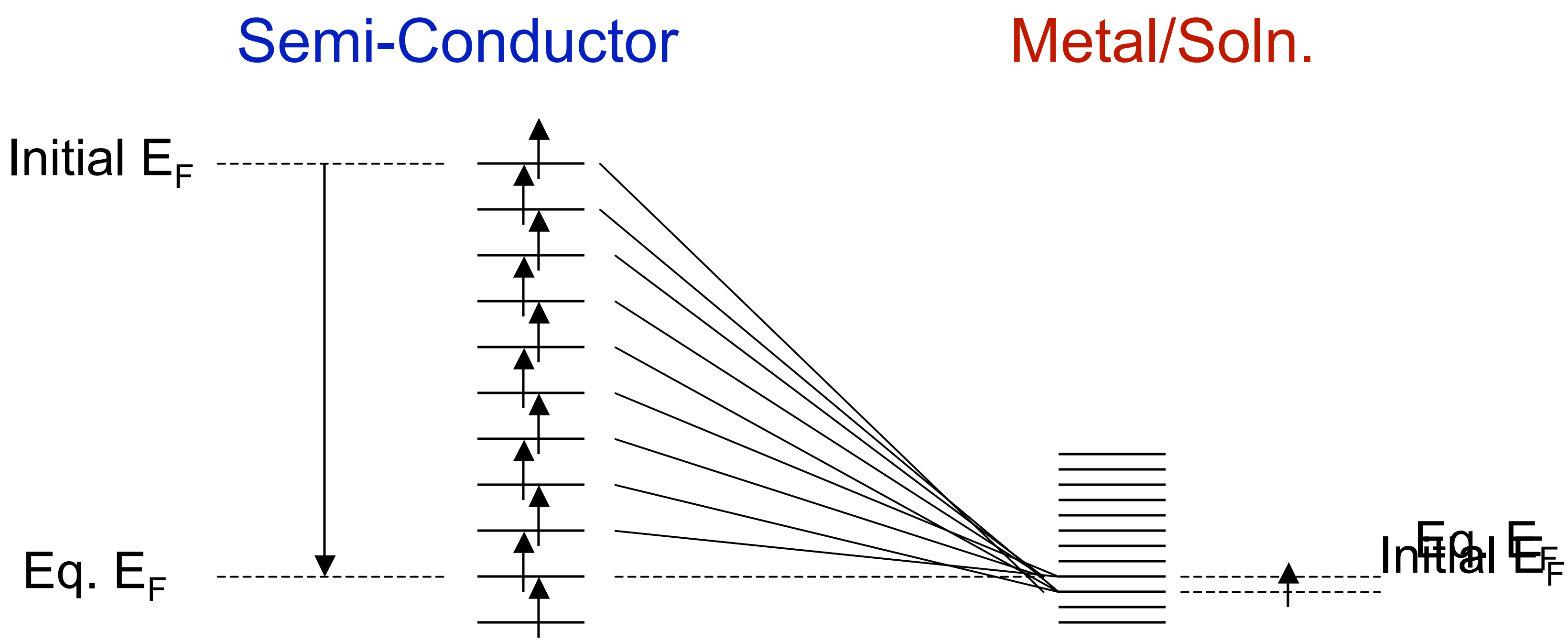
Chemistry 140a

Lecture #5

Jan, 29 2002

Fermi-Level Equilibration

- When placing two surfaces in contact, they will equilibrate; just like the water level in a canal lock.
- The E_F of the semi-conductor will always lower to the E_F of the metal or the solution. This can be understood by looking at the density of states for each material/soln.

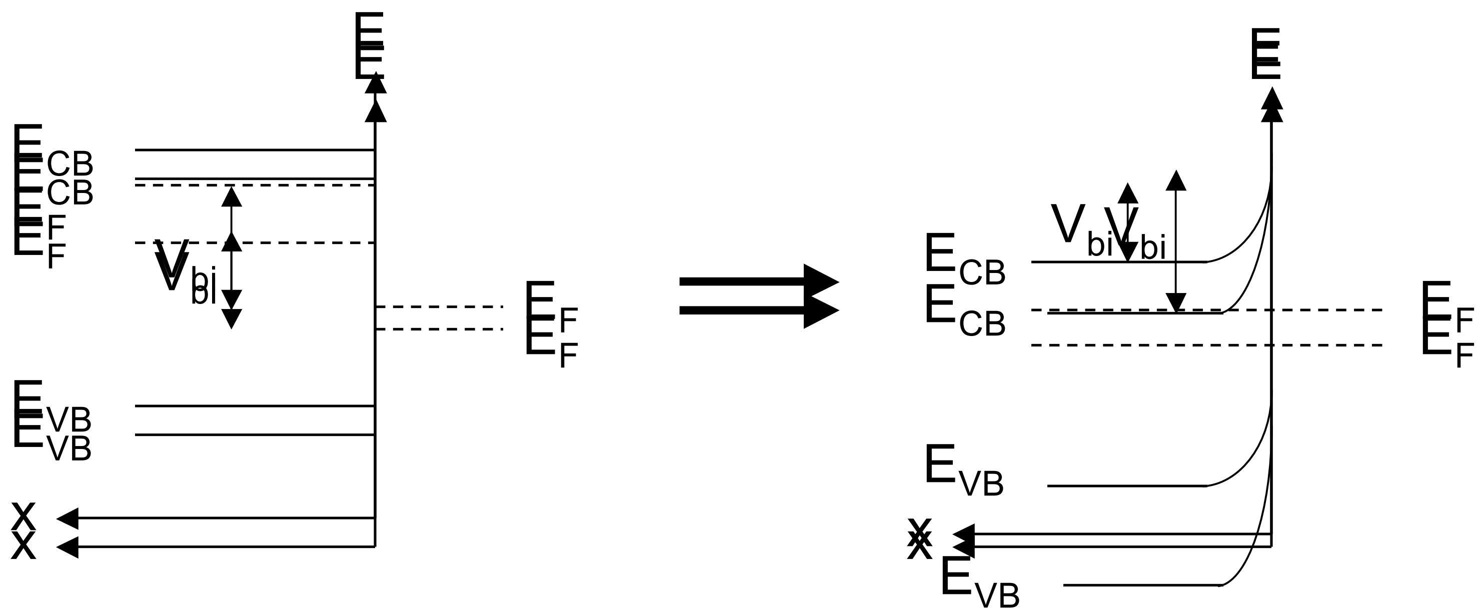


Fermi-Level Equilibration

- Charge comes from the easiest thing to ionize, the dopant atoms. This leads to a large region of (+) charges within the semi-conductor.

