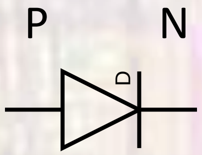
PN Diodes

Last updated 7/1/23

These concepts have been greatly simplified

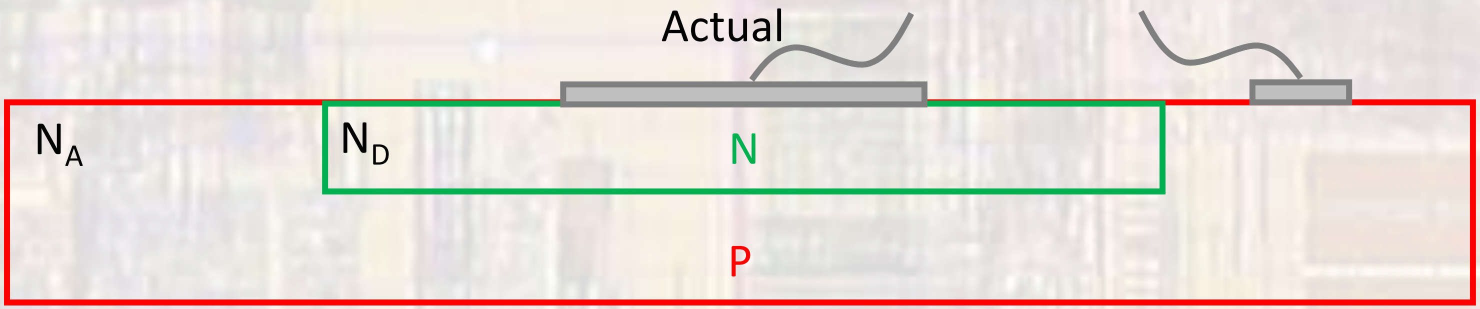
PN Diodes

- Construction



Conceptual

Actual

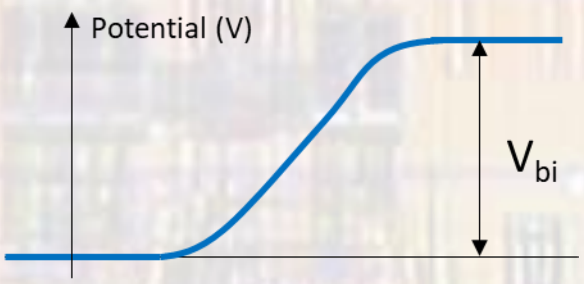


PN Diodes

- Carrier Concentrations – built-in Potential

Electric Potential: Amount of work needed to move a unit charge from a reference point to a specific point against an electric field

Required voltage to get current to flow from P→N



$$V_{bi} = \frac{kT}{q} ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$V_{bi} = V_T ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$V_T = \frac{kT}{q} = 26mV\ @RT$$

k - Boltzmann's Constant
$k = 1.38 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1}$

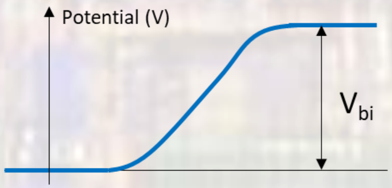
q – electron charge
$q = 1.60 \times 10^{-19}$ coulombs

n_i = Intrinsic carrier concentration
$n_i = 1.5x10^{10}cm^{-3}$ for Si at RT

T – Temperature in Kelvin
70°F → 21°C → 294K
Typically call Room Temp (RT) 300K

PN Diodes

- Carrier Concentrations – built-in Potential



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Si diode @RT with $N_A = 10^{17}$, $N_D = 10^{16}$

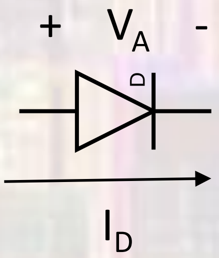
$$V_{bi} = \frac{1.38 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1} \times 300K}{1.60 \times 10^{-19}\ \text{coulombs}} ln\left(\frac{10^{17} cm^{-3} \times 10^{16}\ cm^{-3}}{(1.5 \times 10^{10} cm^{-3})^2}\right)$$

$$V_{bi} = 753mV$$

Note: @RT, $V_T = \frac{kT}{q} = 25.9mV \approx 26mV$
this is a common simplification
$V_{bi} = 757mV$

PN Diodes

- Ideal Diode Equation



$$I_D = I_S\left[e^{\left(\frac{qV_A}{nkT}\right)} - 1\right] = I_S\left[e^{\left(\frac{V_A}{nV_T}\right)} - 1\right]$$

