Georgia Tech

ECE 4813

Semiconductor Device and Material Characterization

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As with all of these lecture slides, I am indebted to Dr. Dieter Schroder from Arizona State University for his generous contributions and freely given resources. Most of (>80%) the figures/slides in this lecture came from Dieter. Some of these figures are copyrighted and can be found within the class text, *Semiconductor Device and Materials Characterization*. ***Every serious microelectronics student should have a copy of this book!***

Diodes

PN Junction Diodes

Current - Voltage

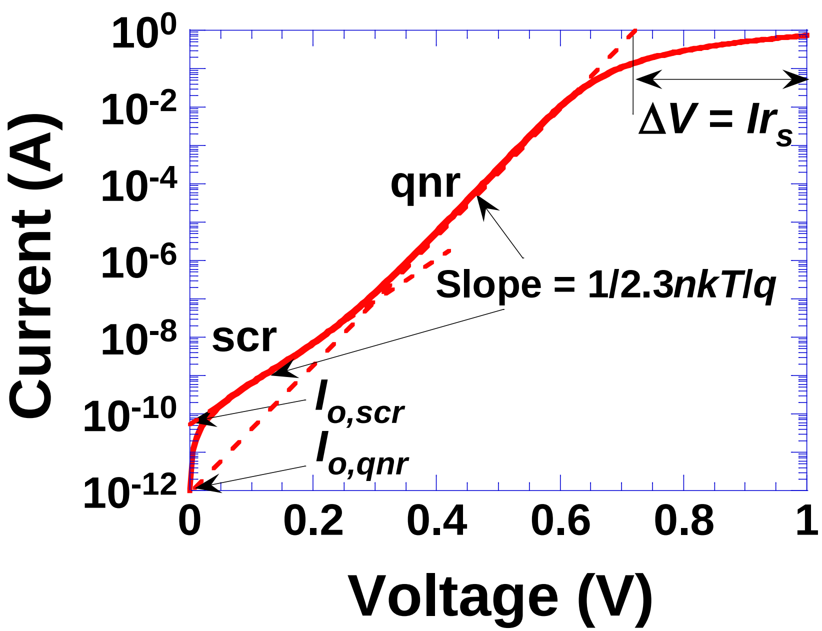
Series Resistance

Schottky Diodes

PN Junction Diodes

- The current in a Si pn junction diode at room temperature is due to recombination in the *space-charge region*, I_{scr}, and the *quasi-neutral regions*, I_{qnr}

$$I = I_{o,scr}\left(\exp\left(\frac{q(V - Ir_s)}{n_{scr}kT}\right) - 1\right) + I_{o,qnr}\left(\exp\left(\frac{q(V - Ir_s)}{n_{qnr}kT}\right) - 1\right)$$



For V > 3kT/q and negligible r_s:

$$I = I_o \exp\left(\frac{qV}{nkT}\right)$$

$$\log I = \log I_o + qV/nkT\ \ln 10$$

$$V = 0 \text{ intercept} \Rightarrow I = I_o$$

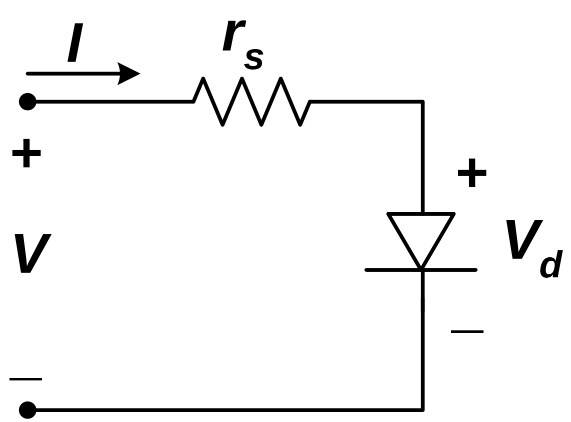
$$Slope = \frac{d\log I}{dV} = \frac{1}{\ln 10\, nkT/q}$$