- In the metal all of the charge goes to the surface. (Gauss's Law)

- The more charge transferred the more band bending.

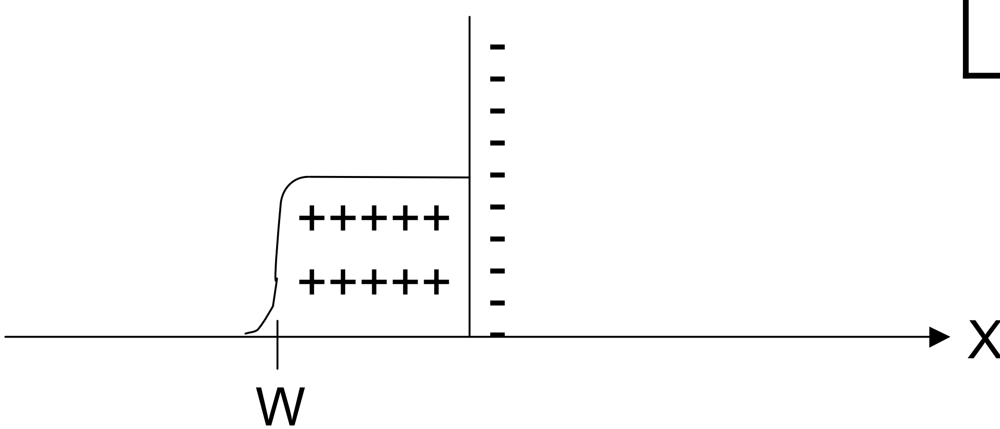


Depletion Approximation

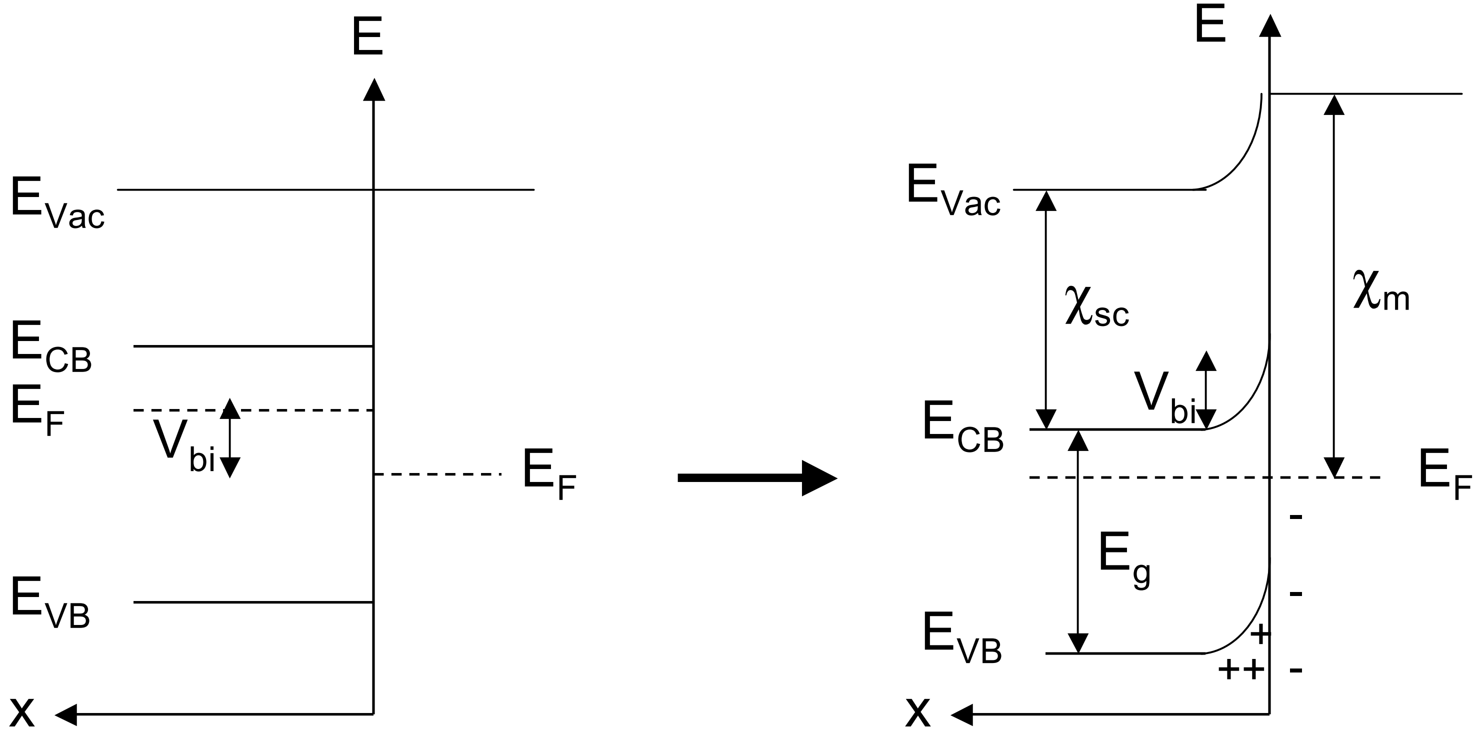
- All donors are fully ionized to a certain distance, W, from the interface.

