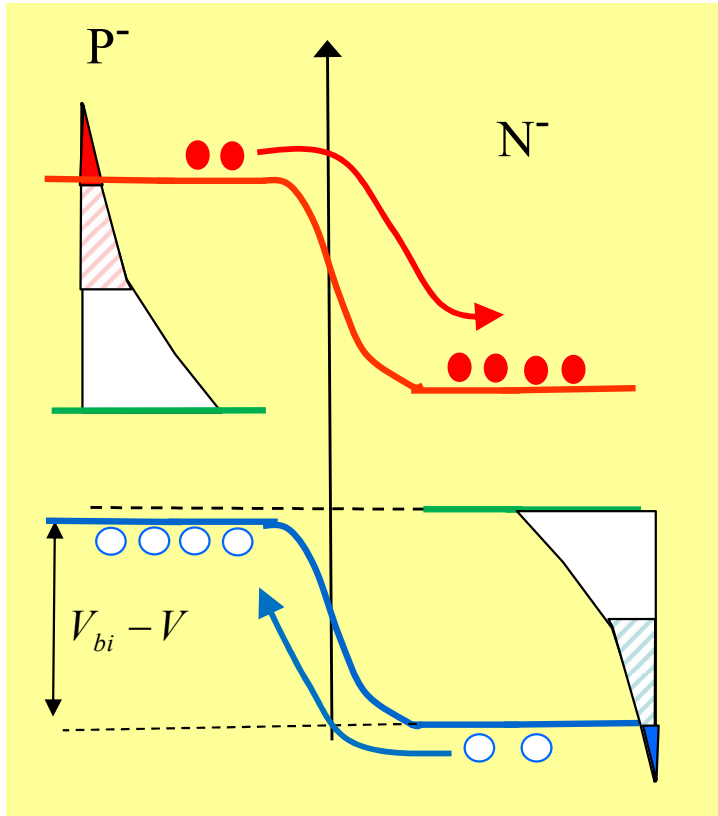
Courant N

Minoritaires  
côté P

**Constant**

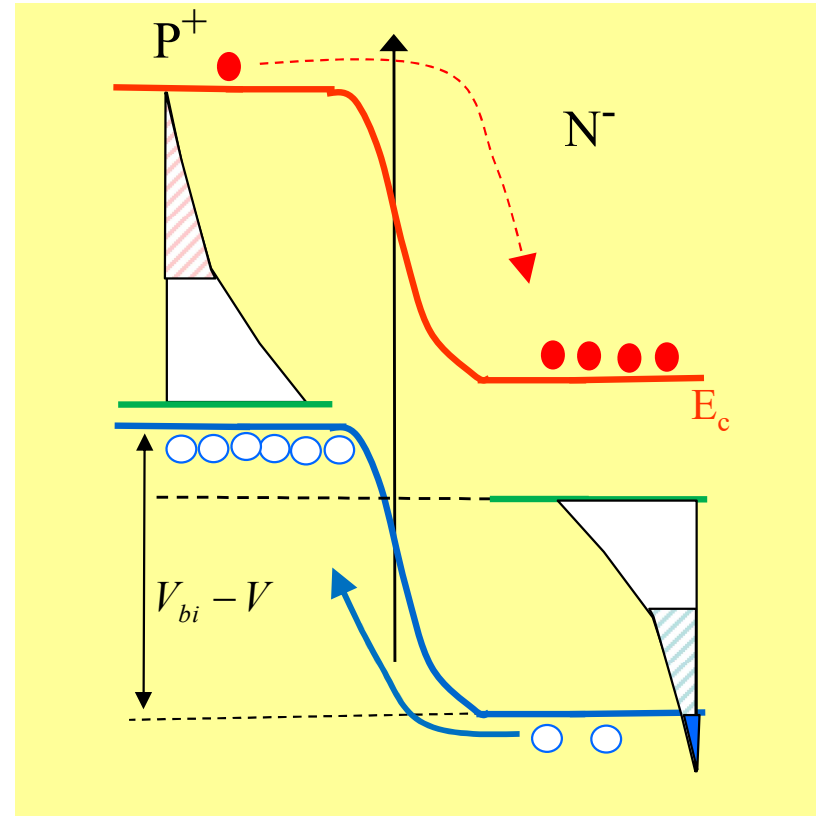
**Diminue**

# 6.1: Diode p<sup>+</sup>/n<sup>-</sup> «idéale»: mode reverse



$$J_{s,p} \equiv \frac{qD_p}{L_p} \cdot p_{no}$$

