ECE-305: Spring 2018
Metal-Semiconductor Diodes

Pierret, *Semiconductor Device Fundamentals* (SDF)
Chapter 14 (pp. 487-496)

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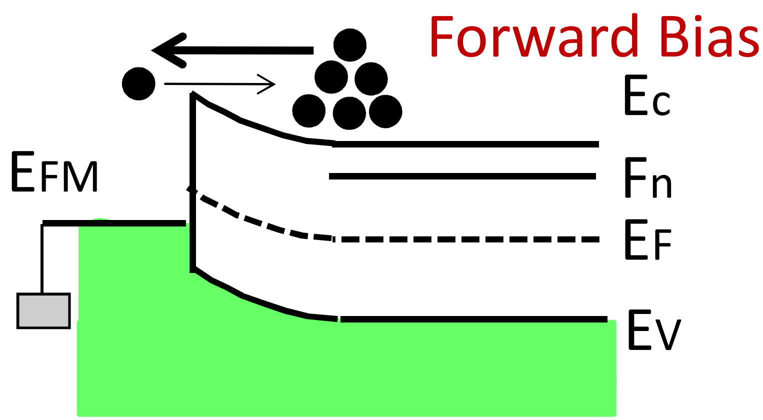
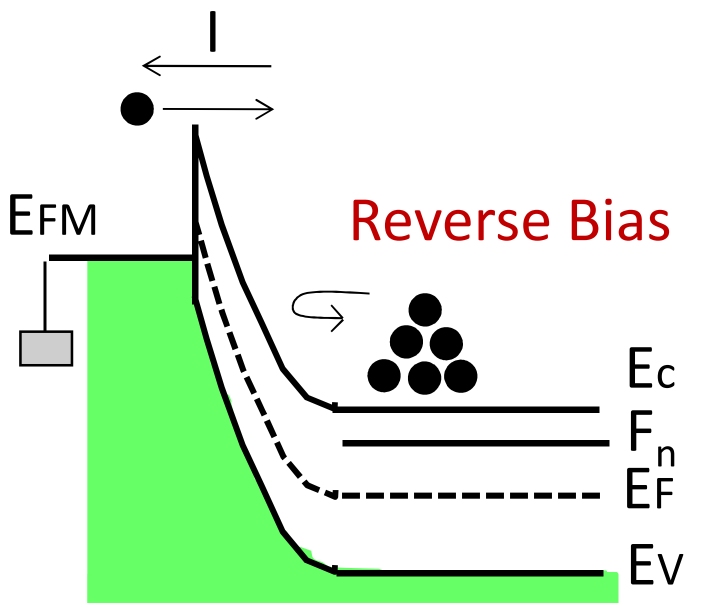
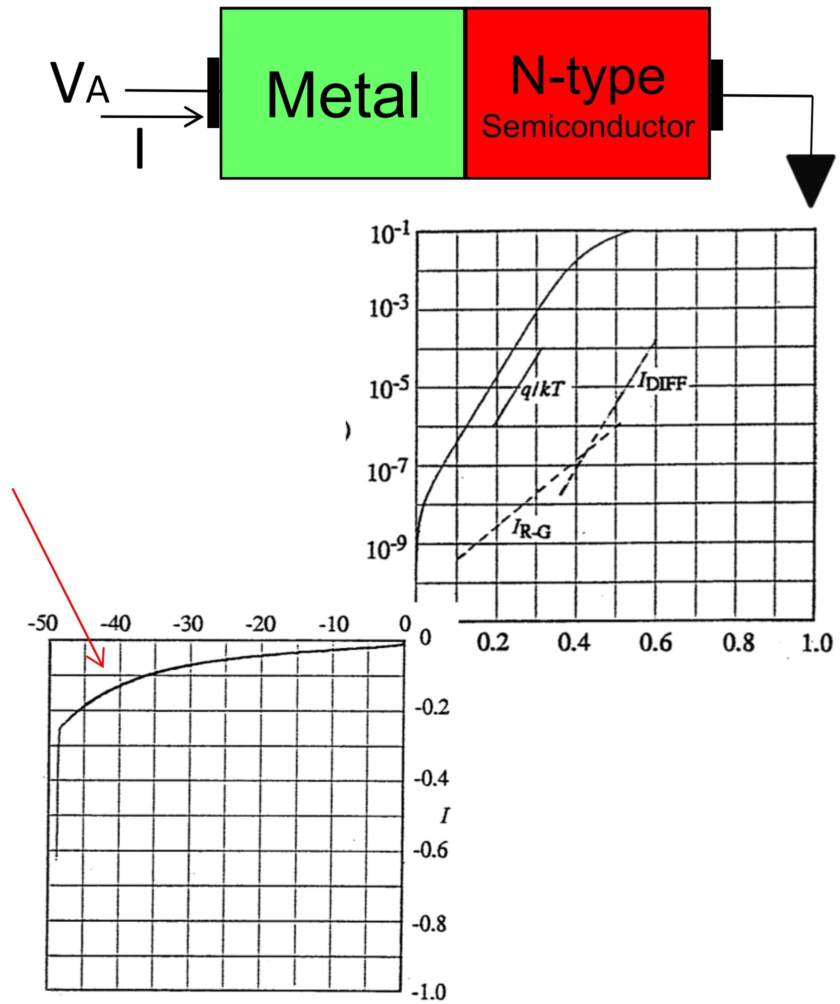
outline

1) DC Thermionic current, nonideal current
2) AC small signal and large-signal response