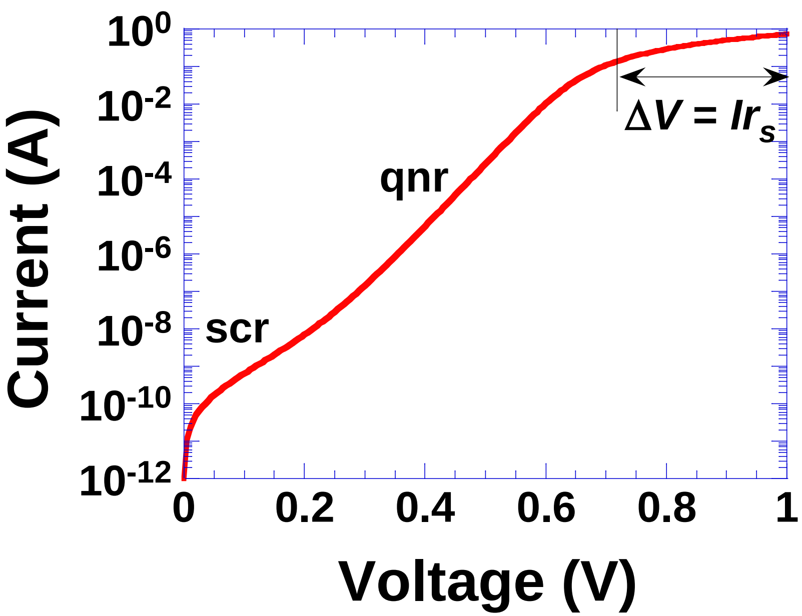
PN Junction Diode Resistance

- Diode series resistance reduces the current

$$I = I_0\left(\exp\left(\frac{qV_d}{nkT}\right) - 1\right) \qquad V = V_d + Ir_s$$

$$I = I_0\left(\exp\left(\frac{q(V - Ir_s)}{nkT}\right) - 1\right)$$





Diode Resistance

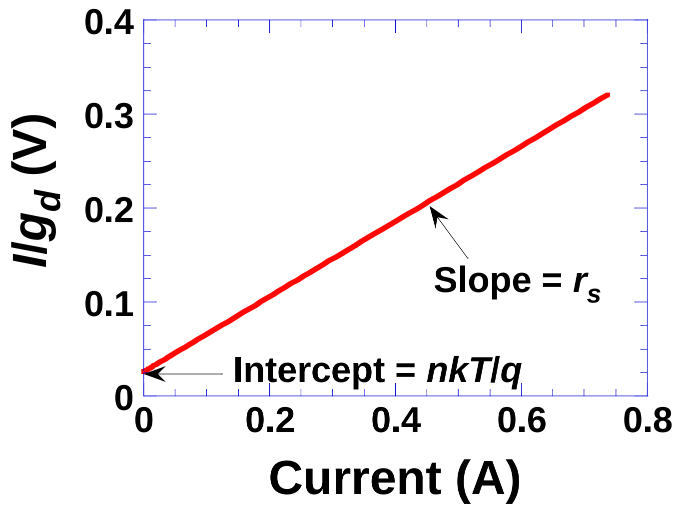
$$I = I_o \exp\left(\frac{q(V - Ir_s)}{nkT}\right)$$