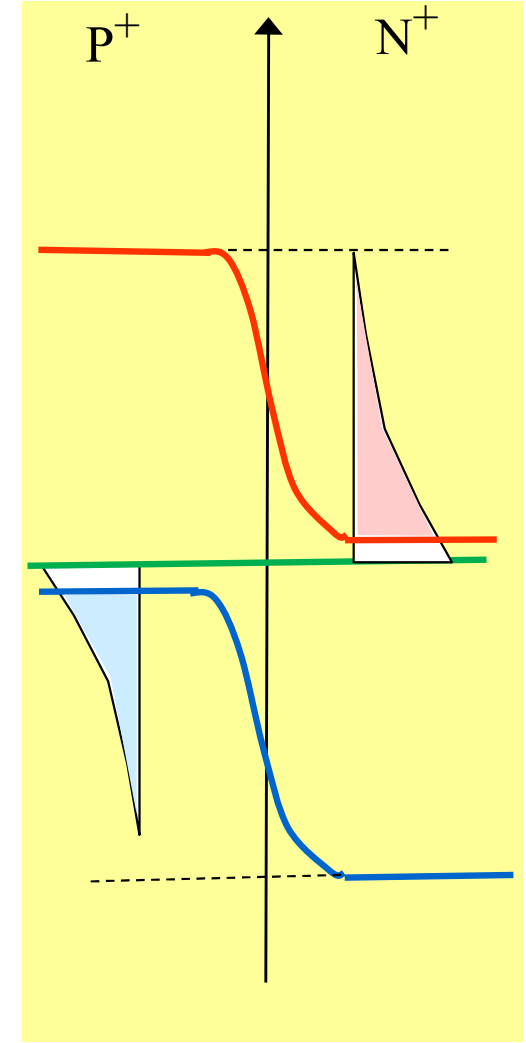
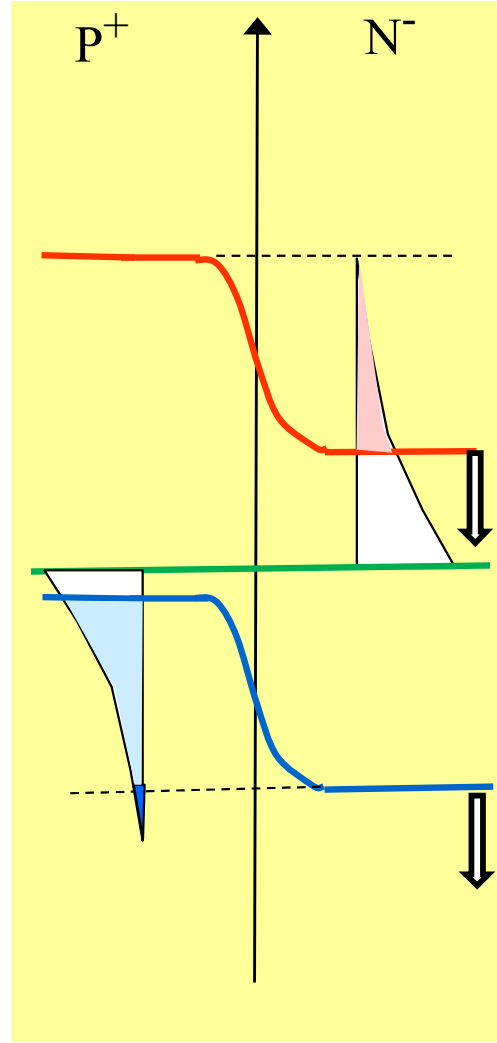
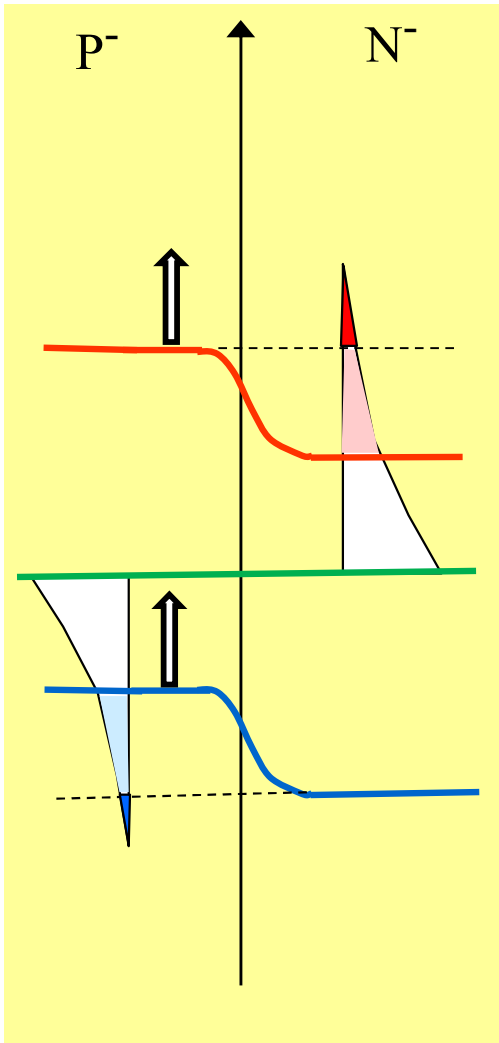
Constant



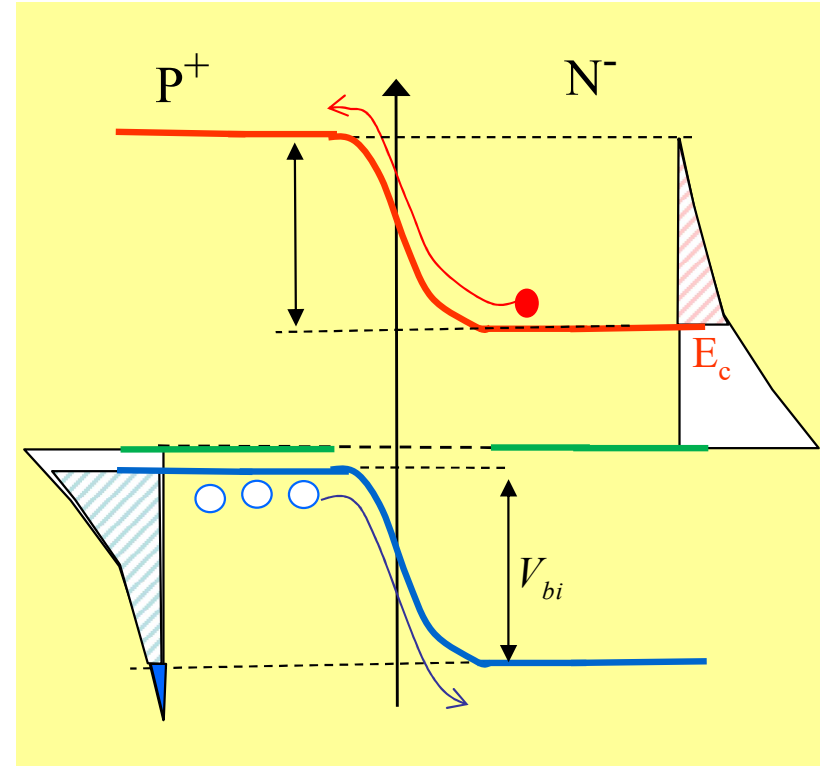
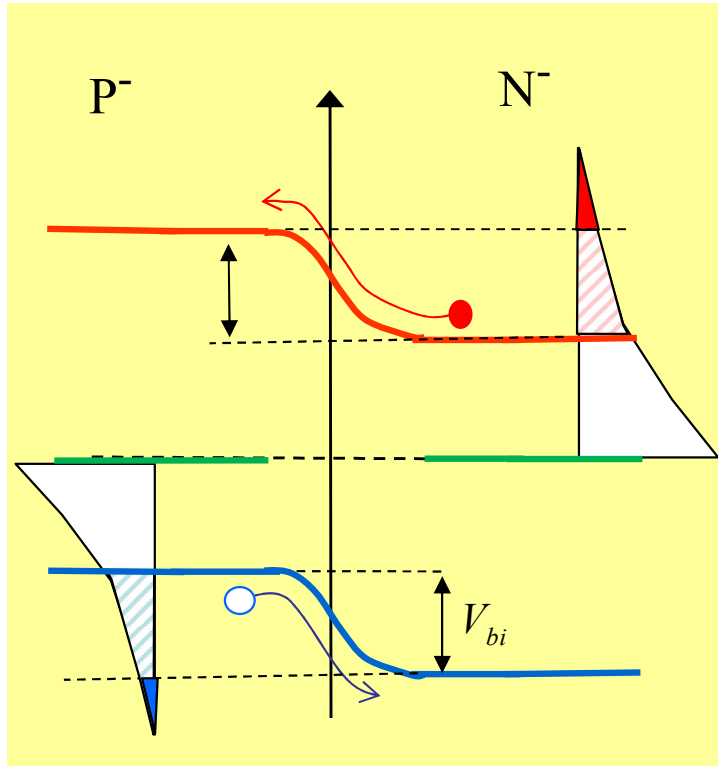
$$J_{s,n} \equiv \frac{qD_n}{L_n} \cdot n_{p0}$$