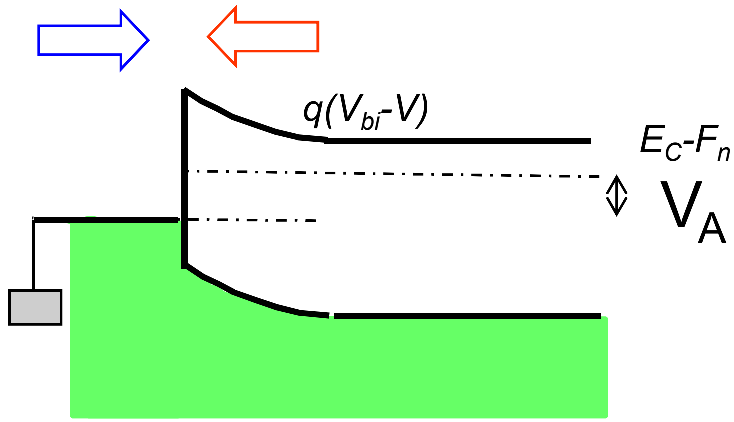
I-V Characteristics







Left Boundary Condition



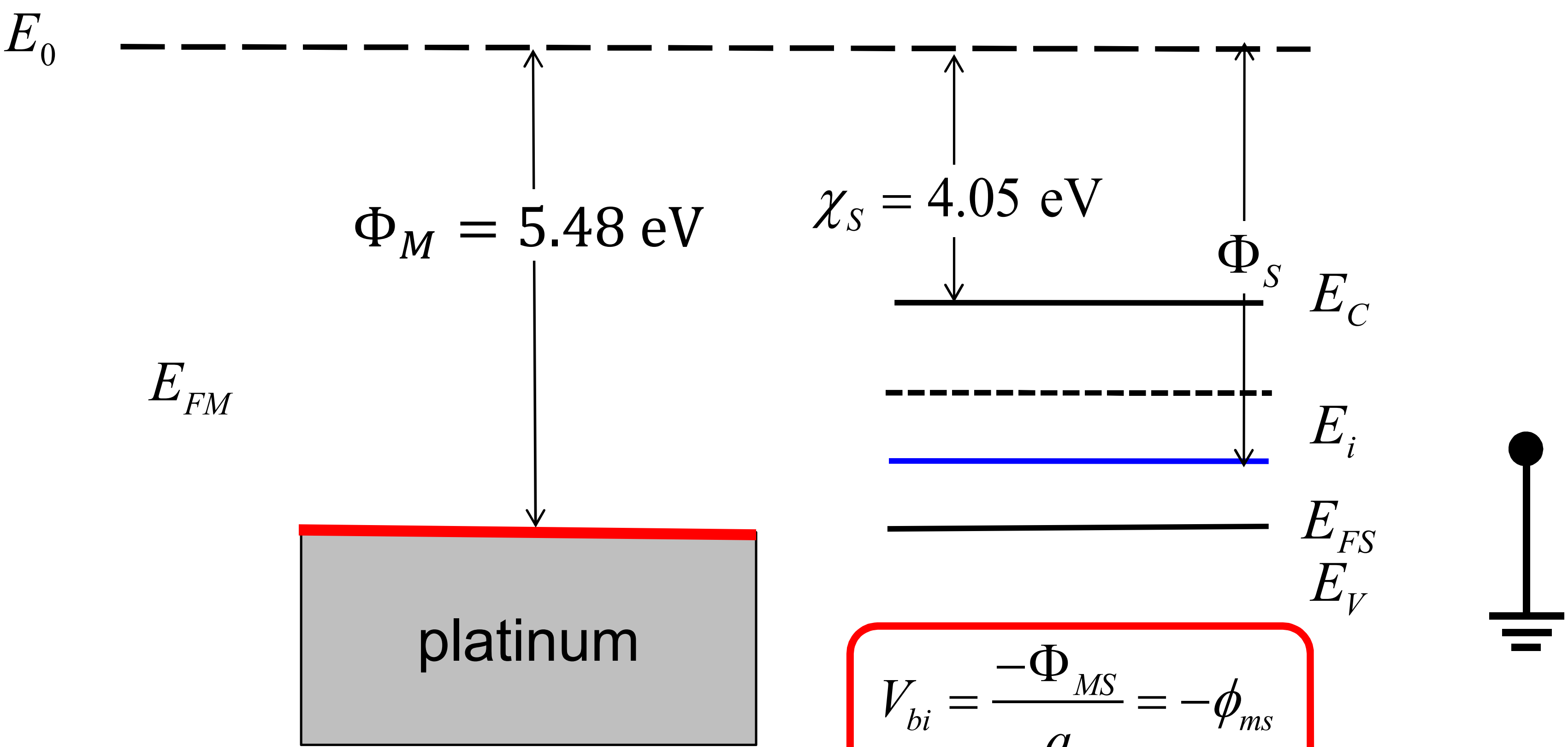
$$J_T(V_A) = J_{m\to s}(V_A) - J_{s\to m}(V_A)$$

$$J_T(V_A = 0) = 0 = J_{m\to s}(0) - J_{s\to m}(0)$$

$$\Rightarrow J_{m\to s}(0) = J_{s\to m}(0)$$

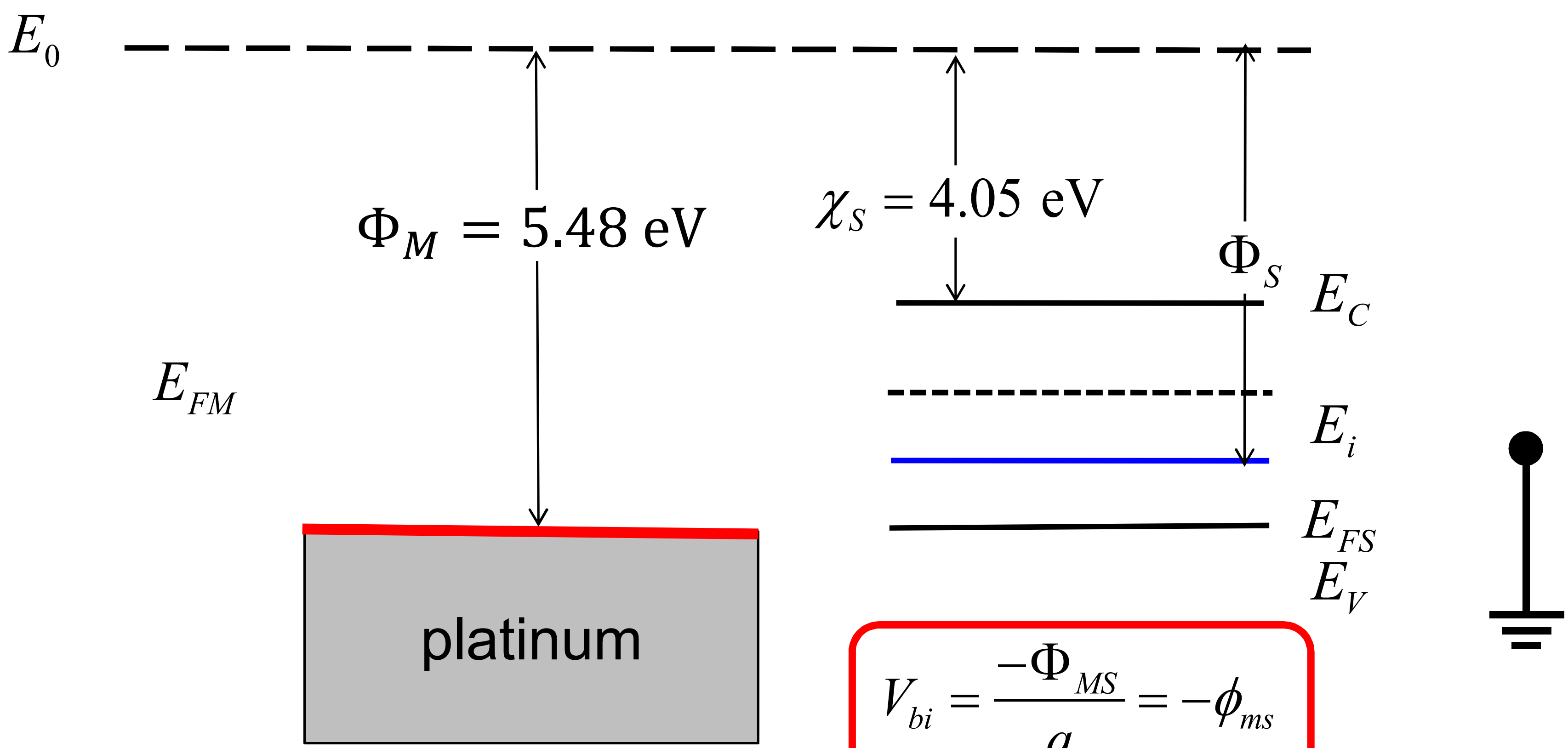
$$J_T(V_A) = J_{s\to m}(0) - J_{s\to m}(V_A)$$

Example: MS junction band structure



$$V_{bi} = \frac{-\Phi_{MS}}{q} = -\phi_{ms}$$

Example: MS junction built-in potential



$$V_{bi} = \frac{-\Phi_{MS}}{q} = -\phi_{ms}$$

$$qV_{bi} = \left(E_{FM} - E_{FS}\right) = \left(\Phi_S - \Phi_M\right) = -\left(\Phi_M - \Phi_S\right) = -\Phi_{MS}$$