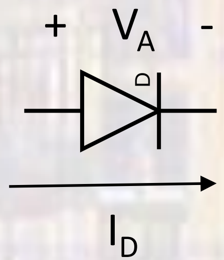
n	Accounts for non-idealities Typically, between 1 and 2
I_S	proportional to Area (A) Inversely proportional to Doping (n_{po}, p_{no}) Typically, 10^{-12}A – 10^{-18}A

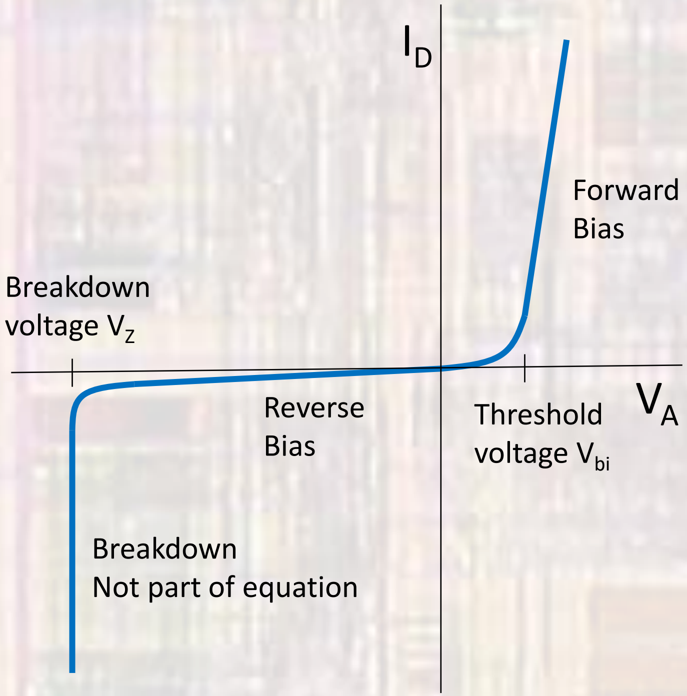
n

PN Diodes

- Real diode behavior

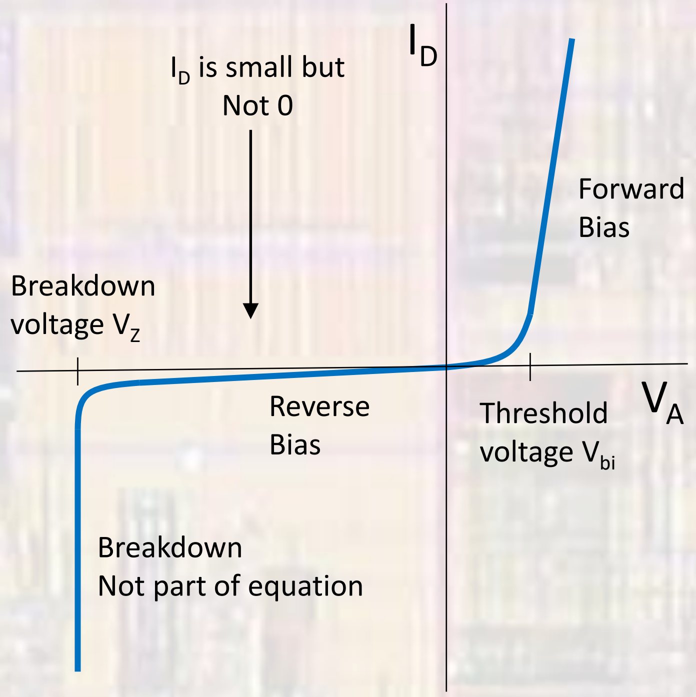
$$I_D = I_S\left[e^{\left(\frac{qV_A}{nkT}\right)} - 1\right] = I_S\left[e^{\left(\frac{V_A}{nV_T}\right)} - 1\right]$$





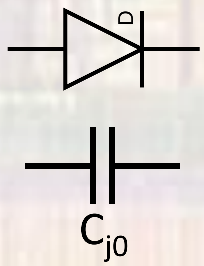
PN Diodes

- Reverse bias leakage current
  - For negative biases – the current is NOT 0
  - This will impact our digital circuit power consumption



PN Diodes

- Carrier Concentrations – junction capacitance



  - The depletion region (area near the junction) acts like an insulator
    - No mobile charge
    - At 0V external bias the capacitance is C_{j0}
  - This will limit the speed of our digital systems