Diminue

# 6.1: Diode $p^+/n^-$ «idéale» mode passant



# 6.1: Diode p<sup>+</sup>/n<sup>-</sup> «idéale» mode passant



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

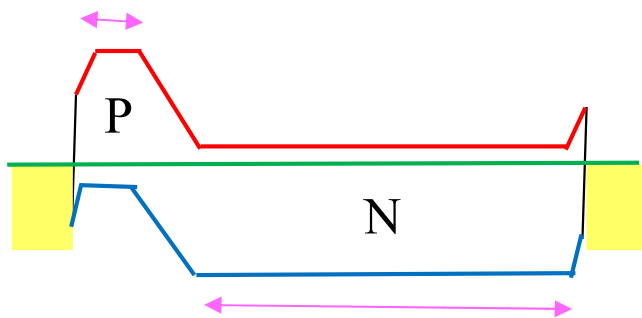
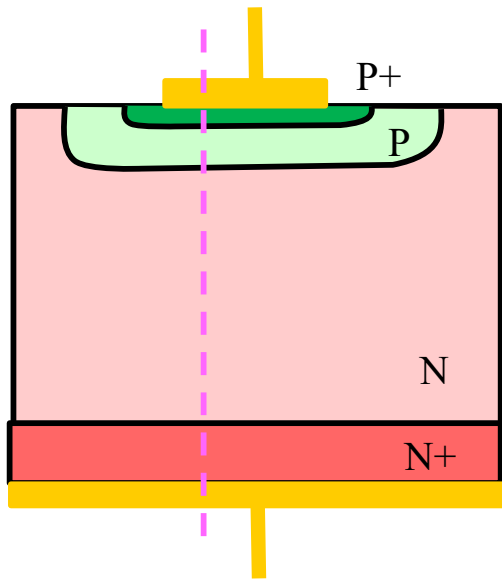
Constant

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

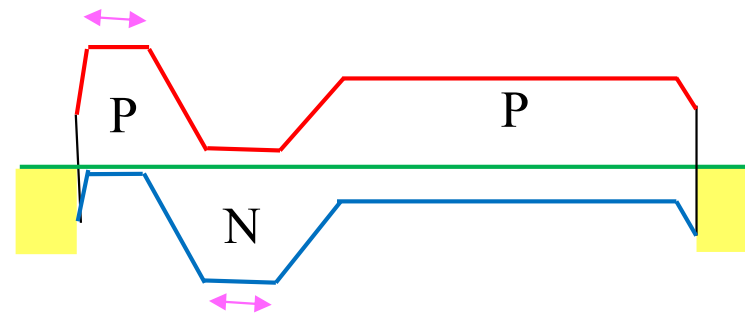
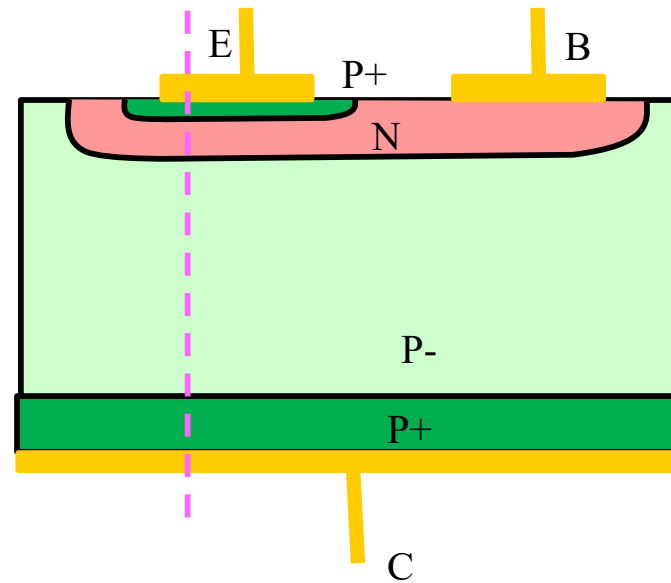
Diminue