Example: MS junction built-in potential

Platinum metal and p-type Si

$$N_A = 10^{16} \text{ cm}^{-3}$$

$$p_0 = N_V e^{(E_V - E_{FS})/k_B T} \text{ cm}^{-3}$$

$$E_{FS} - E_V = k_B T \ln\left(\frac{N_V}{N_A}\right)$$

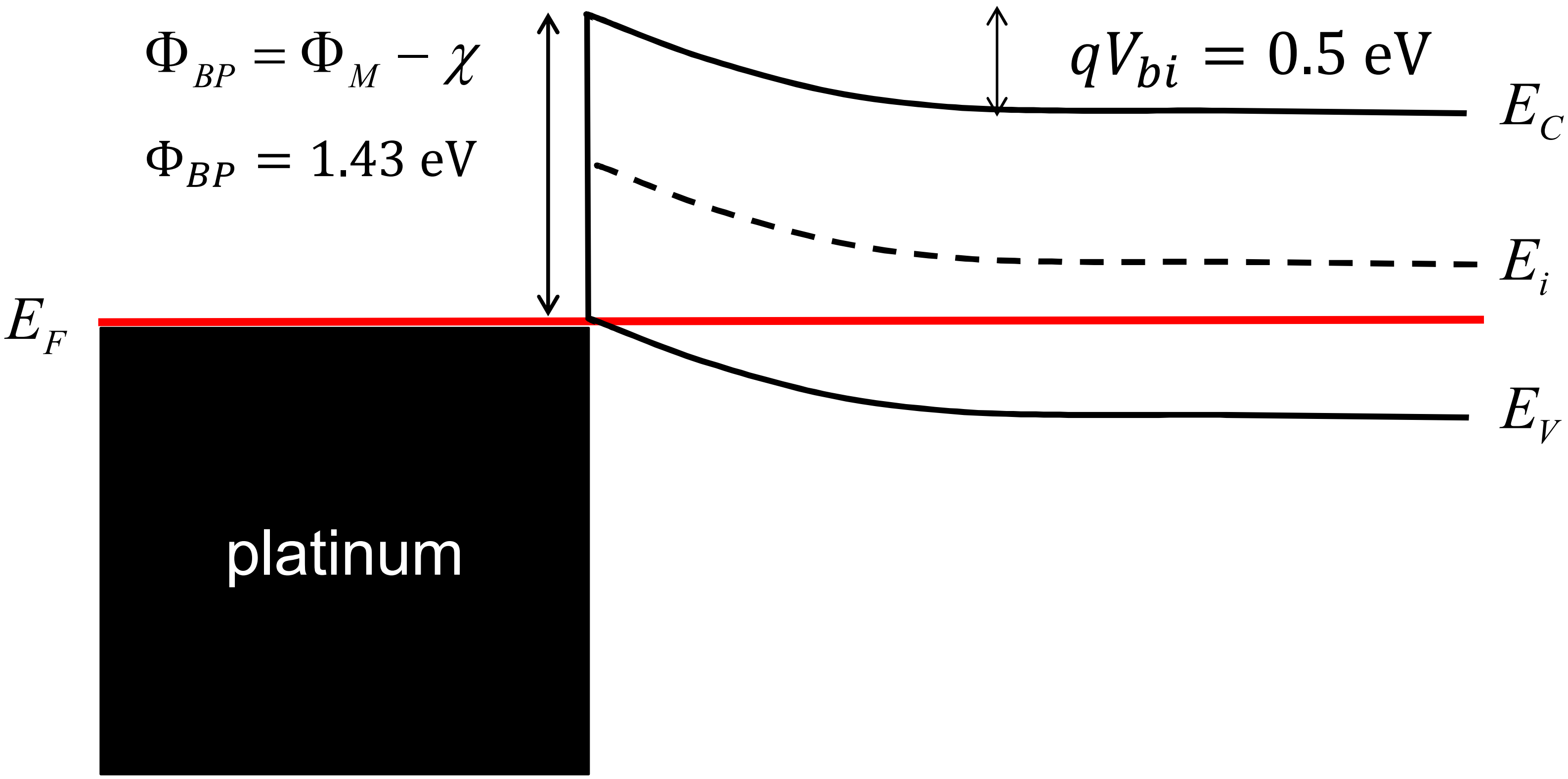
$$N_V = 2\left[\frac{\left(m_p^* k_B T\right)}{2\pi\hbar^2}\right]^{3/2} = 1.83 \times 10^{19} \text{ cm}^{-3}$$

$$\Phi_M = 5.48 \text{ eV}$$

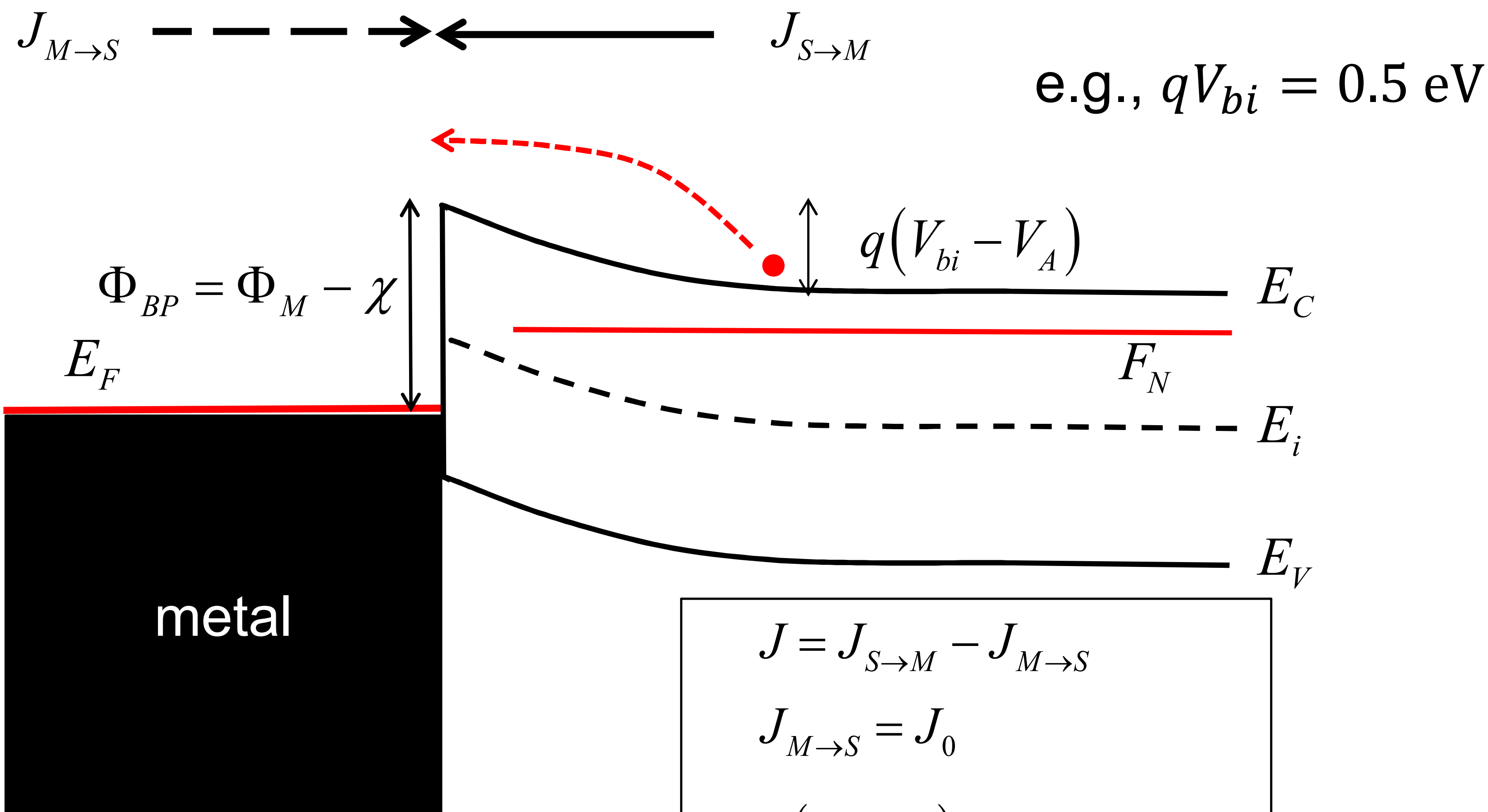
$$\Phi_S = \chi_S + E_G - \left(E_{FS} - E_V\right)/q$$

