Lecture #8

OUTLINE

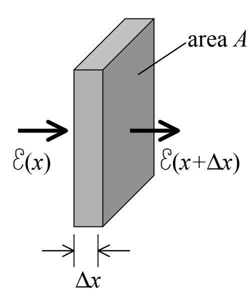
- Poisson's Equation
- Work Function
- Metal-Semiconductor Contacts
  - – equilibrium energy-band diagram
  - – depletion-layer width

Reading: Chapter 5.1.2,14.1, 14.2

Poisson's Equation

Gauss's Law:

$$\varepsilon_s \mathcal{E}(x+\Delta x)A - \varepsilon_s \mathcal{E}(x)A = \rho \Delta x A$$



ε_s : permittivity (F/cm)
ρ : charge density (C/cm^3)

$$\frac{\mathcal{E}(x+\Delta x) - \mathcal{E}(x)}{\Delta x} = \frac{\rho}{\varepsilon_s}$$

$$\frac{d\mathcal{E}}{dx} = \frac{\rho}{\varepsilon_s}$$

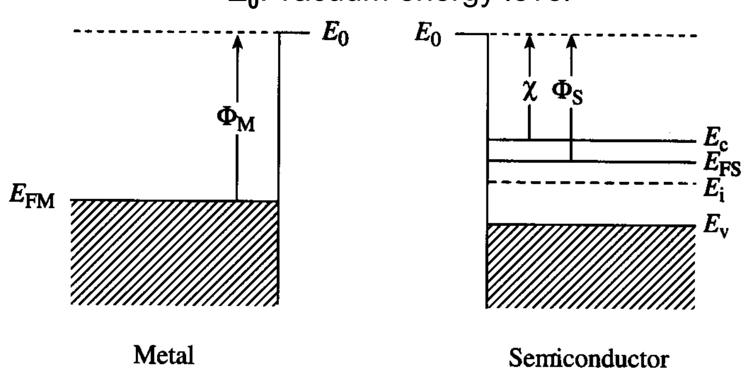
Charge Density in a Semiconductor

- Assuming the dopants are completely ionized:

$$\rho = q\,(p - n + N_D - N_A)$$

Work Function

E_0: vacuum energy level



Φ_M: metal work function Φ_S: semiconductor work function

Metal-Semiconductor Contacts

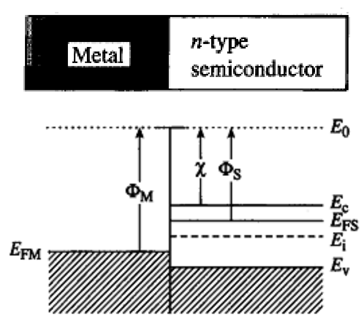
There are 2 kinds of metal-semiconductor contacts:

- rectifying
  "Schottky diode"

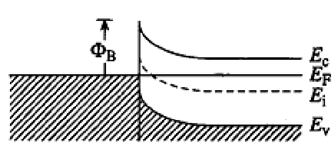
- non-rectifying
  "ohmic contact"

Ideal MS Contact: $\Phi_M > \Phi_S$, n-type

Band diagram instantly after contact formation:



Equilibrium band diagram:



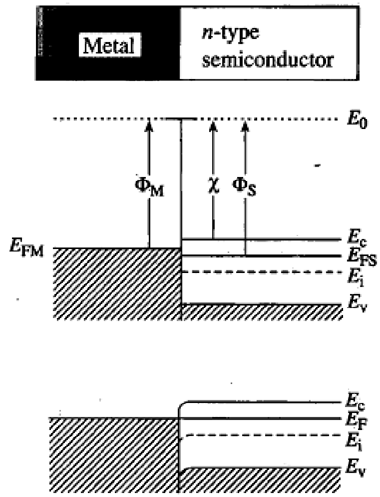
Schottky Barrier :