# Exercice 6.2

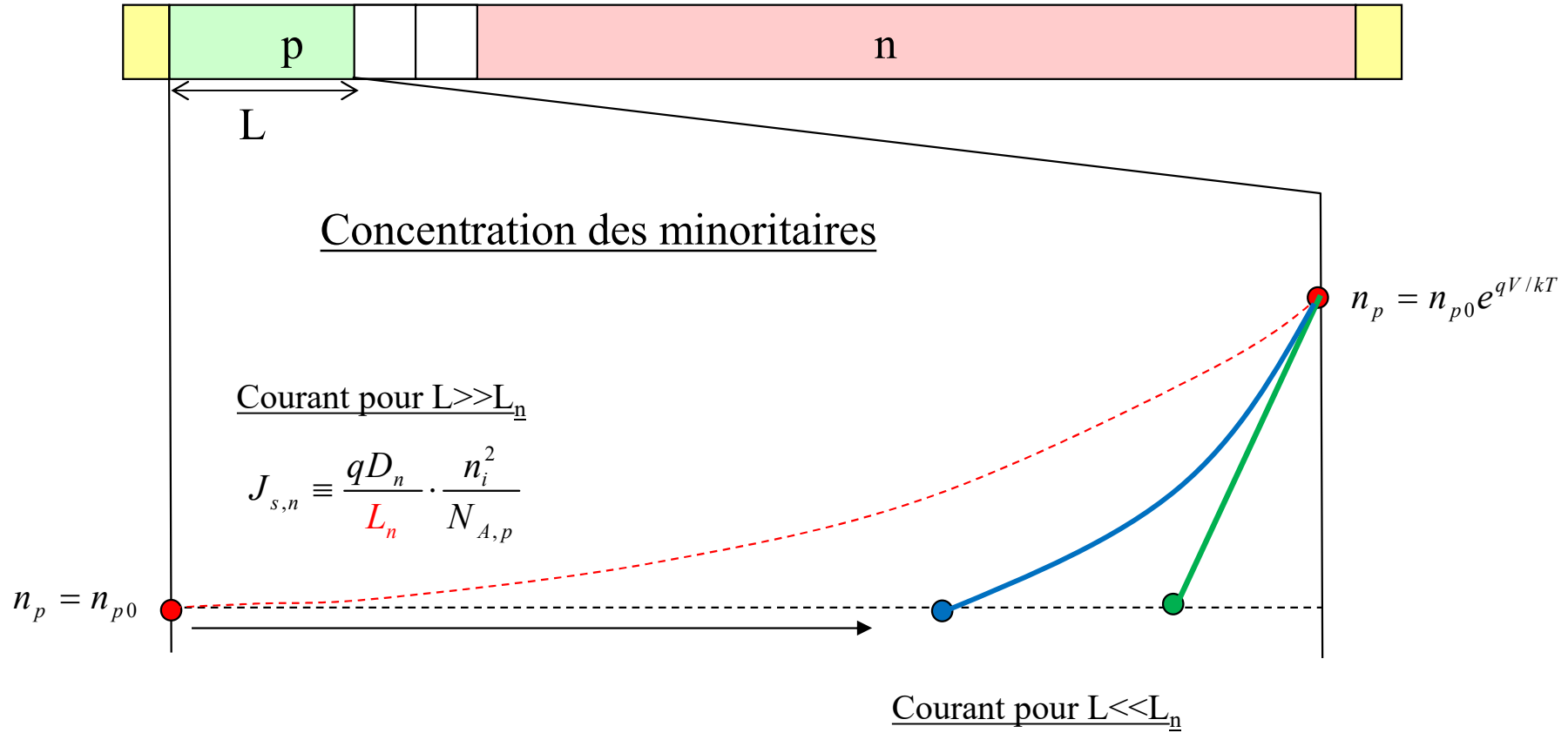
PN diode



PNP- bipolar transistor



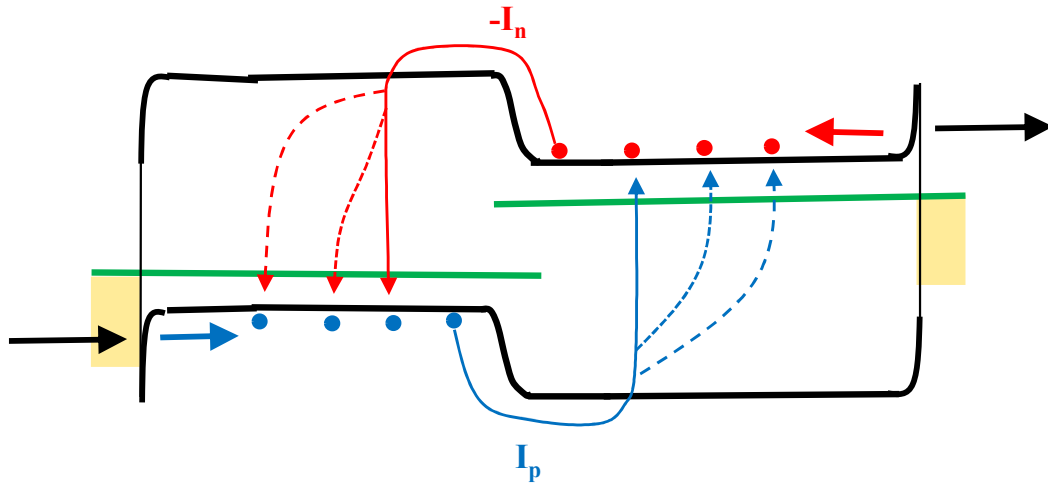
# 6.2: Jonctions courtes



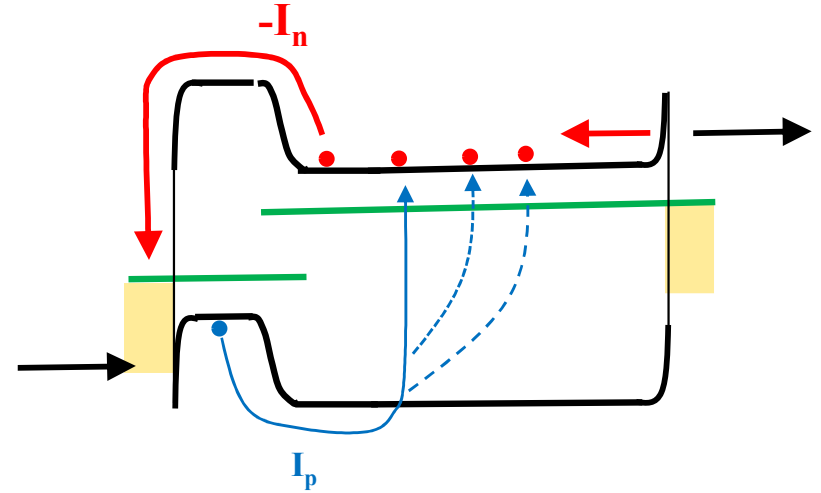
$$J_{s,n} \equiv \frac{qD_n}{L} \cdot \frac{n_i^2}{N_{A,p}}$$

# Comparaison avec des diodes passantes

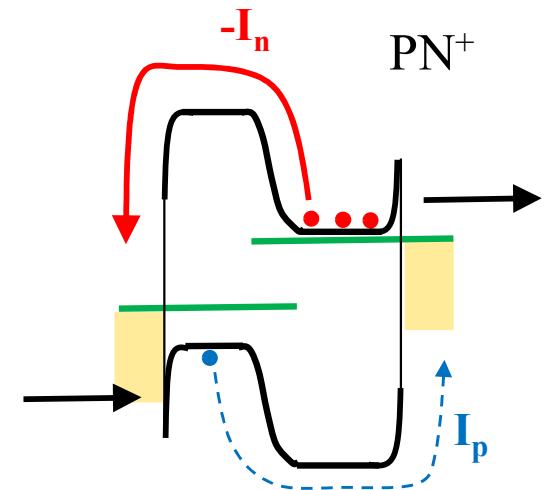
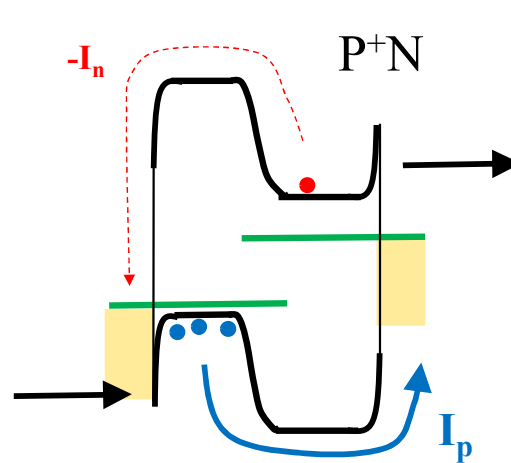
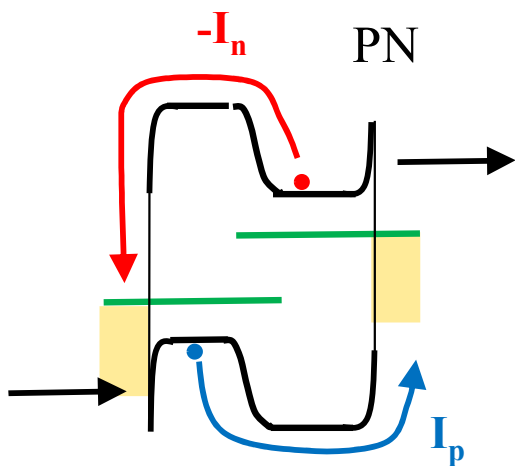
Diode PN longue