$$\Phi_S = 4.97 \text{ eV}$$

Example: MS junction band diagram



Non-equilibrium band diagram



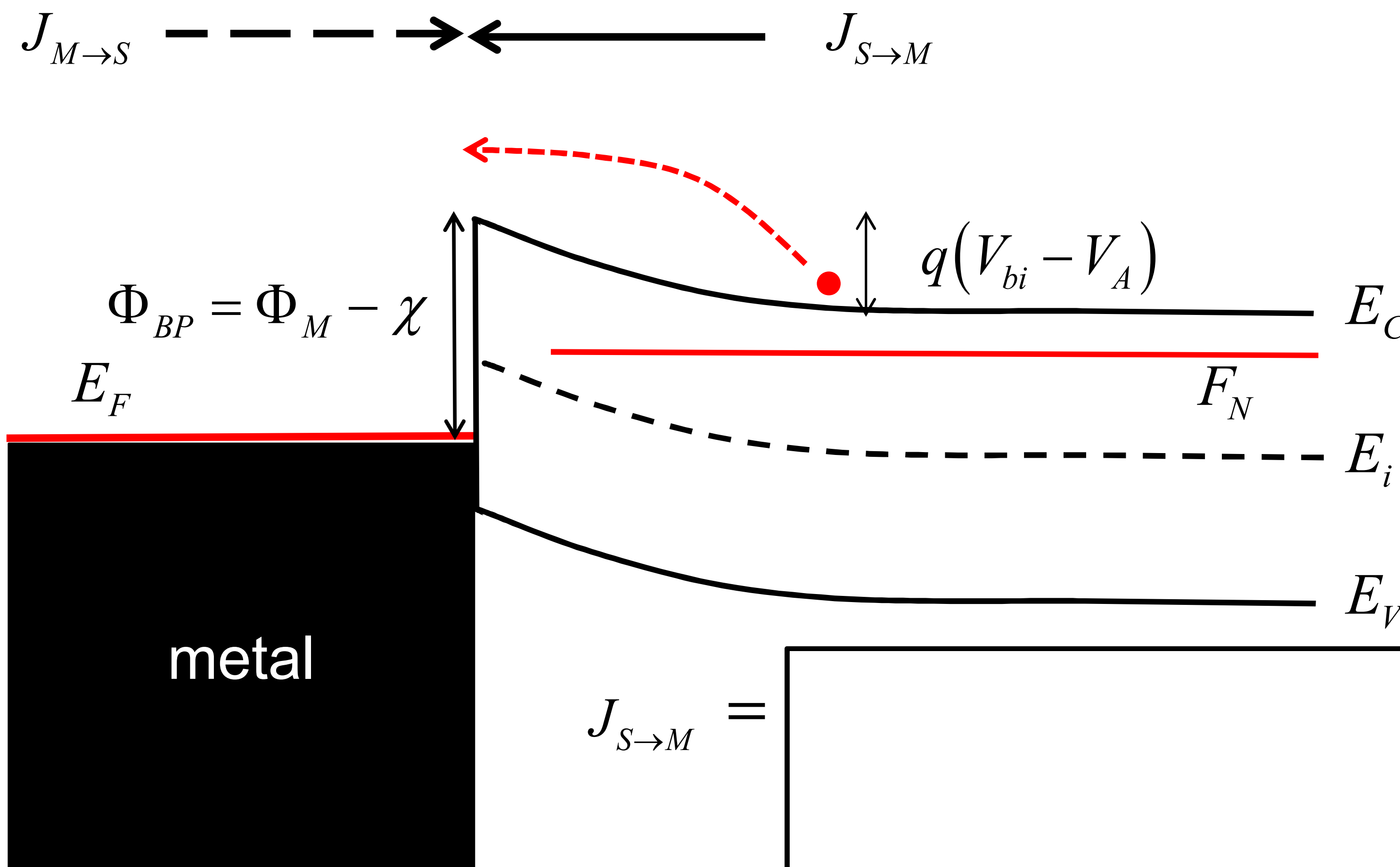
$$J = J_{S\rightarrow M} - J_{M\rightarrow S}$$

$$J_{M\rightarrow S} = J_0$$

$$J(V_A = 0) = J_0$$

$$J_{S\rightarrow M}(V_A > 0) = J_0 e^{qV_A/k_BT}$$

Non-equilibrium band diagram



$J_{S \to M} =$

$J_o =$

Schottky barriers

The most reliable way to work is to take the Schottky barrier as the known (measured) quantity.

Computing Schottky barriers from workfunctions and electron affinities can lead to large errors and interface effects can affect the Schottky barrier height.