- $W = W(N_D, V_{bi})$

N_D	↗	W	↘
V_{bi}	↗	W	↗



Final Picture



Useful Equations

$\mathfrak{E}(x)$ = Electric Field (V/cm) $\psi(x)$ = Electric Potential (V)

$E(x)$ = Electric Potential Energy (J)

$$\mathfrak{E}(x) = -\frac{d\psi(x)}{dx} \qquad E(x) = -q\psi(x)$$

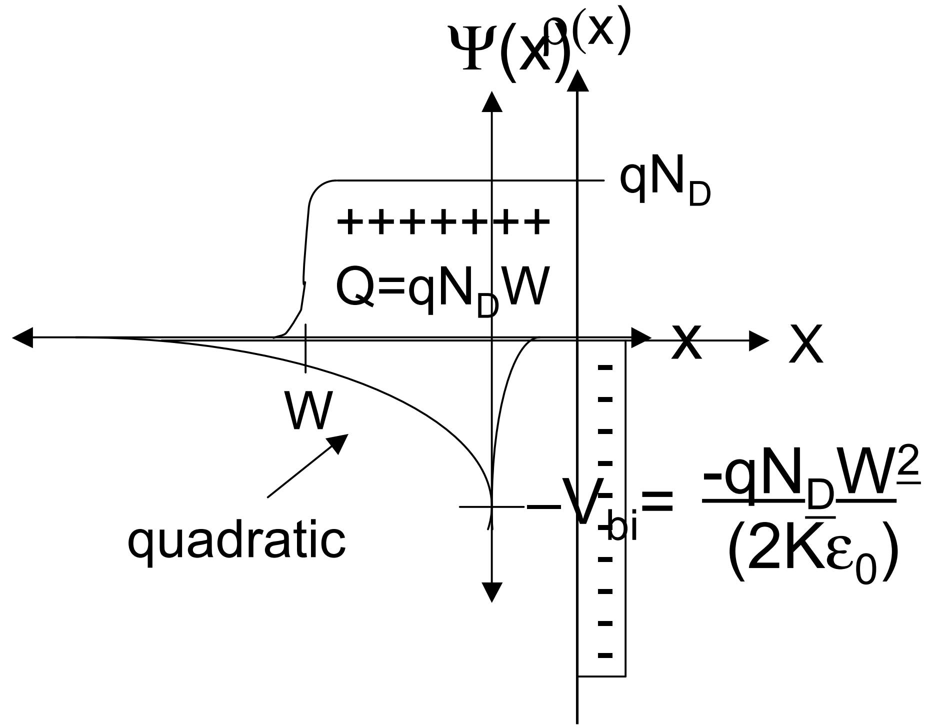
$$\rho(x) = q\left[p(x) - n(x) - N_A(x) + N_D(x)\right]$$

Poisson's Eqn: $$-\frac{d^2\psi(x)}{dx^2} = \frac{\rho(x)}{K\varepsilon_0}$$

Electric Potential (V)

Integrate Poisson's Eqn.

$$-\frac{d^2\psi(x)}{dx^2} = \frac{\rho(x)}{K\varepsilon_0}$$



B.C.'s

$$\frac{d\psi(x)}{dx} = 0 \qquad x \geq W$$

$$\psi(x) = 0 \qquad x = W$$

Result: $$\psi(x) = \frac{-qN_D}{2K\varepsilon_0}\left(x - W\right)^2$$

Depletion Width

- Rearranging for W: $$W = \sqrt{\frac{2K\varepsilon_0 V_{bi}}{qN_D}}$$
- As expected, W increases w/ V_{bi} and decreases w/ N_D
- If one accounts for the free carrier distribution's tail around x=W

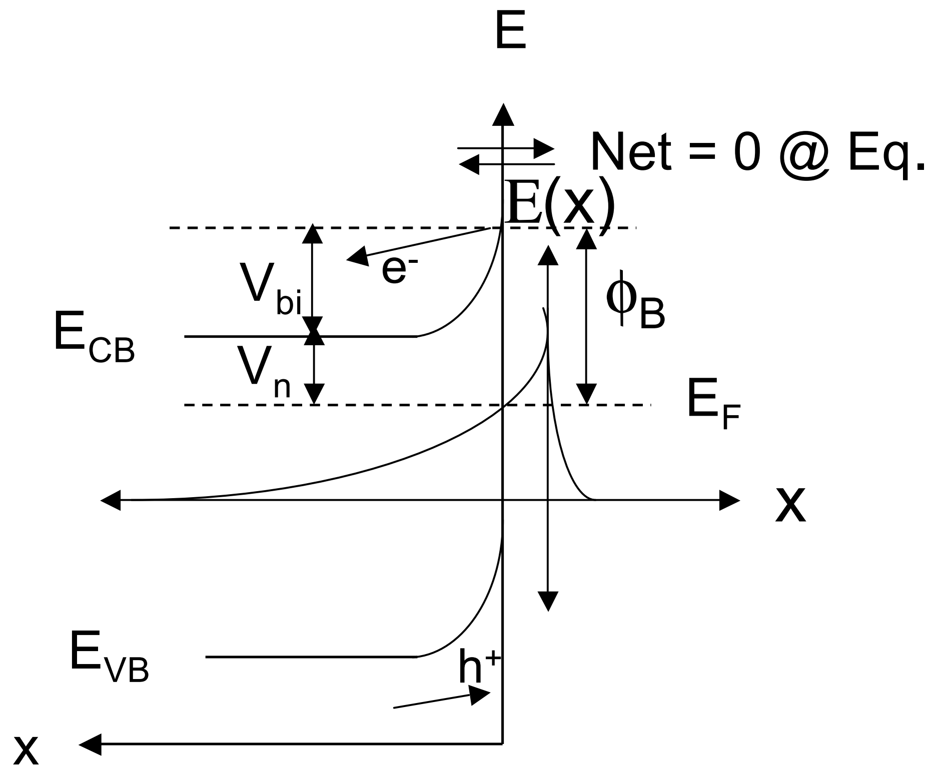
$$W = \sqrt{\frac{2K\varepsilon_0\left(\mathrm{V_{bi}} - \frac{\mathrm{kT}}{\mathrm{q}}\right)}{qN_D}}$$