$$\Phi_{Bn} = \Phi_M - \chi$$

Ideal MS Contact: $\Phi_M < \Phi_S$, n-type

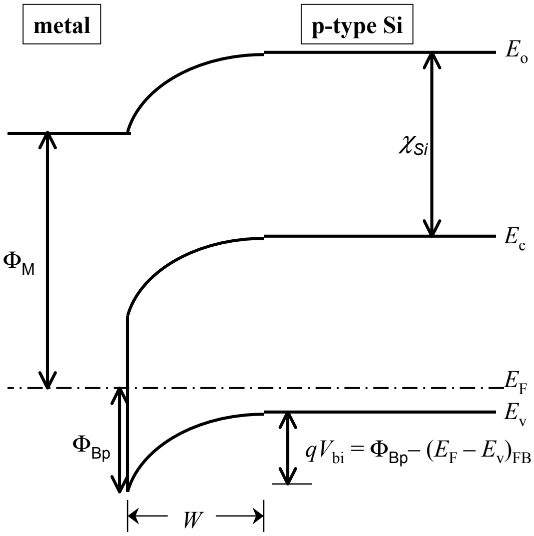
Band diagram instantly after contact formation:

Equilibrium band diagram:



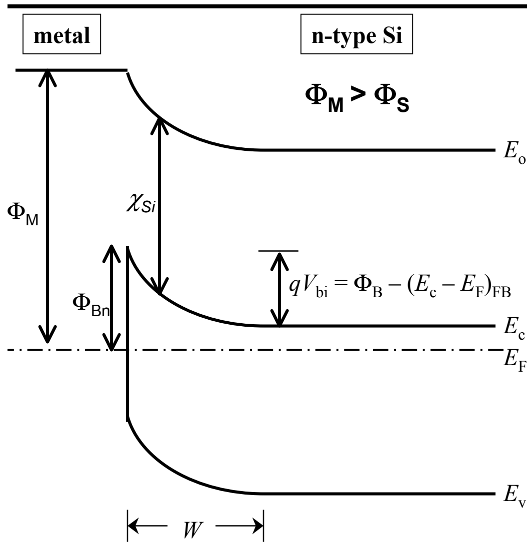
$$\Phi_{Bn} = \Phi_M - \chi$$

Ideal MS Contact: $\Phi_M < \Phi_S$, p-type



$$\Phi_{Bp} = \chi + E_G - \Phi_M$$

Effect of Interface States on Φ_{Bn}



- **Ideal MS contact:**
  $\Phi_{Bn} = \Phi_M - \chi$
- **Real MS contacts:**
  - A high density of allowed energy states in the band gap at the MS interface pins E_F to the range 0.4 eV to 0.9 eV below E_c

Schottky Barrier Heights: Metal on Si

Metal	Mg	Ti	Cr	Ni	W	Mo	Pd	Au	Pt
Φ_{Bn} (eV)	0.4	0.5	0.61	0.61	0.67	0.68	0.77	0.8	0.9
Φ_{Bp} (eV)		0.61	0.5	0.51		0.42		0.3	
Φ_M (eV)	3.7	4.3	4.5	4.7	4.6	4.6	5.1	5.1	5.7

- Φ_{Bn} tends to increase with increasing metal work function

Schottky Barrier Heights: Silicide on Si

Silicide	$ErSi_{1.7}$	HfSi	$MoSi_2$	$ZrSi_2$	$TiSi_2$	$CoSi_2$	WSi_2	$NiSi_2$	Pd_2Si	PtSi
Φ_{Bn} (V)	0.28	0.45	0.55	0.55	0.61	0.65	0.67	0.67	0.75	0.87
Φ_{Bp} (V)		0.45	0.55	0.49	0.45	0.45	0.43	0.43	0.35	0.23

Silicide-Si interfaces are more stable than metal-silicon interfaces. After metal is deposited on Si, a thermal annealing step is applied to form a silicide-Si contact. The term ***metal-silicon contact*** includes silicide-Si contacts.