Diode PN courte sur un côté

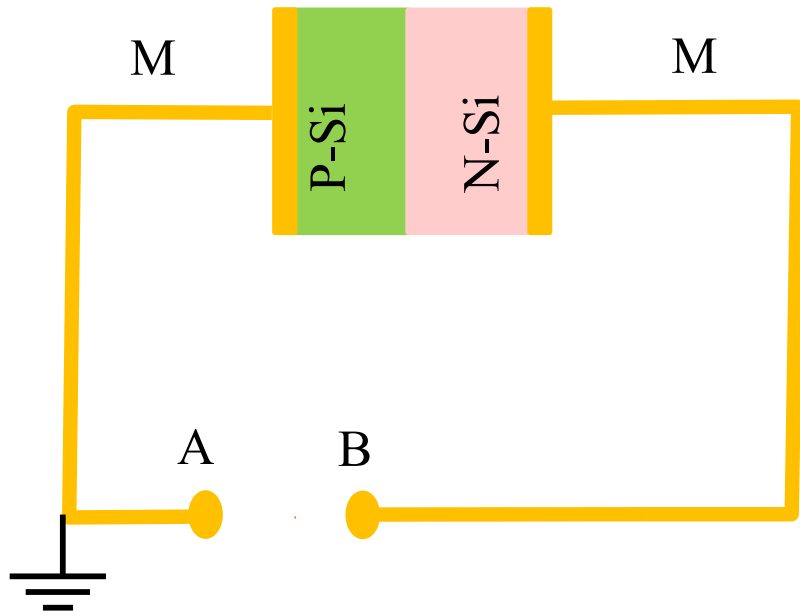


Diode PN courte sur deux côtés

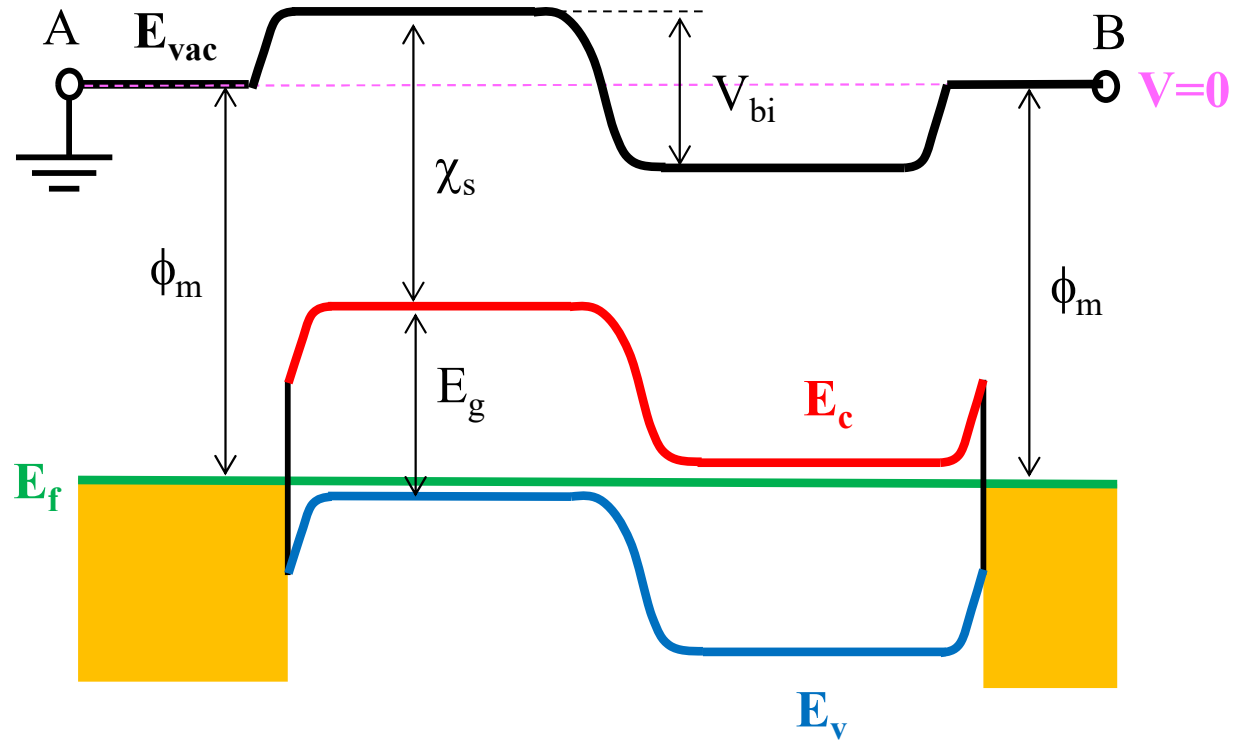


# Exercice 6.3

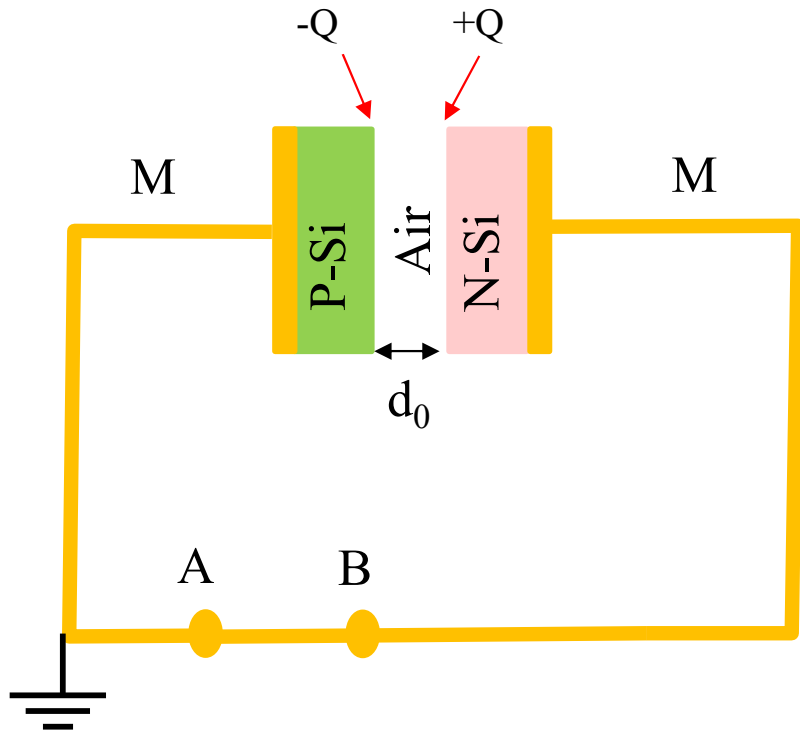
# Exercice E6.3: Tension de built-in (1)