Typical Values

V_{bi}^{max} (V)	N_D (cm^{-3})	W (μm)	Q (C/cm^2)
1	10^{13}	11	10^{10}
1	10^{16}	0.36	$3*10^{11}$

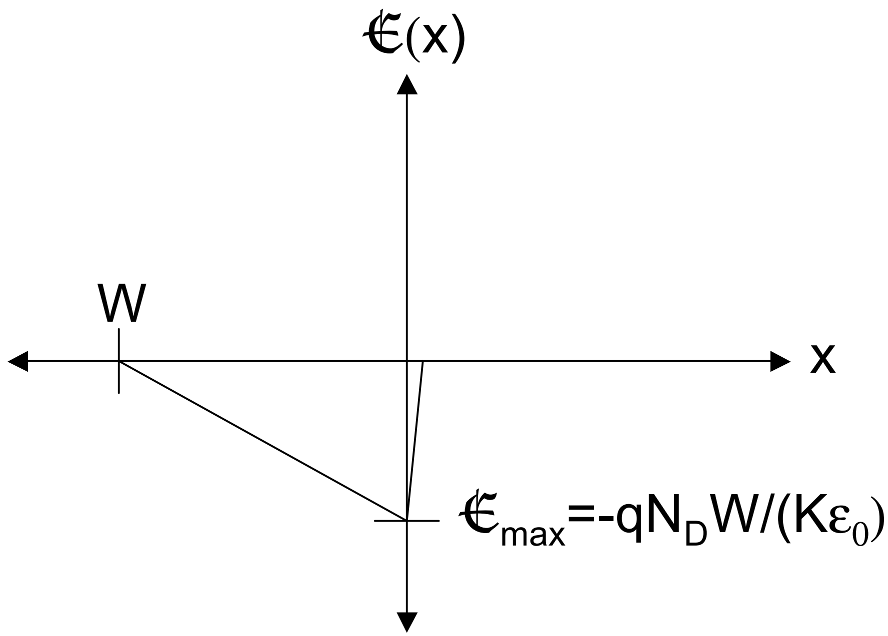
Electric Potential Energy

- $E(x) = -q\Psi(x)$
- $\Psi(0) = -V_{bi}$
- $qV_{bi} = (E_{F,SC} - E_{F,M})$
- $\phi_B = V_{bi} + V_n$
  - Barrier height
  - Independent of doping
  - V_{bi} and V_n are doping dependent

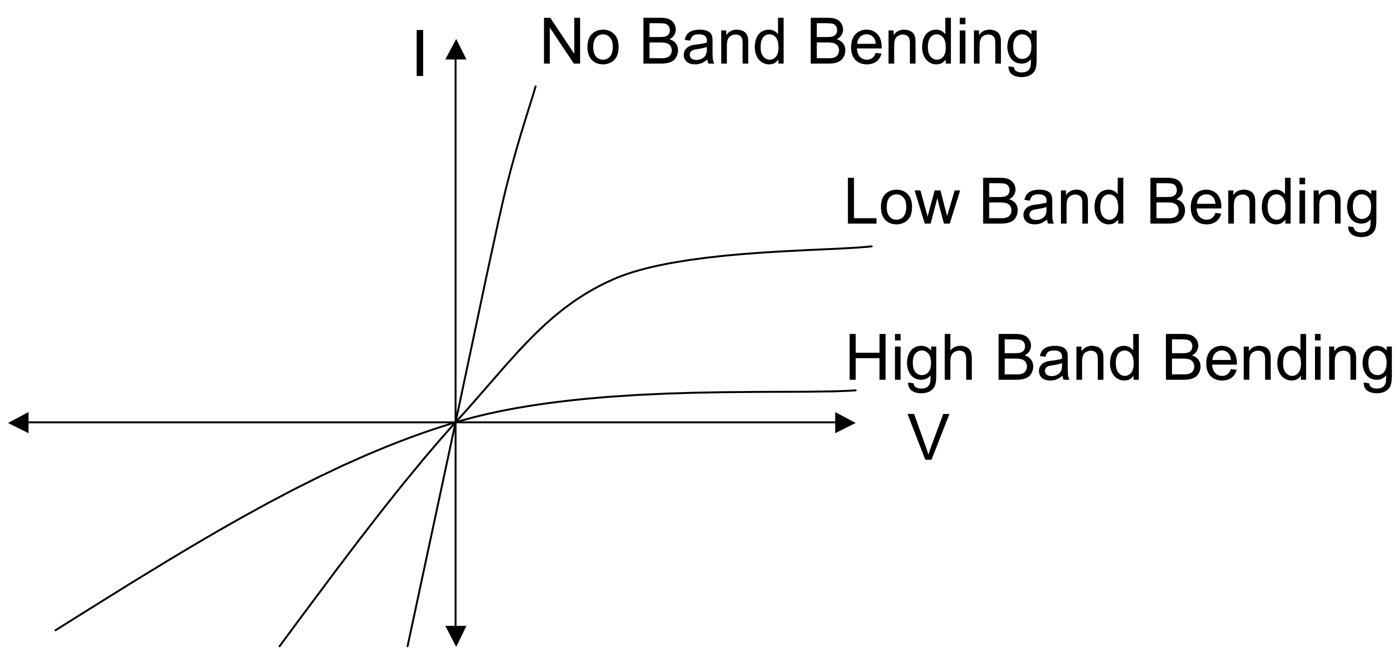


Electric Field (V/cm)