http://www.cleanroom.byu.edu/ohmic-schottky.phtml

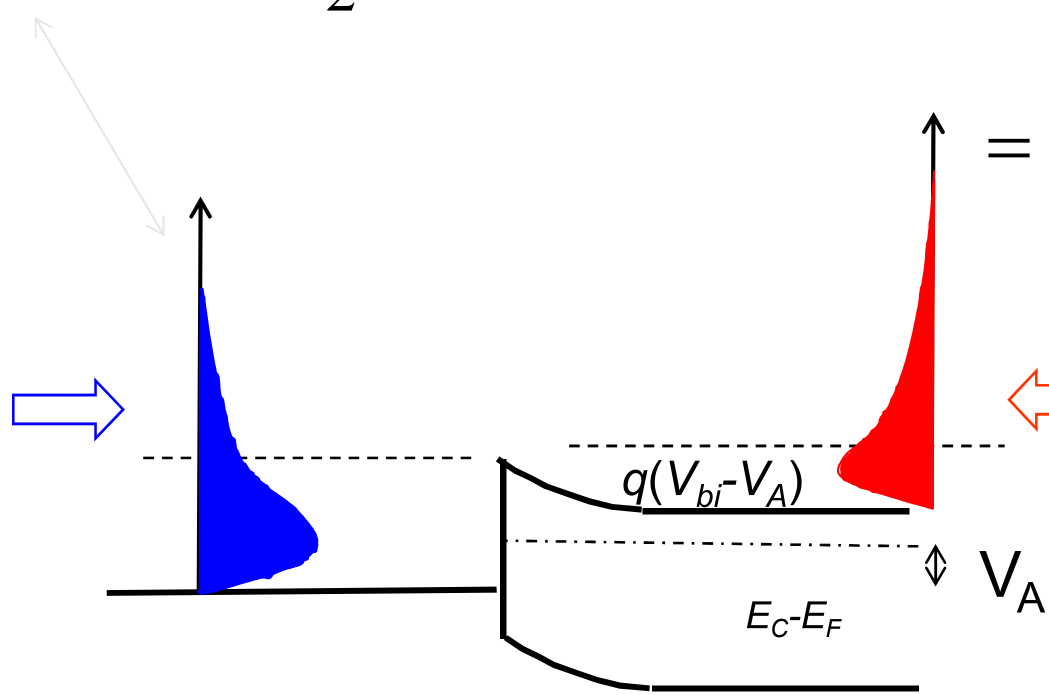
Semiconductor to Metal Flux

$$J_{m\to s}(V_A) = -q\frac{n_m}{2}e^{-\frac{q\Phi_B}{kT}}\upsilon_{th}$$

$$J_{s\to m}(V_A) = -q\frac{n_s}{2}e^{-q\frac{V_{bi}-V_A}{kT}}\upsilon_{th}$$

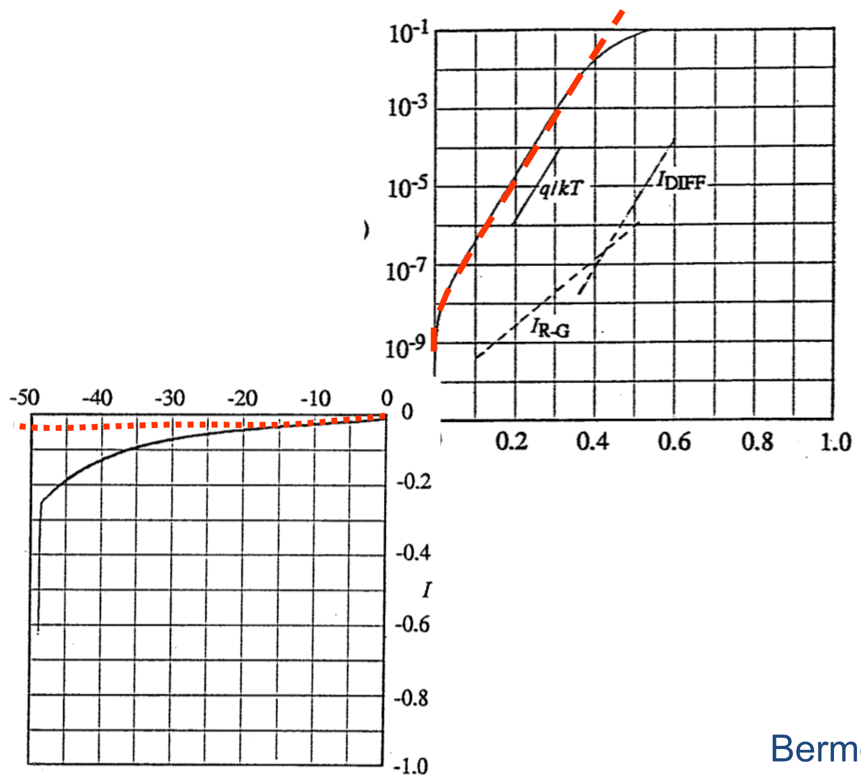
$$= -q\frac{n_s\upsilon_{th}}{2}e^{-\frac{qV_{bi}}{kT}}\times e^{\frac{qV_A}{kT}}$$

$$= -q\frac{n_m\upsilon_{th}}{2}e^{-\frac{q\Phi_B}{kT}}e^{\frac{qV_A}{kT}}$$



Total Flux…

$$J_T = J_{s\to m}(0) - J_{s\to m}(V_A) = \frac{q n_m \upsilon_{th}}{2} e^{\frac{-q\Phi_m}{kT}} \left[e^{\frac{qV_A}{kT}} - 1 \right]$$



saturation current density, J_0

$$J_0 = qN_D \frac{\upsilon_T}{2} e^{-qV_{bi}/k_BT}$$

$$qV_{bi} = \Phi_{BN} - \left(E_C - E_{FN}\right)\Big|_{x\to\infty}$$

$$n_0 = N_D = N_C e^{\left(E_{FN} - E_C\right)/k_BT}$$

$$qV_{bi} = \Phi_{BN} - k_BT \ln\left(\frac{N_C}{N_D}\right)$$

$$J_0 = qN_C \frac{\upsilon_T}{2} e^{-\Phi_{BN}/k_BT}$$

saturation current density, J_0

$$J_0 = qN_C \frac{\upsilon_T}{2} e^{-\Phi_{BN}/k_B T}$$

$$N_C = 2\left[\frac{\left(m_n^* k_B T\right)}{2\pi\hbar^2}\right]^{3/2}$$

$$\upsilon_T = \sqrt{\frac{2k_B T}{\pi m_n^*}}$$

saturation current

$$J = J_0\left(e^{qV_A/k_BT} - 1\right)$$

$$J_0 = A^* T^2 e^{-\Phi_{BP}/k_BT}$$

$$A^* = \frac{4\pi q m_n^* k_B^2}{h^3}$$

"Richardson's constant"

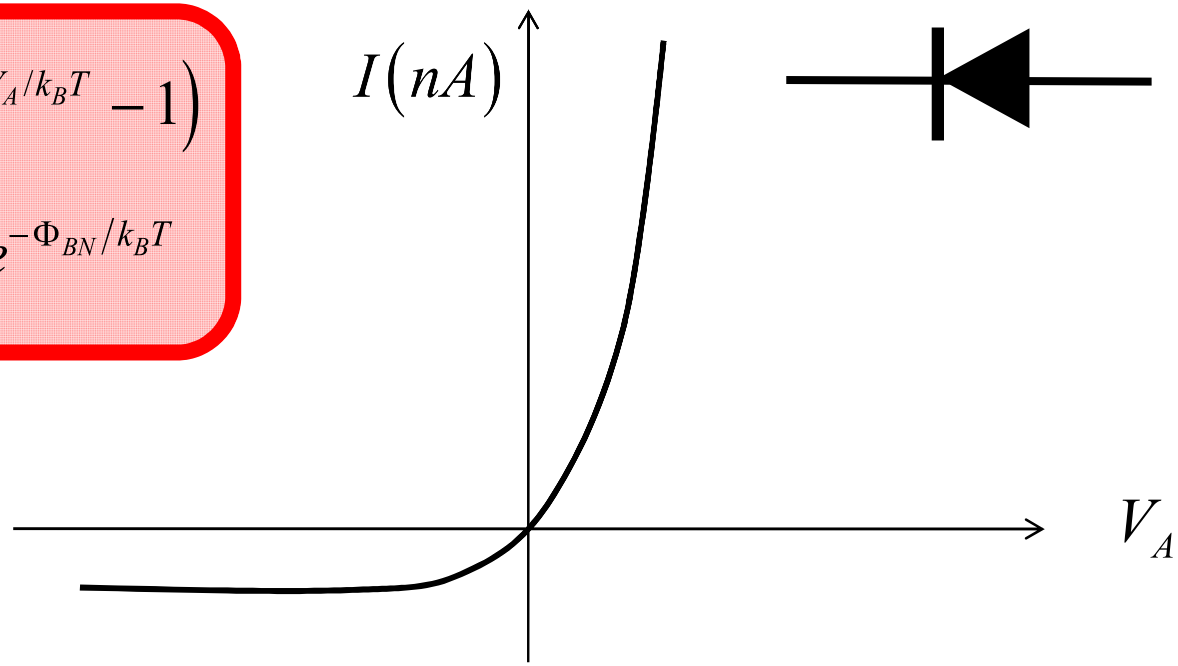
$$A = \frac{4\pi q m_0 k_B^2}{h^3} = 120\ \frac{\text{A}}{\text{cm}^2\text{-K}^2}$$