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

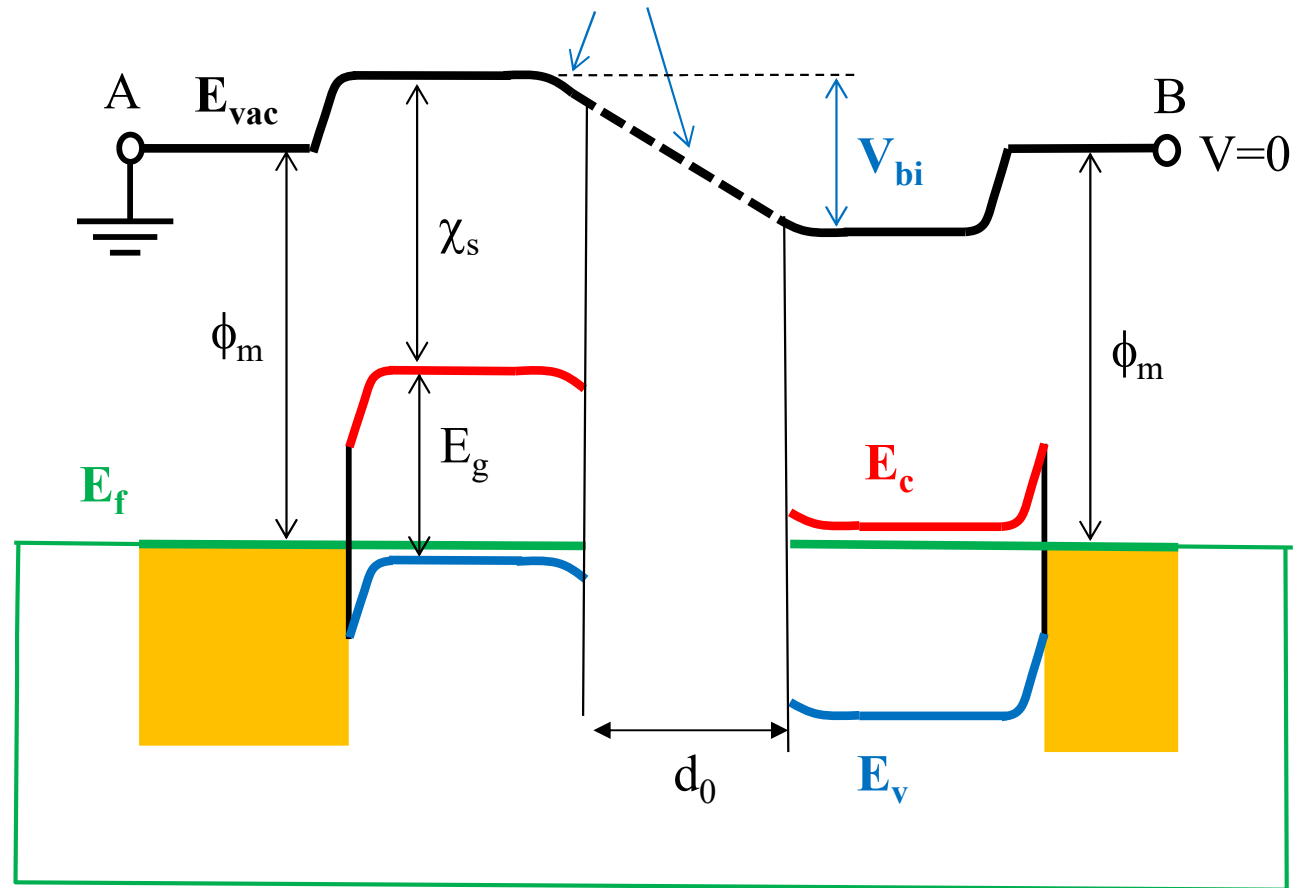


# Exercice E6.3: Tension de built-in (2)

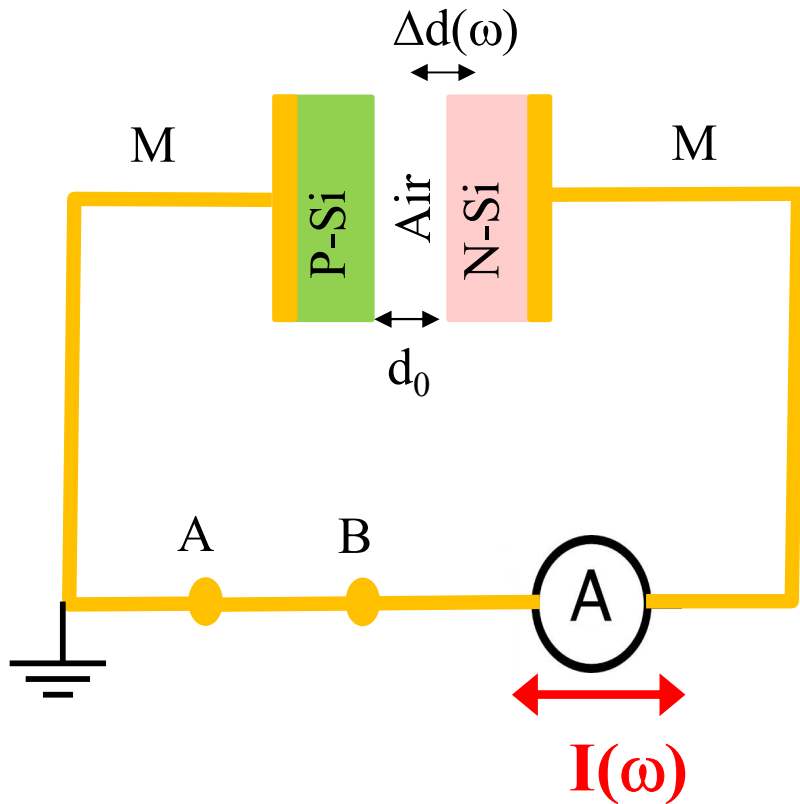


Si  $d_0$  augmente:

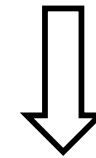
- $V_{bi}$  reste constant
- La courbure (donc les charges) diminuent
- Le champ électrique diminue



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



- La tension est constante sur la capa ( $= V_{bi}$ )
- Les charges varient avec la distance  $\Delta d(\omega)$



Il faut apporter et extraire périodiquement ces charges

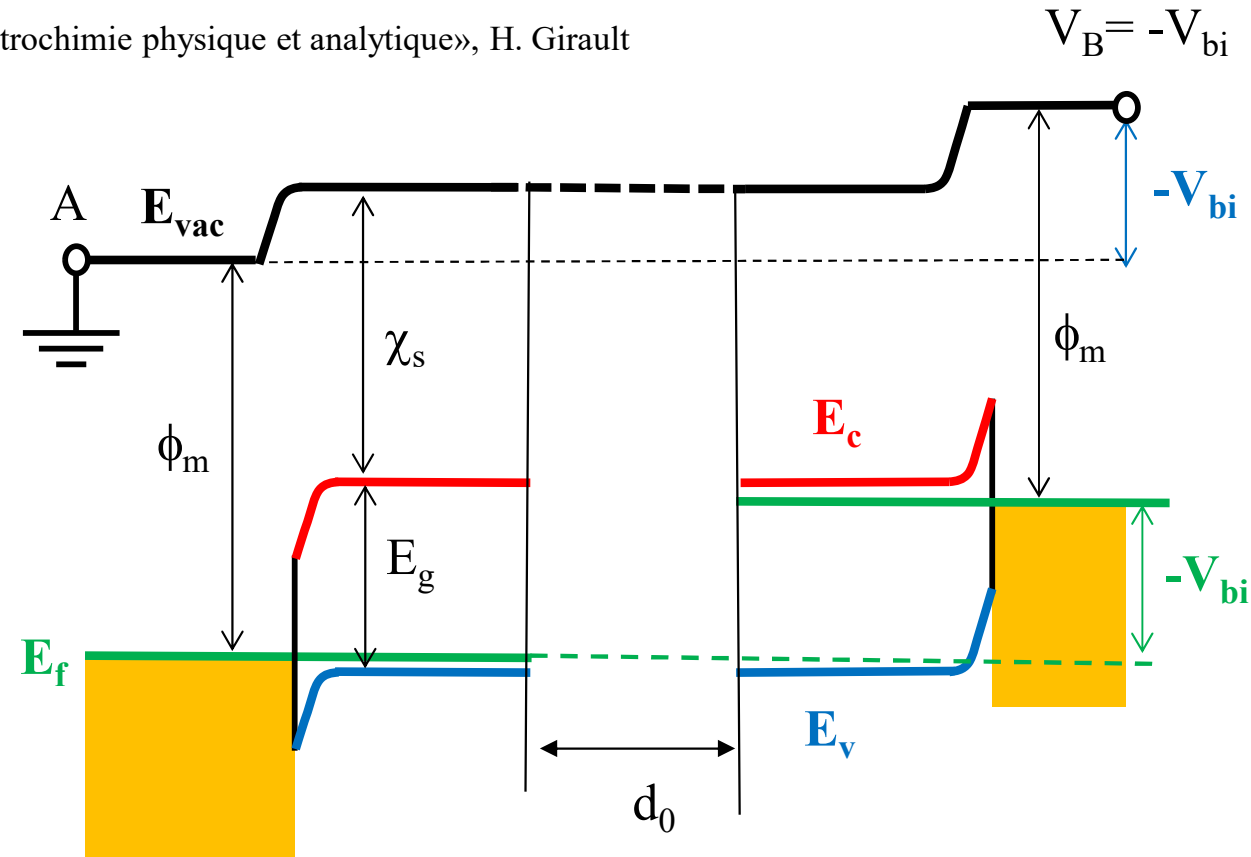
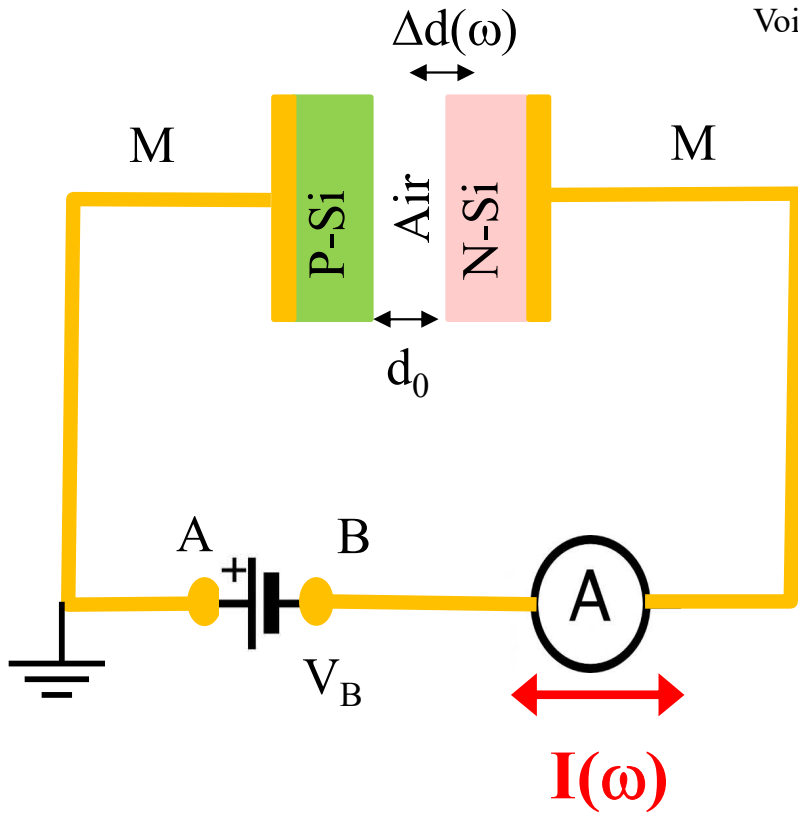
→ Cela génère un courant dans l'ampèremètre