$$\mathcal{E}(x) = -\frac{d\psi(x)}{dx} = \frac{qN_D}{K\varepsilon_0}(x - W)$$

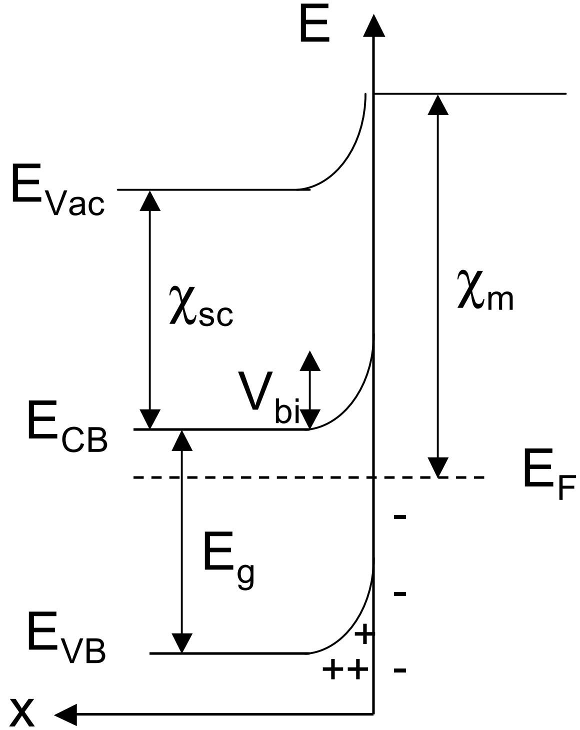


I-V Curve

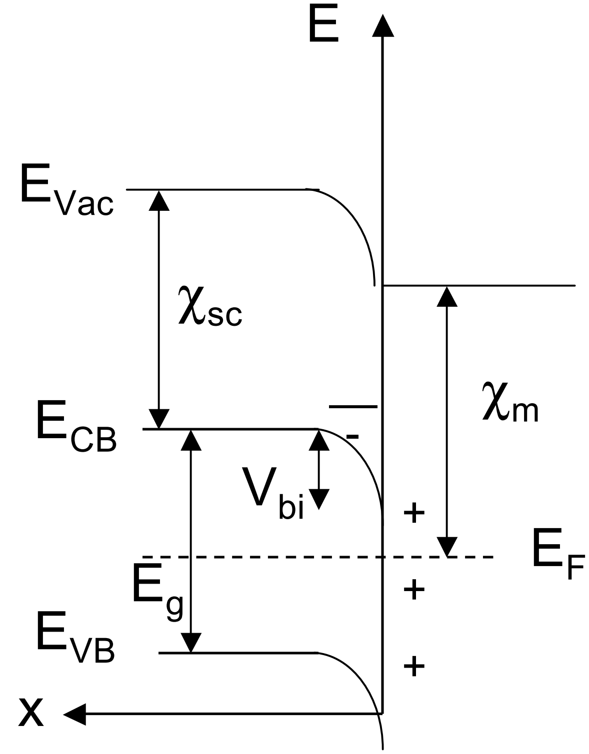


Review

- N-type

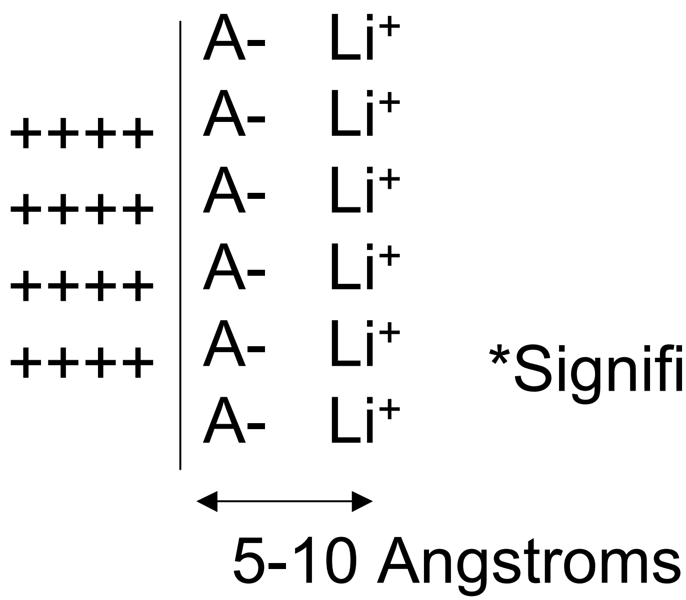


P-type



Solution Contact

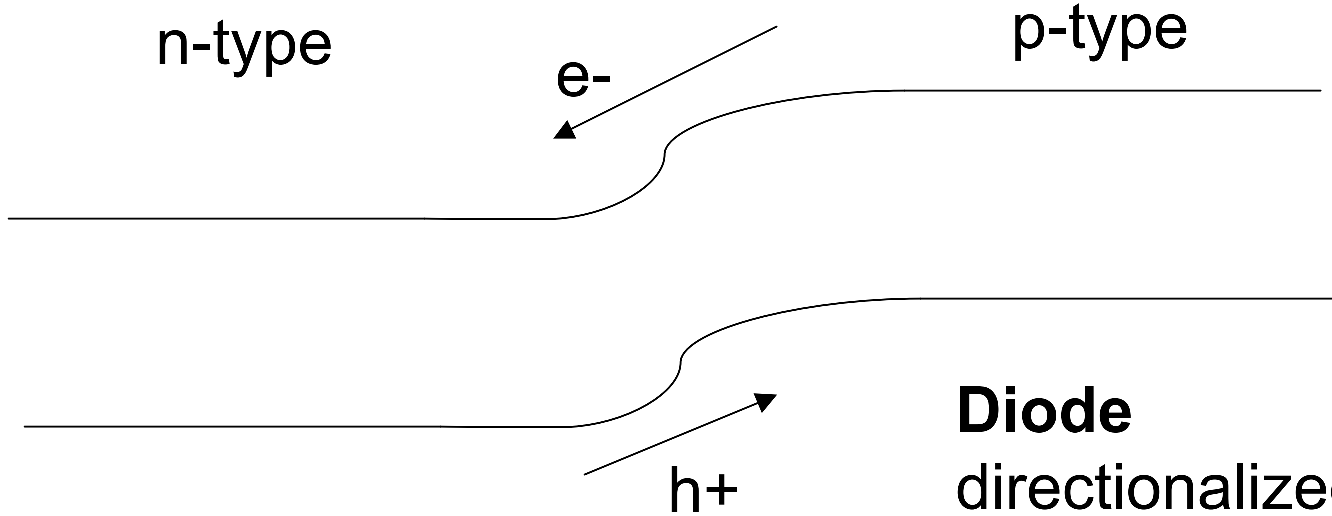
- 10^{17} atoms in 1mL of 1mM solution
- D.O.S. argument holds
- Difference in exchange current across the interface