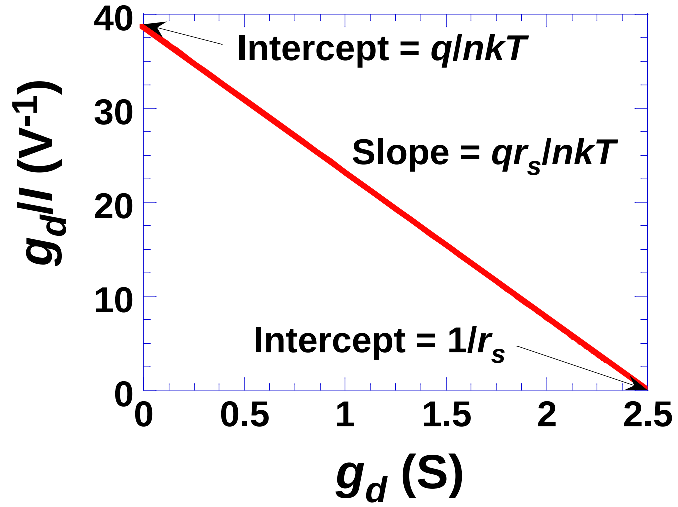
- Diode conductance

$$g_d = \frac{I(1 - r_s g_d)}{nkT/q}$$

$$\frac{g_d}{I} = \frac{1 - r_s g_d}{nkT/q}$$

$$\frac{I}{g_d} = \frac{nkT}{q} + Ir_s$$





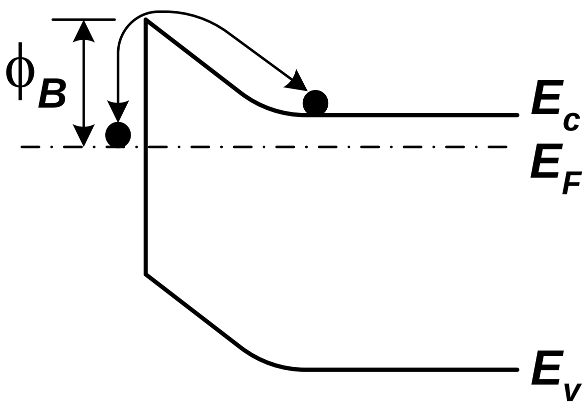
Schottky Barrier Diodes

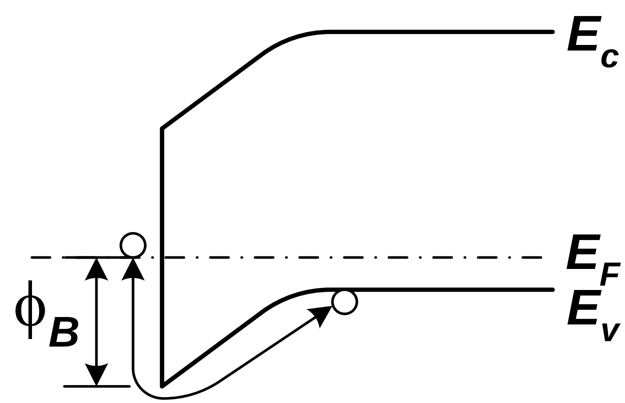
- **Schottky barrier diodes have *I-V* curves very similar to *pn* junction diodes**
- **The turn-on voltage can be controlled more than that of *pn* diodes because the barrier height can be controlled somewhat**