$$A^* = \frac{m_n^*}{m_0}$$

IV characteristics of a Schottky diode

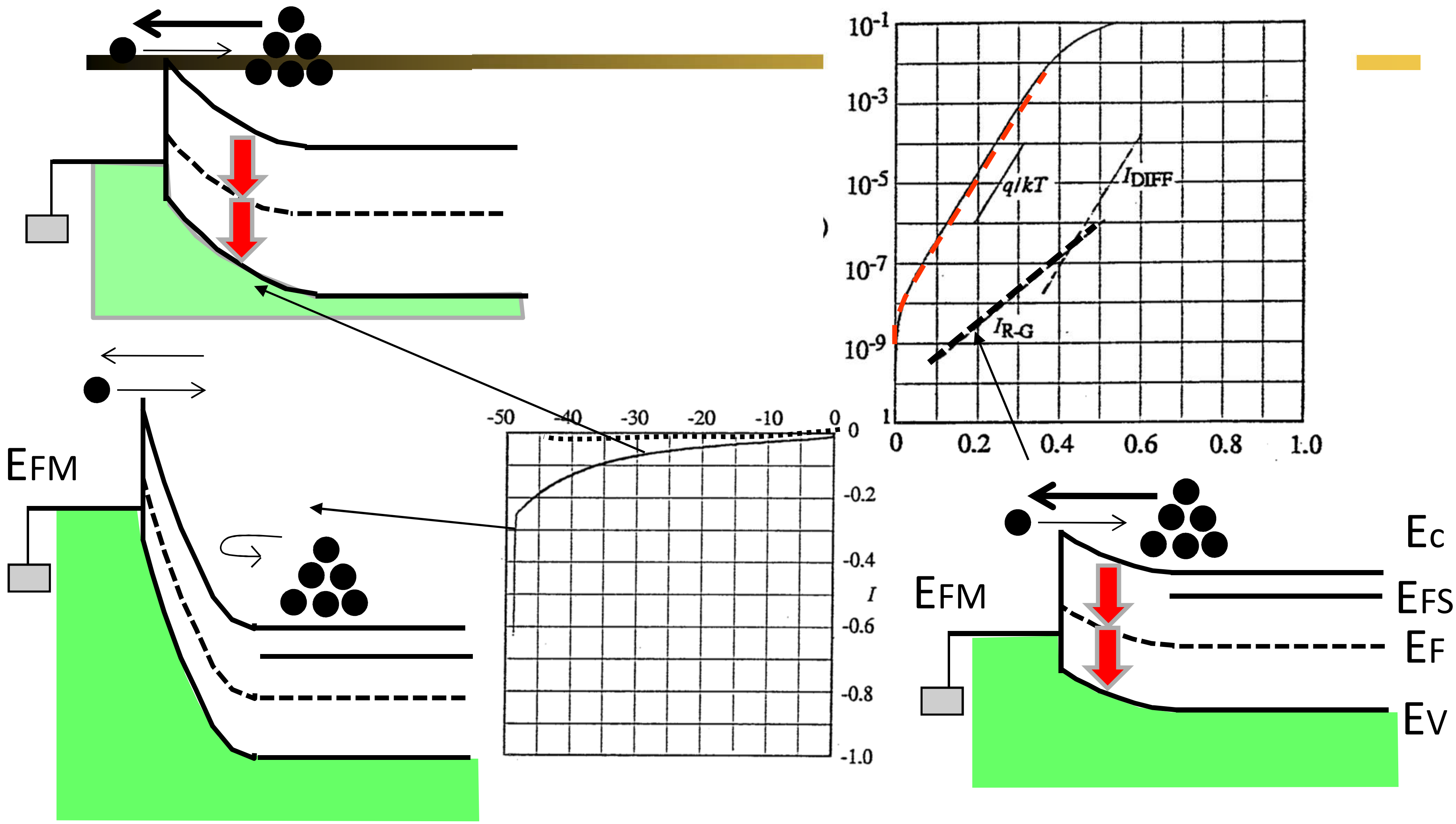
$$J = J_0\left(e^{qV_A/k_BT} - 1\right)$$

$$J_0 = A^*T^2e^{-\Phi_{BN}/k_BT}$$



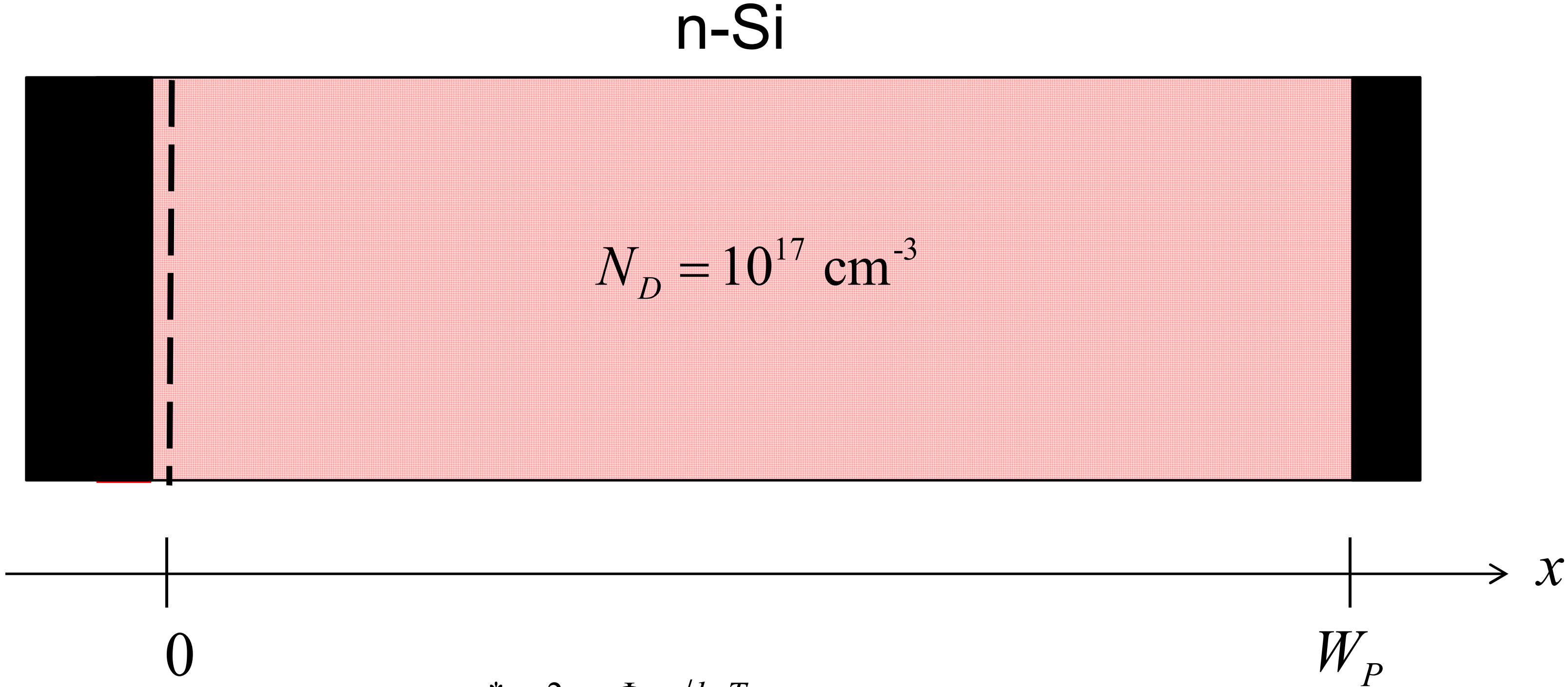
How does an MS diode compare to an NP junction?

