Diode Modeling
(Part 1)

Dr. José Ernesto Rayas Sánchez

Some figures of this presentation were taken from the instructional resources of the following textbooks:

A. S. Sedra and K. C. Smith, *Microelectronic Circuits*. New York, NY: Oxford University Press, 2003.

A. R. Hambley, *Electronics: A Top-Down Approach to Computer-Aided Circuit Design*. Englewood Cliffs, NJ: Prentice Hall, 2000.

R. C. Jaeger, *Microelectronic Circuits Design*. New York, NY: McGraw Hill, 1997.

D. A. Neamen, *Electronic Circuits Analysis and Design*. New York, NY: McGraw Hill, 2001.

1

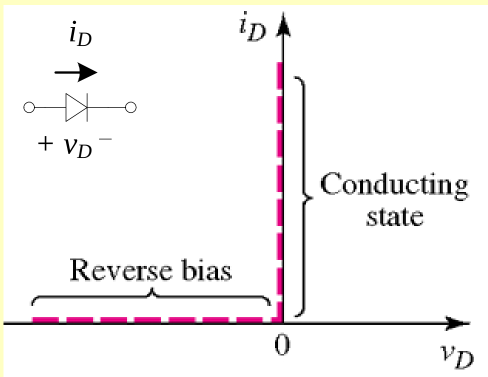
Outline

- The ideal diode
- I-V characteristics
- Shockley equation
- I-V characteristics of practical diodes
- Improving model based on Shockley equation
- Simplified large signal DC models