The Depletion Approximation

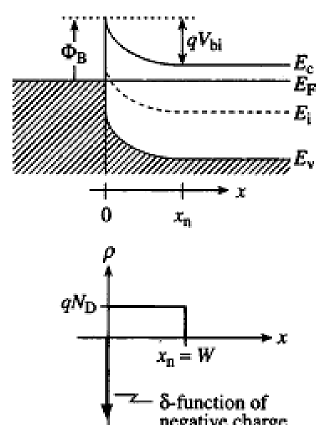
The semiconductor is depleted of mobile carriers to a depth W

$\Rightarrow$ In the depleted region ($0 \le x \le W$):

$$\rho = q\,(N_D - N_A)$$

Beyond the depleted region ($x > W$):

$$\rho = 0$$

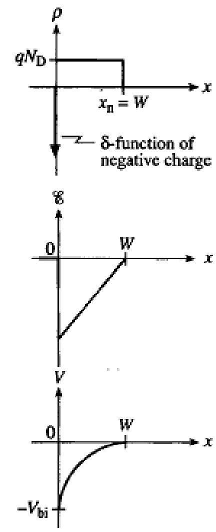


Electrostatics

- Poisson's equation: $\frac{\partial \mathcal{E}}{\partial x} = \frac{\rho}{\varepsilon_s} \cong \frac{qN_D}{\varepsilon_s}$

- The solution is: $\mathcal{E}(x) = -\frac{qN_D}{\varepsilon_s}(W - x)$

$$V(x) = -\int \mathcal{E}(x')dx'$$



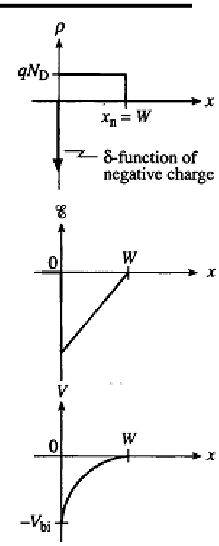
Depleted Layer Width, *W*

$$V(x) = \frac{-qN_D}{2K_S\varepsilon_0}(W - x)^2$$

At $x = 0$, $V = -V_{bi}$

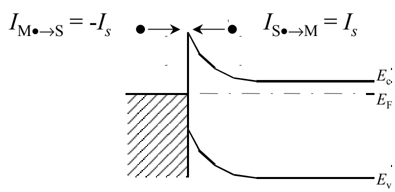
$$\Rightarrow \quad W = \sqrt{\frac{2\varepsilon_s V_{bi}}{qN_D}}$$

- ***W* decreases with increasing N_D**

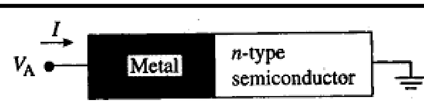


Equilibrium Current Flow – Qualitative

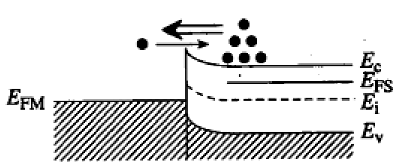
$V_A = 0$



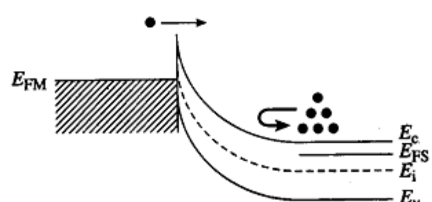
Current Flow with D.C. Bias – Qualitative

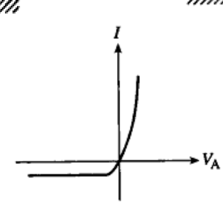


$V_A > 0$



$V_A < 0$





Fermi level splits into two levels (E_{FM} and E_{FS}) separated by qV_A

W Dependence on D.C. Bias (n-type Si)

$$W = \sqrt{\frac{2\varepsilon_s (V_{bi} - V_A)}{qN_D}}$$

- *W* increases with increasing $-V_A$
- *W* decreases with increasing N_D

W Dependence on D.C. Bias (p-type Si)

$$W = \sqrt{\frac{2\varepsilon_s (V_A + V_{bi})}{qN_A}}$$

- *W* increases with increasing V_A
- *W* decreases with increasing N_A