*Significantly less than typical W ~ 10nm

Semiconductor Contacting Phase

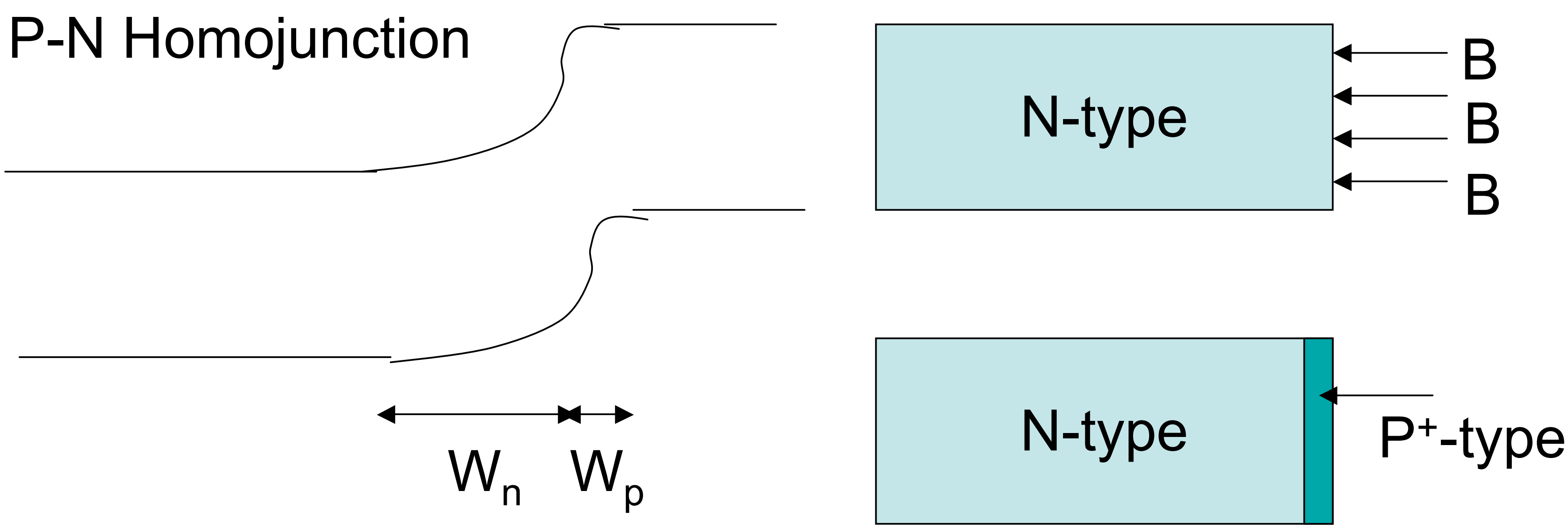
- No longer 1-Sided Abrupt Jxn. as the semi-conductor doesn't have infinite capacity to accept charge
- Assume N_D(n-type)=N_A(p-type), then W_n=W_p



Diode
directionalized current

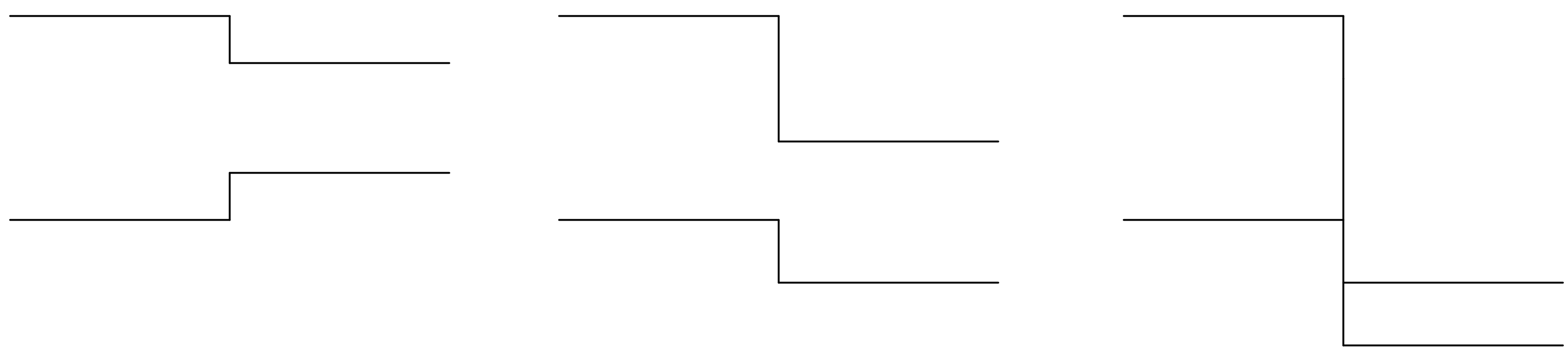
Degenerate Doping

- Dope p-type degenerately
- N_A>>N_D --> 1-sided Abrupt Jxn.