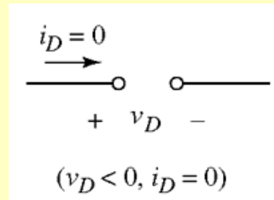
Dr. J. E. Rayas Sánchez

2

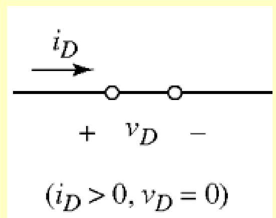
Ideal Diode



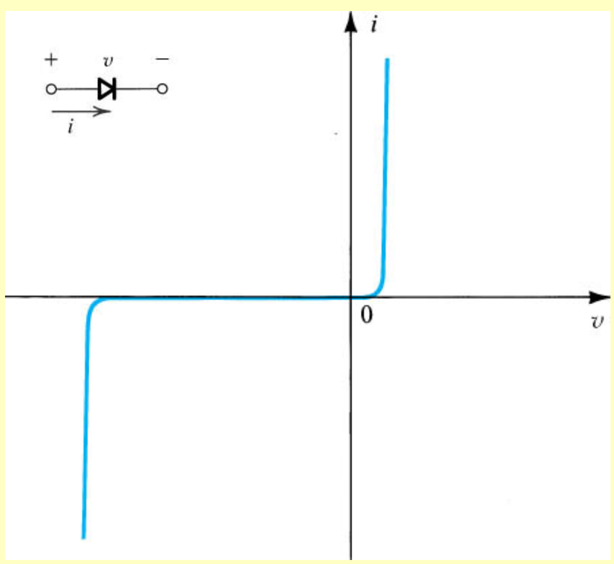
Reverse biased



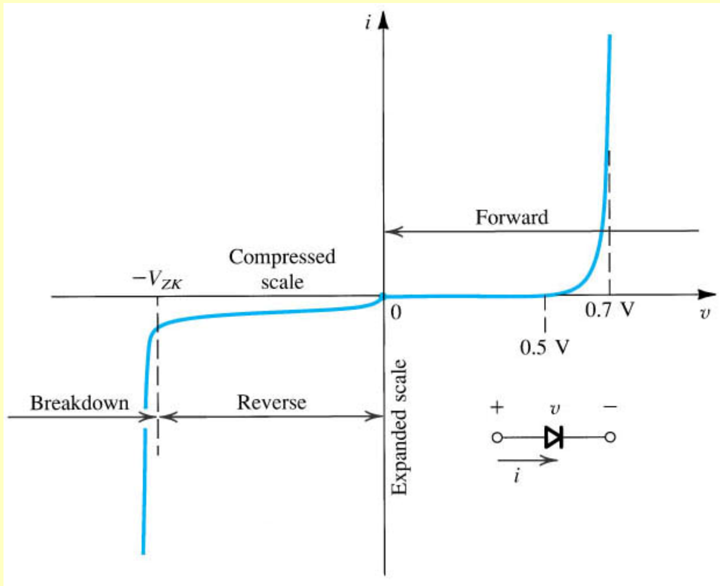
Forward biased



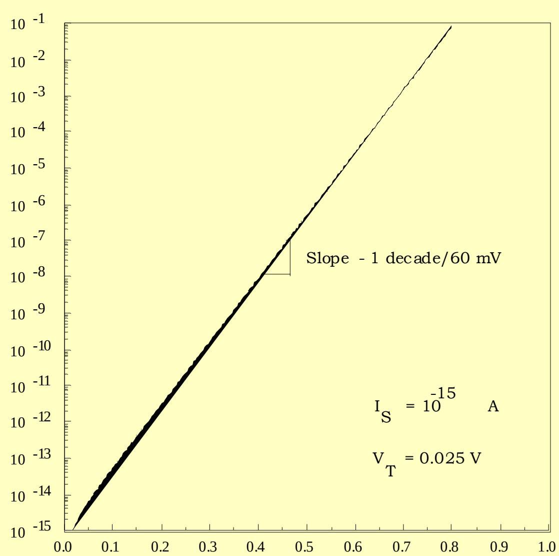
I-V Characteristics



I-V Characteristics (cont)



I-V Characteristics – Logarithmic Scale



Diode Models – Shockley Equation

It can be derived from semiconductor physics

$$I_D = I_S(e^{\frac{V_D}{\eta V_T}} - 1)$$

η : Emission coefficient

I_S : Saturation current (or scaling current)

V_T : Thermal voltage

Dr. J. E. Rayas Sánchez 7

Diode Models – Shockley Equation (cont)

- Emission coefficient, η, typically lies within $1 \le \eta \le 2.5$

  $\eta \approx 1.1$ for high-diffusion p-n junctions (I.C. diodes)

  $\eta \approx 2.3$ for high-recombination p-n junctions (discrete diodes)

- Thermal voltage, V_T , is given by

$$V_T = \frac{kT}{q} \approx \frac{T}{11{,}594}$$

k : Boltzman constant ($k = 1.38\times10^{-23}$ J/Kelvin)

T : Ambient temperature in Kelvins ($T_{\text{Kelvins}} = 273 + T_{\circ\text{C}}$)

q : Electron charge ($q = 1.6\times10^{-19}$ C)

Dr. J. E. Rayas Sánchez 8

Diode Models – Shockley Equation (cont)

Saturation or scaling current, I_S , is given by

$$I_S = qA\left(\frac{D_p p_o}{L_p} + \frac{D_n n_o}{L_n}\right)$$

A : Area of the p-n junction cross-section (m^2)

D_n, D_p: Diffusion constant of the electrons and holes, respectively (m^2/s)

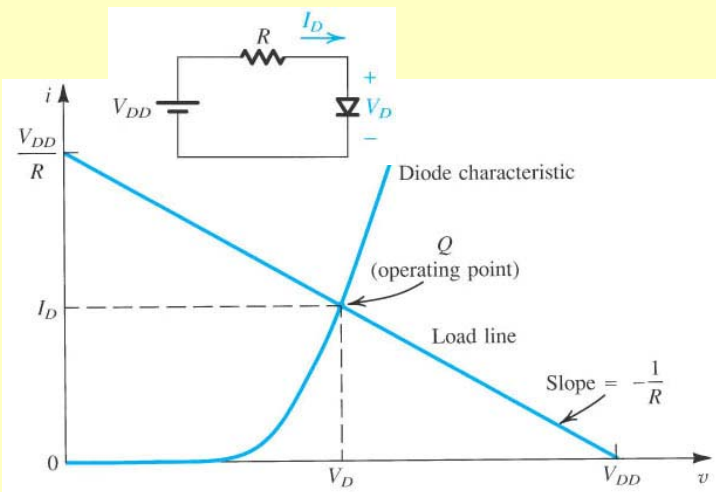
L_n, L_p: Diffusion length of the electrons and holes, respectively (m)

n_o, p_o: Concentration of minority carriers at thermal equilibrium in regions n and p, respectively (m^{-3})

I_S is directly proportional to A

Using Shockley Equation

In practice, Shockley equation can only be used by numerical methods or by graphical methods