Recombination/Generation/Impact-ionization



SAME technique as in p-n junction except integrate to x_p only

example: MS junction



$$J_0 = A^* T^2 e^{-\Phi_{BP}/k_B T}$$

$$m_n^*/m_0 = 1.18$$

$$\Phi_{BN} \approx 0.65 \text{ eV}$$

$$I_D = I_0\left(e^{qV_A/k_B T} - 1\right)$$

$$I_0 = 0.2 \times 10^{-3} \text{ A}$$

application

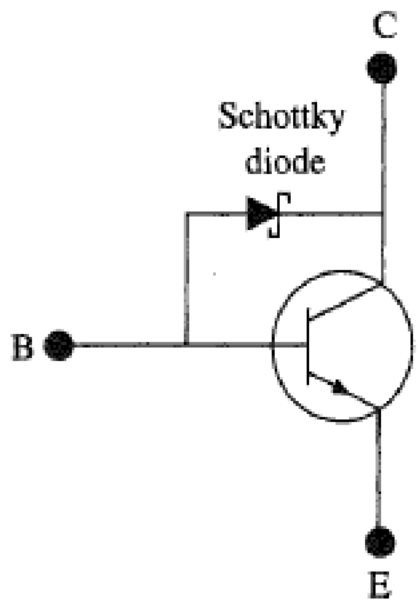


Fig. 14.9 Pierret, Semiconductor Device Fundamentals

CREE

CSD01060
Silicon Carbide Schottky Diode
Zero Recovery® Rectifier

V_{RRM}	=	600 V
I_F (T_C=135˚C)	=	2 A
Q_c	=	3.3 nC

Features

- 600-Volt Schottky Rectifier
- Zero Reverse Recovery Current
- Zero Forward Recovery Voltage
- High-Frequency Operation
- Temperature-Independent Switching Behavior
- Extremely Fast Switching
- Positive Temperature Coefficient on V_F

Benefits

- Replace Bipolar with Unipolar Rectifiers
- Essentially No Switching Losses
- Higher Efficiency
- Reduction of Rectifier Heat Sink
- Parallel Devices Without Thermal Runaway

Applications

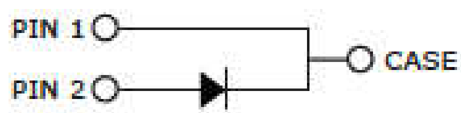
- Switch Mode Power Supplies
- Power Factor Correction
  - Typical PFC P_{out} : 100W-200W
- Motor Drives
  - Typical Power : 0.25HP-0.5HP

Package

TO-252-2

TO-220-2

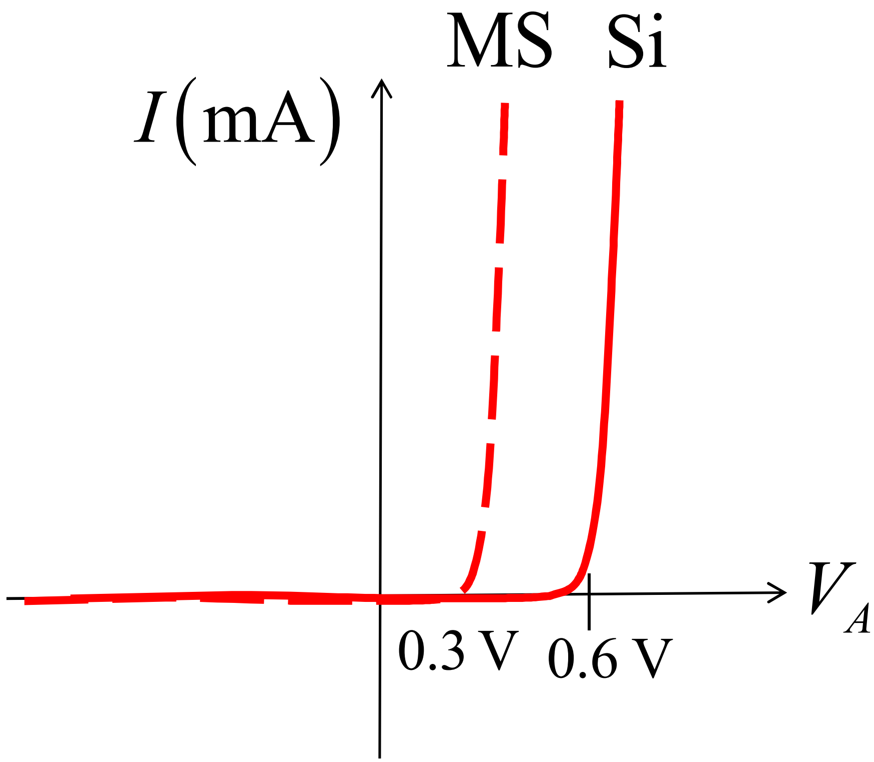
RoHS

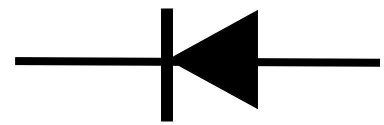


Halogen-Free

Part Number	Package	Marking
CSD01060A	TO-220-2	CSD01060
CSD01060E	TO-252-2	CSD01060

IV characteristics





$$J = J_0\left(e^{qV_A/k_BT} - 1\right)$$

$$J_0 = A^* T^2 e^{-\Phi_{BN}/k_BT}$$

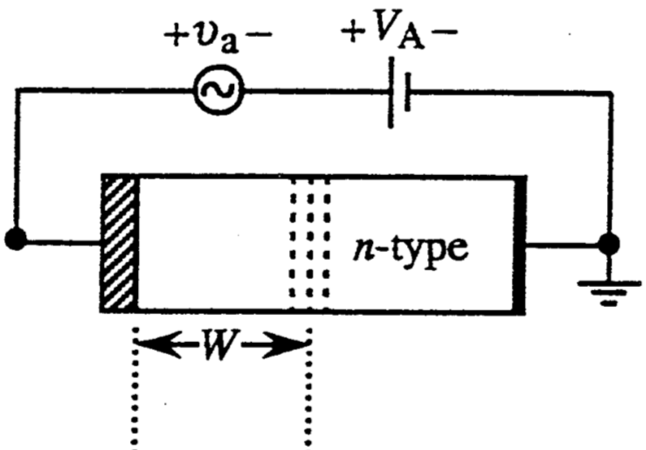
$$\boxed{J_0(MS) >> J_0(NP)}$$

Strongly controlled by SB height.

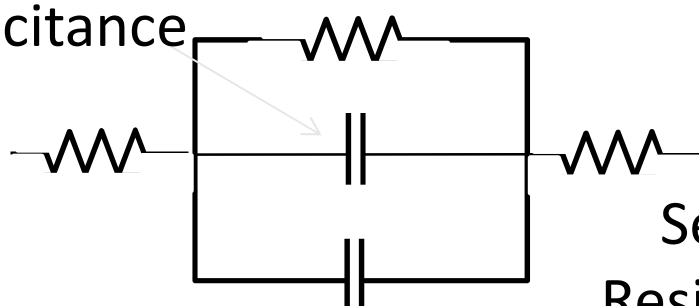
Topic Map

	Equilibrium	DC	**Small signal**	Large Signal	Circuits
Diode					
Schottky			◆		
BJT/HBT					
MOSFET					