Heterojunctions

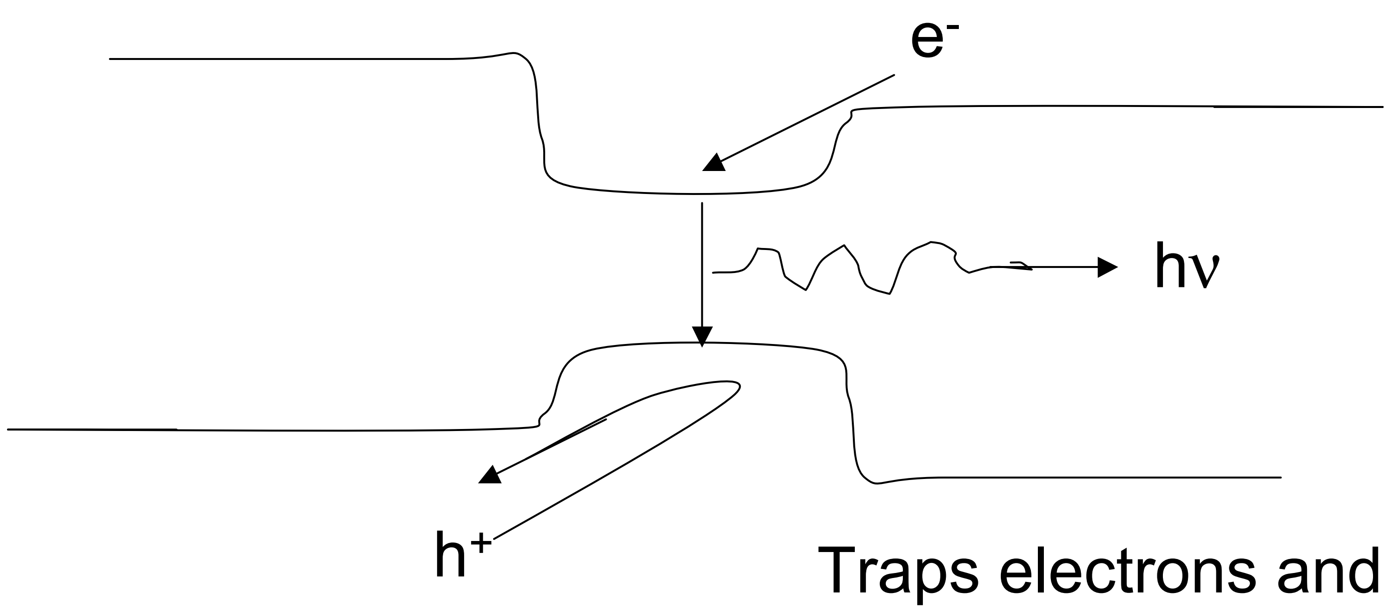
- 2 different semiconductors grown w/ the same cyrstal structure (difficult)
  - Ge/GaAs a_o~5.65 angstroms



Normal Staggered Broken

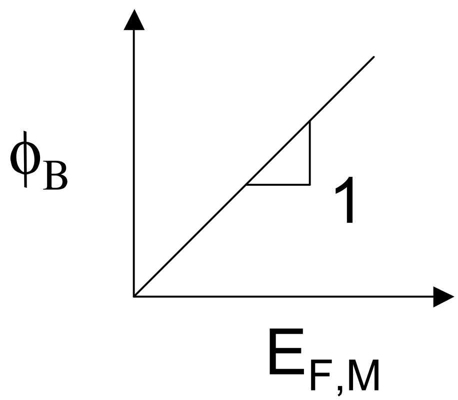
LASERs

- 3 Pieces --> 2 Heterjunctions
  - p$^-$(Al,Ga)As | GaAs | n$^-$(Al, Ga) As



Traps electrons and holes

Fermi-Level Pinning



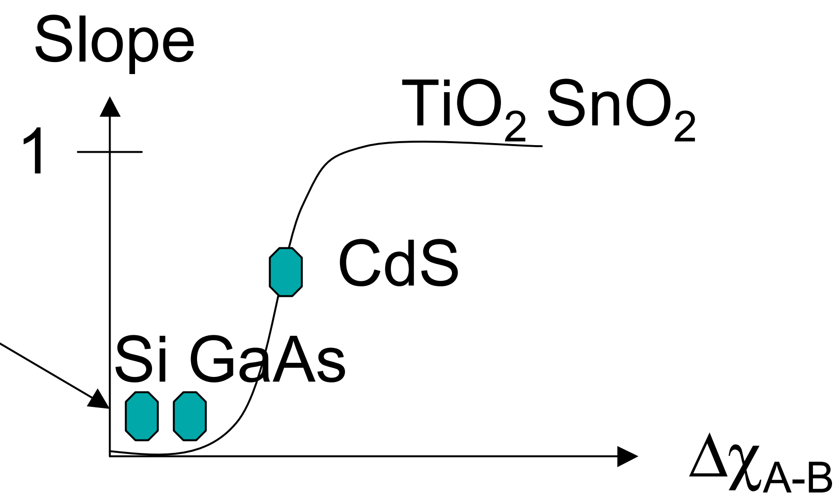
•Ideal Case

(only works for very ionic semiconductors like TiO_2 and SnO_2)