I-V Characteristics of a Real Discrete Diode

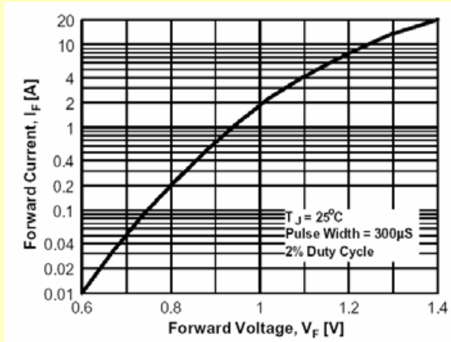


Figure 2. Forward Voltage Characteristics

At high currents, the exponential behavior is no longer observed

I-V Characteristics of a Real Discrete Diode

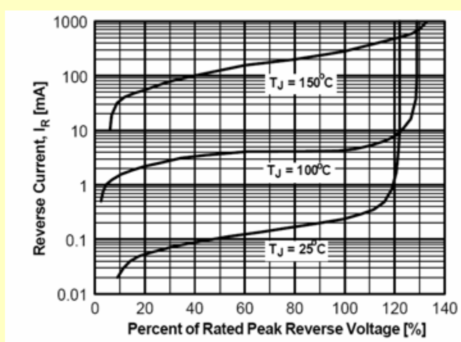
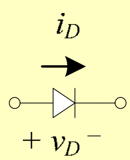
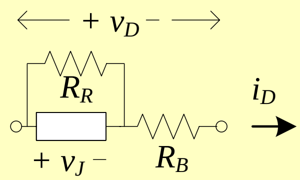


Figure 4. Reverse Current vs Reverse Voltage

With large reverse voltages, the current is much larger than I_S

Improving Model based on Shockley Equation





$$i_J = I_S\left(e^{\frac{v_J}{\eta V_T}} - 1\right)$$

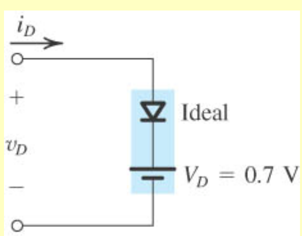
R_R Reverse resistor ($I_R >> I_S$)

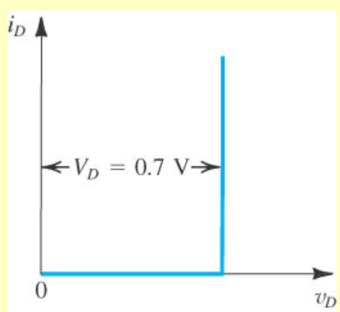
R_B Bulk resistor and resistor of metal contacts

$$R_R \approx \frac{PIV}{I_{R_{\max}}} \qquad R_B \approx \frac{V_{F_{\max}} - V_{F_{\text{nom}}}}{I_{F_{\max}} - I_{F_{\text{nom}}}}$$

Simplified Large Signal DC Models

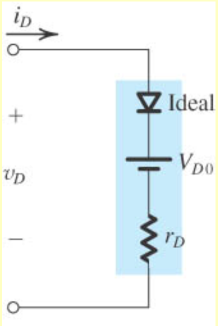
- Ideal Diode + Battery

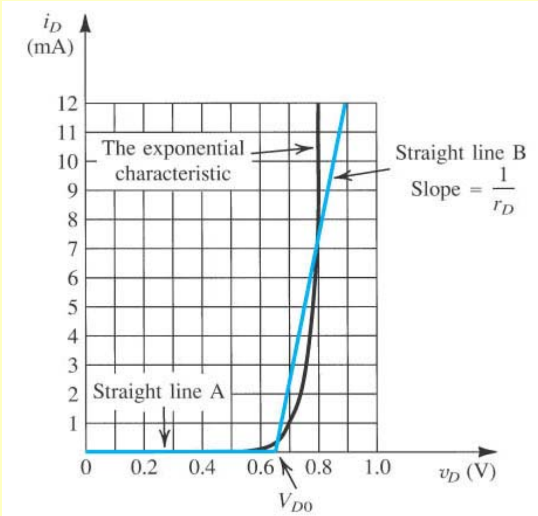




Simplified Large Signal DC Models

- Ideal Diode + Battery + Resistor





Dr. J. E. Rayas Sánchez 15