$$I = I_s\left(e^{qV/nkT} - 1\right); \quad I_s = AA^*T^2 e^{-q\phi_B/kT}$$

$$A^* = 4\pi q k^2 m_n^*/h^3 = 120\left(m_0/m_n^*\right)\ A/cm^2K^2$$

Richardson Constant





Schottky Barrier Diodes: *I - V*

$$I = I_s\left(e^{qV/nkT} - 1\right); \quad I_s = AA^*T^2e^{-q\phi_B/kT}$$

Want n, A^* and ϕ_B

- ***Current - Voltage***

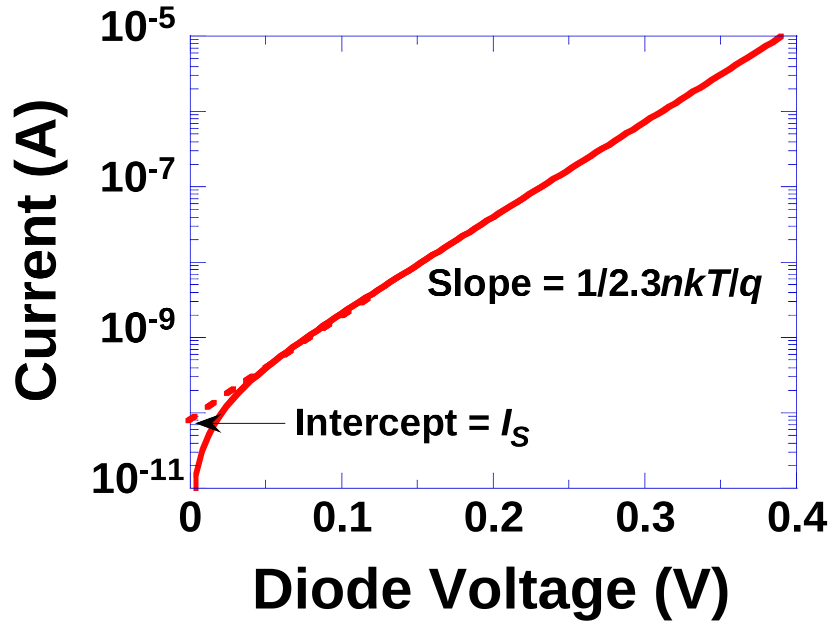
$$\log I = \log I_S + qV/nkT\ \ln 10$$

$$V = 0 \text{ intercept} \Rightarrow I = I_S$$

$$Slope = \frac{d\log I}{dV} = \frac{1}{\ln 10\, nkT/q}$$

$$\phi_B = \frac{kT}{q}\ln\left(\frac{AA^*T^2}{I_S}\right)$$

Need to know A^*



For $V \geq 4\,kT/q \Rightarrow I = I_s e^{qV/nkT}$

Schottky Barrier Diodes: *I* - *T*

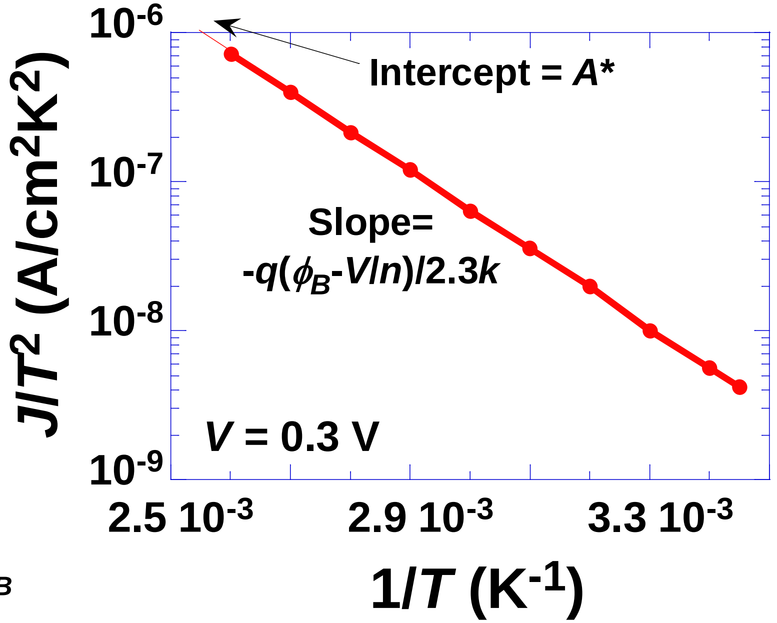
- log(J/T^2) versus 1/T
  - To determine ϕ_B and A^*