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

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

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

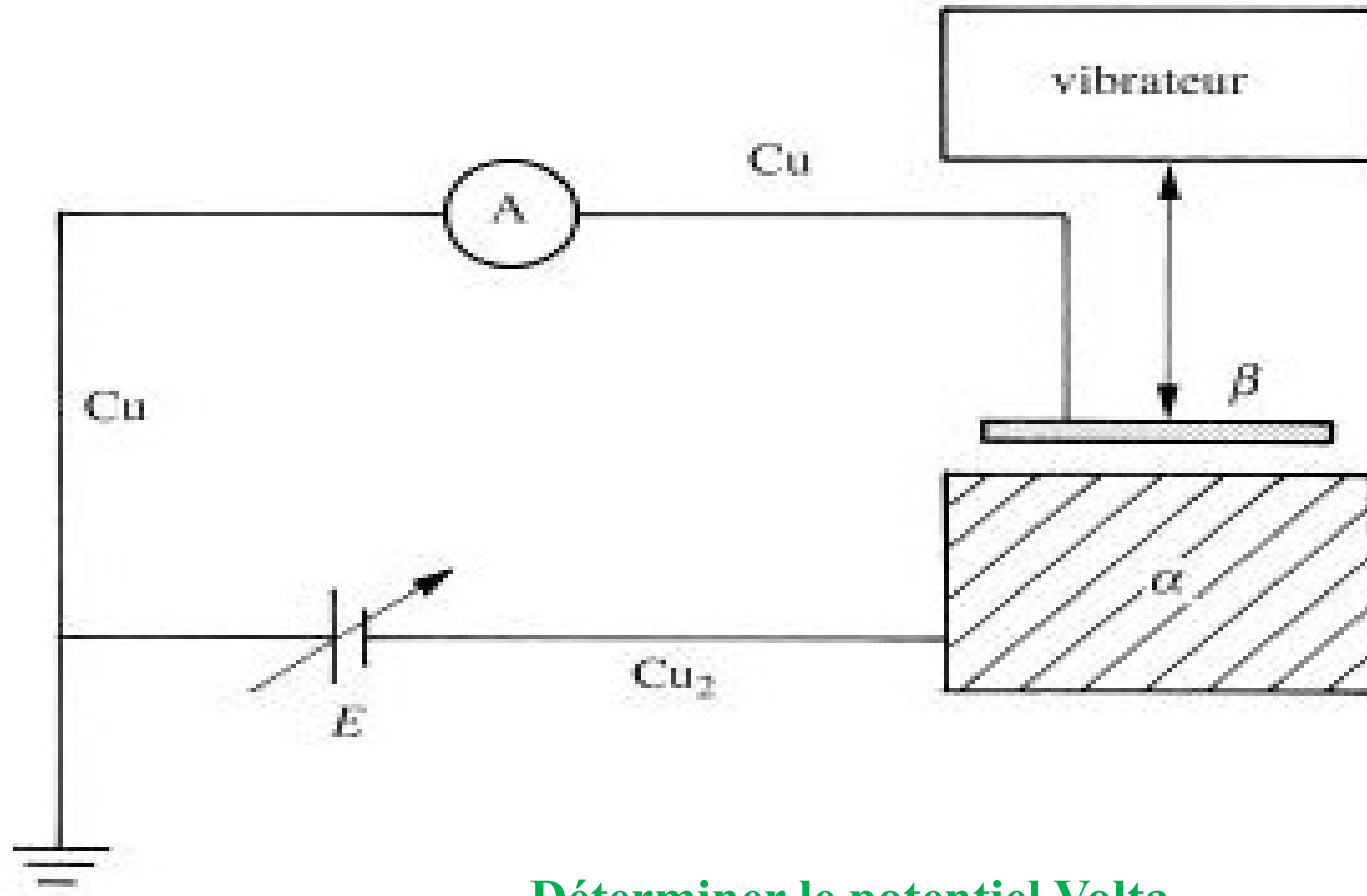
Voir: «Electrochimie physique et analytique», H. Girault



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

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

# Exercice E6.3: Kelvin Probe

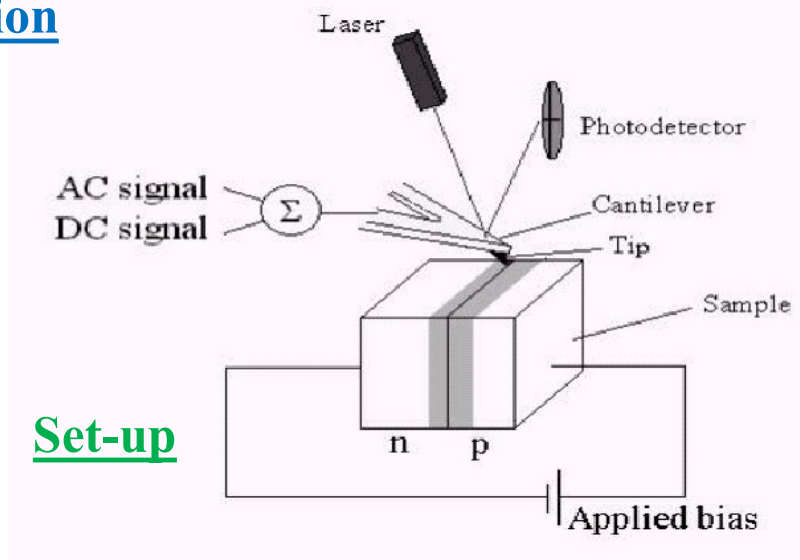


**Déterminer le potentiel Volta**

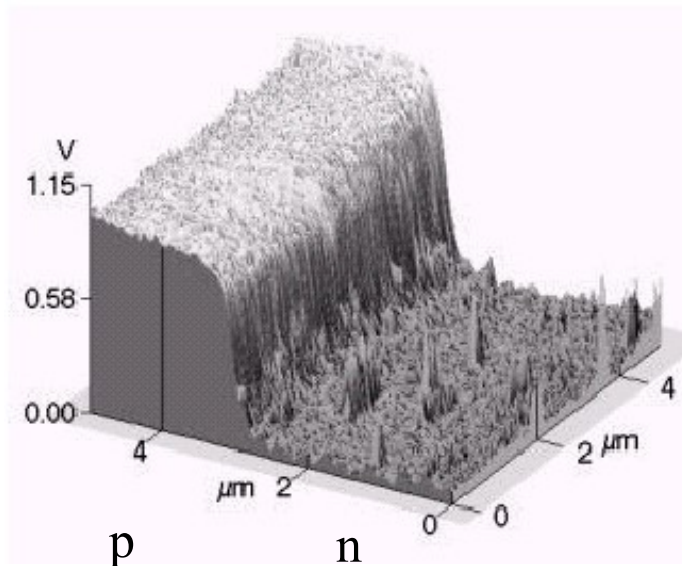
Hubert Girault, «**Electrochimie** physique et analytique», PPUR, p. 32-33

# 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