AC response

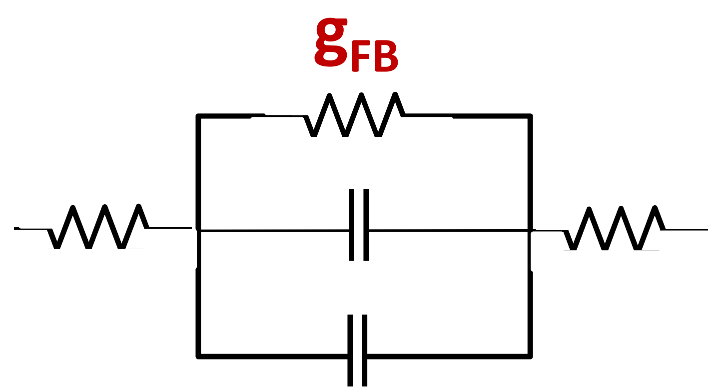


$+v_a-$
$+V_A-$
n-type
W



Conductance
Junction Capacitance
Series Resistance
Diffusion Capacitance

Forward Bias Conductance



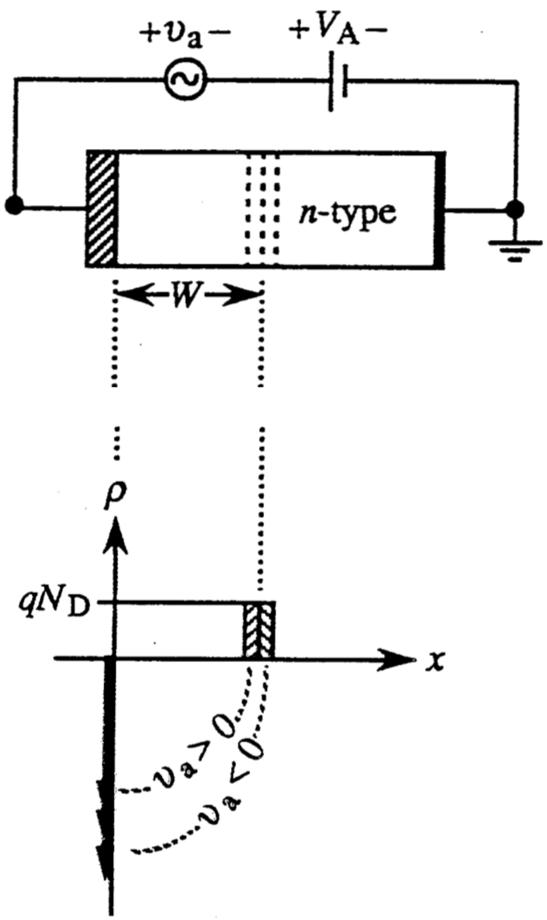
$$I = I_o\left(e^{q(V_A - R_S I)/mk_B T} - 1\right)$$

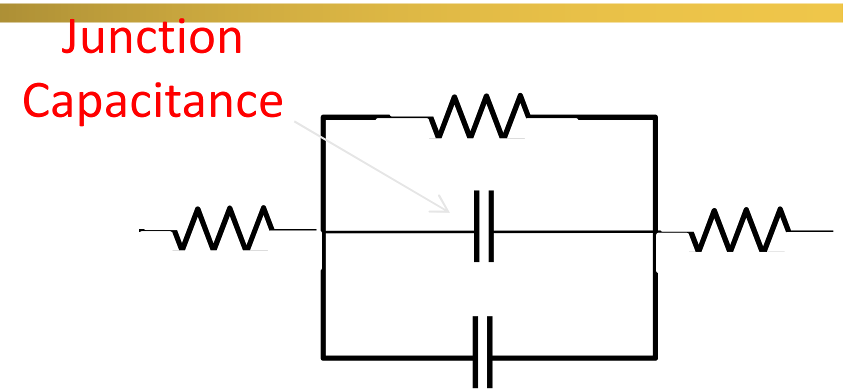
$$\ln\left(\frac{I + I_o}{I_0}\right) = q(V_A - R_S I)/mk_B T$$

$$\frac{mk_B T}{q(I + I_o)} = \frac{dV_A}{dI} - R_S$$

$$\frac{1}{g_{FB}} = R_S + \frac{m}{q\beta(I + I_0)}$$

Junction Capacitance (Majority Carriers)

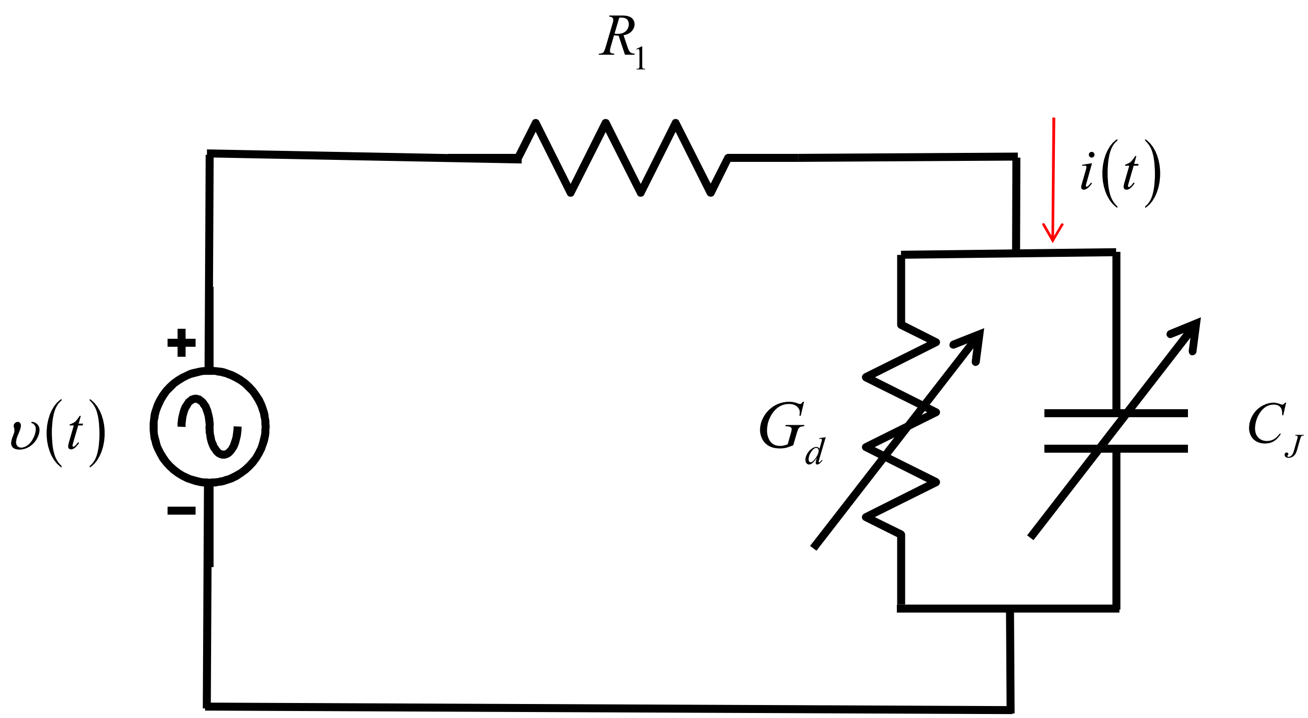




$$C_J = \frac{\kappa_s \varepsilon_0 A}{W}$$

$$C_J = \frac{\kappa_s \varepsilon_0 A}{\sqrt{\frac{2\kappa_s \varepsilon_0}{qN_D}(V_{bi} - V_A)}}$$

small signal model (MS diode)



No diffusion capacitance!

$$G_d = \frac{dI_D}{dV_D}$$

$$C_J(V_A) = \frac{K_S \varepsilon_0 A}{W(V_A)}$$

summary

1) A Schottky diode is a metal-semiconductor majority carrier device
2) It is similar to a one-sided p-n junction transistor, since the electron concentration in metals is very high.
3) Current is calculated using thermionic emission
4) M-S diodes typically have much higher saturation current and no diffusion capacitance, making them very fast