$$J = A^* T^2 \exp\left(-q\left(\phi_B - V/n\right)/kT\right)$$

$$\ln\left(J/T^2\right) = \ln A^* - \frac{q\left(\phi_B - V/n\right)}{kT}$$

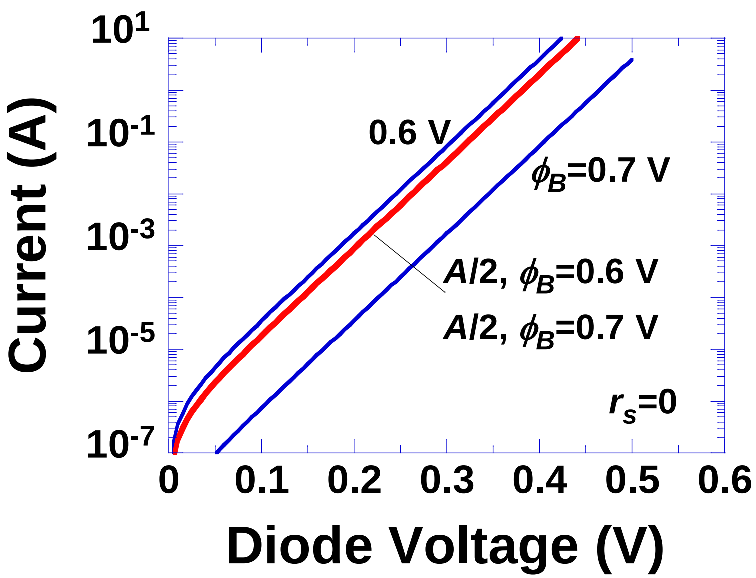
1/T = 0 intercept = A^*

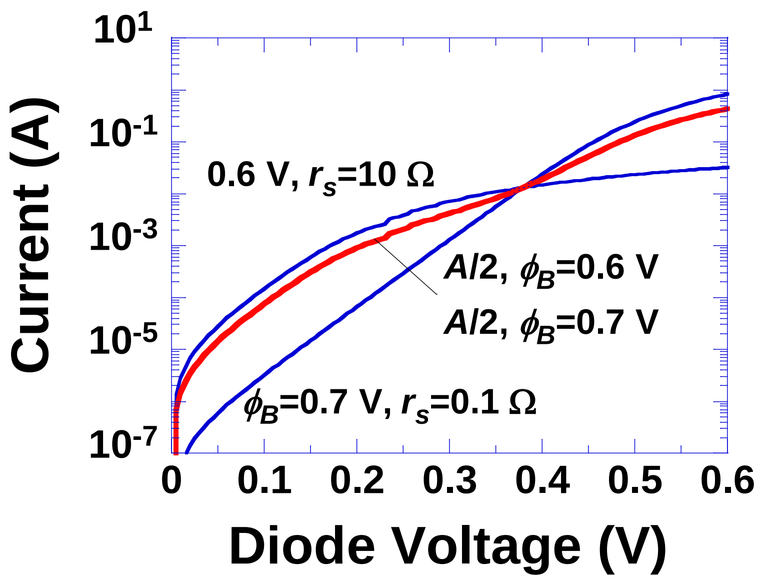
$$Slope = \frac{d\,log\left(J/T^2\right)}{d\left(1/T\right)} = -\frac{q\left(\phi_B - V/n\right)}{k\,ln(10)} \Rightarrow \phi_B$$



Schottky Barrier Diodes: *I - V*

- Barrier height can be determined from *I-V* or *I-T* plots
- Forward-biased current is very sensitive to barrier height
- If barrier height non-uniform, the lowest barrier height regions dominate
- Series resistance is important



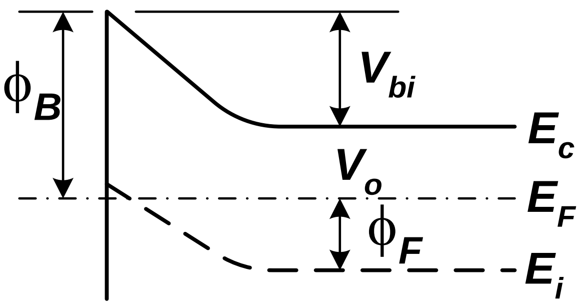


Schottky Barrier Diodes: *C - V*

- ***C-V*** **measurements are less sensitive to ϕ_B variations**

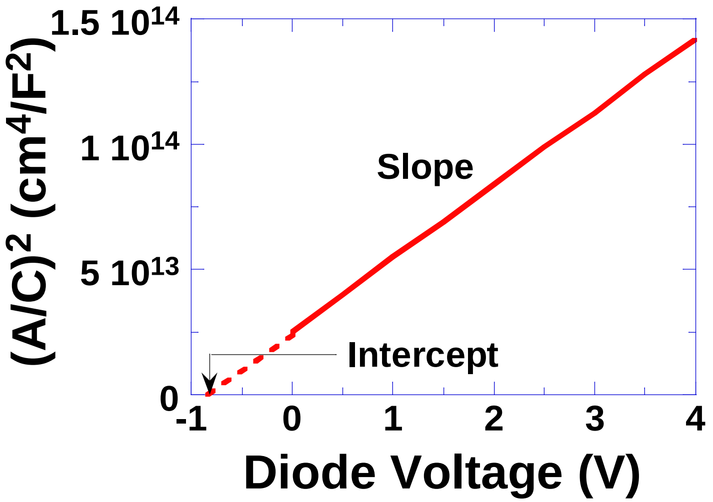
$$\frac{C}{A} = \sqrt{\frac{qK_s\varepsilon_0 N_D}{2(V_{bi} - V)}}$$

$$\left(\frac{A}{C}\right)^2 = \frac{2(V_{bi} - V)}{qK_s\varepsilon_0 N_D}$$



- **Slope $\Rightarrow N_D$**

$$Slope = \frac{-2}{qK_s\varepsilon_0 N_D}$$



- **Intercept $\Rightarrow \phi_B$**

$$\phi_B = V_{bi} + V_o$$

$$V_o = E_G/q - E_i/q - \phi_F$$

Review Questions

- Why is the *I-V* curve a straight line on a semilog plot?
- Why does a Si diode log*I* – *V* curve have two slopes?
- How does series resistance affect the diode current?
- How is the barrier height of Schottky diodes determined?
- Why can the Schottky diode barrier heights be different when determined from *I-V* or *C-V* data?