Never works for Si

Fermi-Level Pinning

Sze p. 278

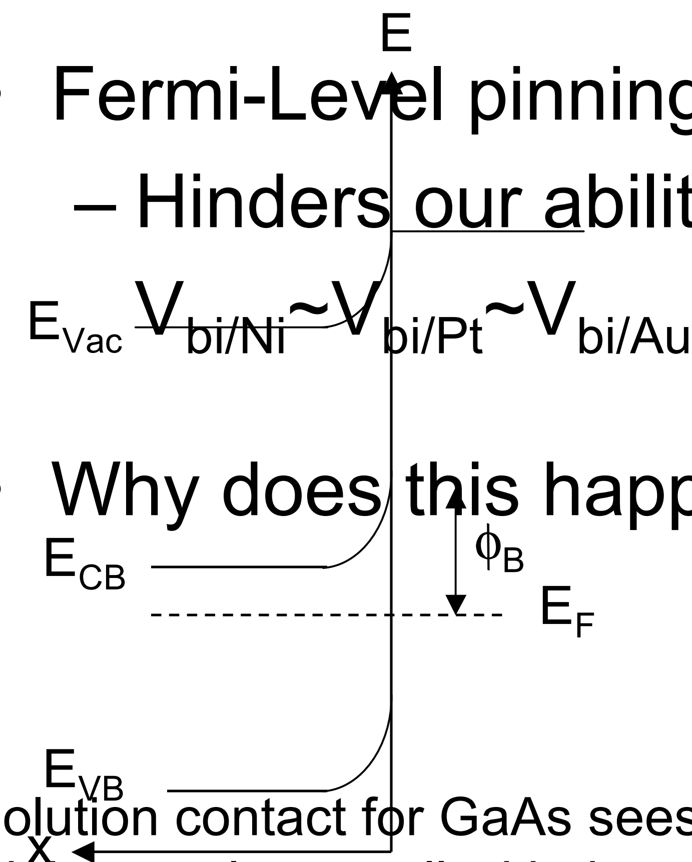


What's Missing?

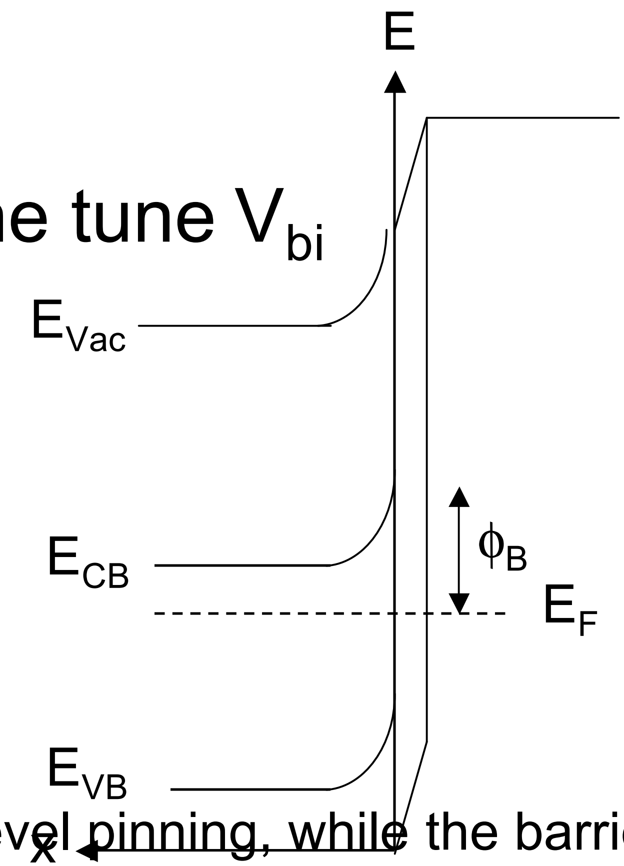
- Fermi-Level pinning hurts
  - Hinders our ability to fine tune V_{bi}

$V_{bi/Ni} \sim V_{bi/Pt} \sim V_{bi/Au}$

- Why does this happen?



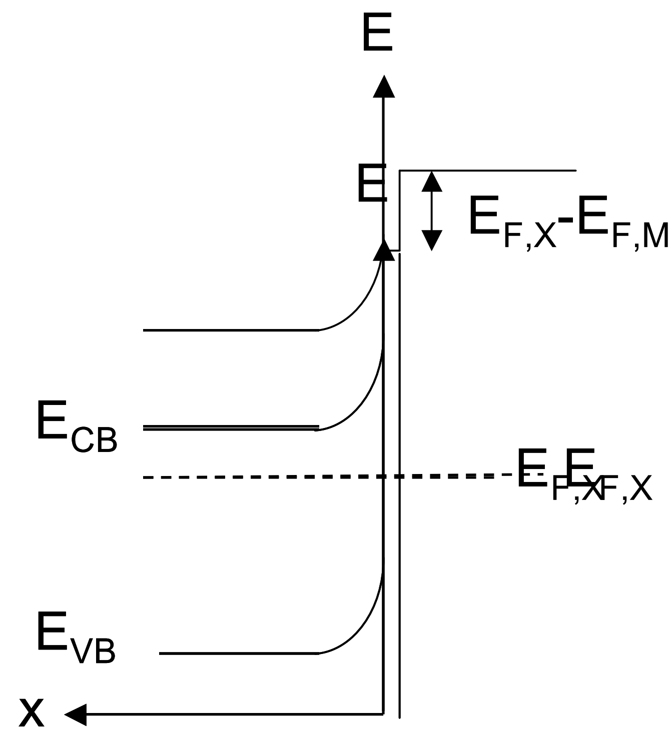
vs.



*Solution contact for GaAs sees Fermi-level pinning, while the barrier height correlates well with the electro-chemical potential for solution contact to Si

Devious Experimenter

- Given a Si sample with a magic type of metal on the surface X
- Thus the Fermi-level will alwaysequilibrate to the Fermi-level of X
- Thin interface --> e^-'s tunnel through it and no additional potential drop is observed



What is X?

- Any source or sink for charge at the interface
  - Dangling bonds
  - Surface states
  - etc.

Questions

- Questions
  - Abrupt 1-sided junction

  (What is it?)
  - Sign of Electric P.E. and Electric Potential

  (Are they correct? I put them as they were in the notes, but this doesn't seem to agree with the algebra to me)