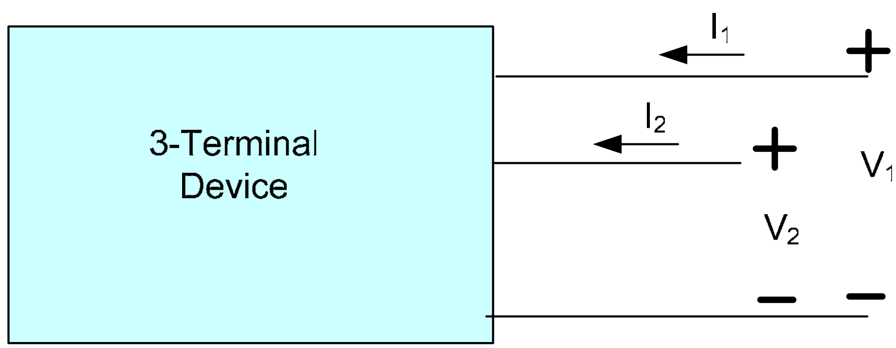
EE 434
Lecture 14

Devices in Semiconductor Processes

Quiz 10

We saw that there were 80 different ways to represent equivalent models for a 4-terminal device with these difference representations being determined by which terminal of the device is selected as a reference and by which port variables are assumed to be independent. What is the corresponding number of different ways to represent equivalent models for a 3-terminal device?



And the number is ….

1 8 7 5 3

6 9 4 2

3

Quiz 10

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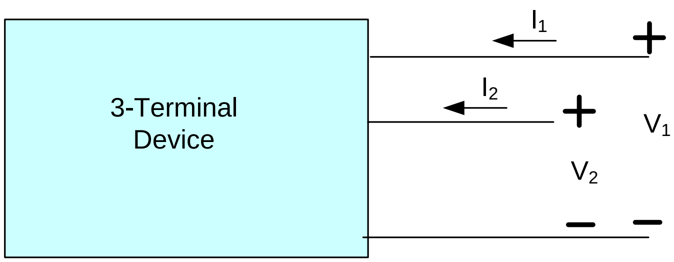
Solution:



Port Variables $= \{I_1, I_2, V_1, V_2\}$

There are n_1=3 ways a reference terminal can be selected

There are a total of 4 port electrical variables and any two of these can be selected as independent variables

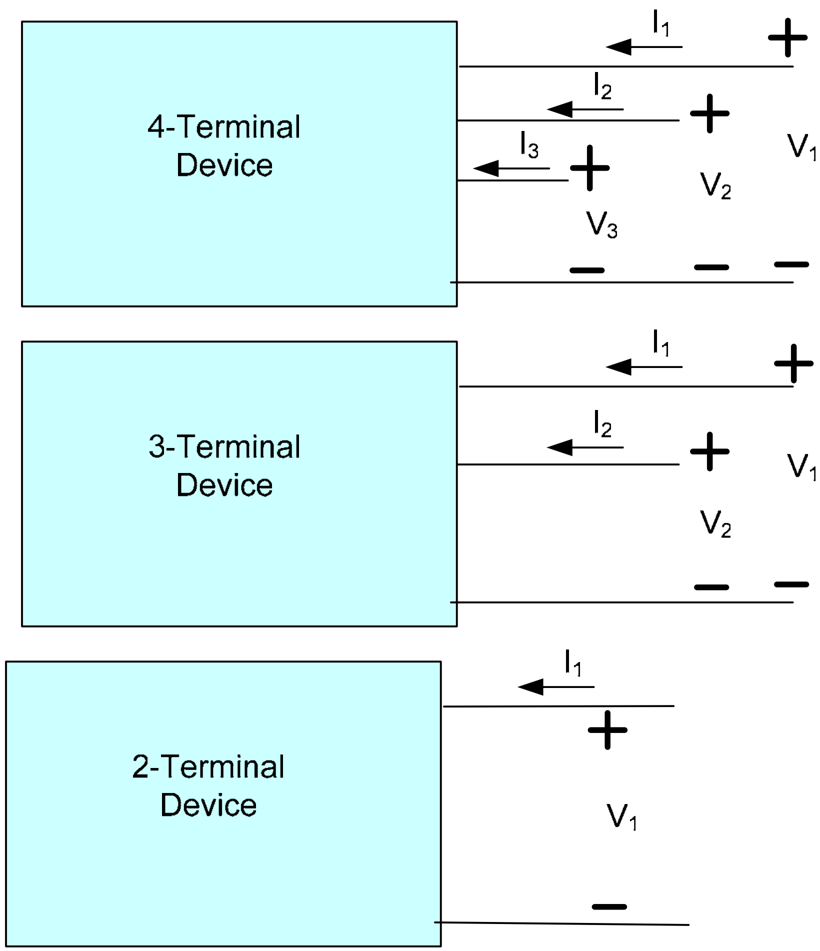
$$n = 3\binom{4}{2} = 3\frac{4!}{(4-2)!2!} = 18$$

$$\left.\begin{aligned} I_1 &= f_1(V_1, V_2) \\ I_2 &= f_2(V_1, V_2) \end{aligned}\right\}$$

Review from Last Time

Device Modeling

Goal: Obtain a mathematical relationship between the port variables of a device.



$$\left.\begin{array}{l} I_1 = f_1(V_1, V_2, V_3) \\ I_2 = f_2(V_1, V_2, V_3) \\ I_3 = f_3(V_1, V_2, V_3) \end{array}\right\}$$

$$\left.\begin{array}{l} I_1 = f_1(V_1, V_2) \\ I_2 = f_2(V_1, V_2) \end{array}\right\}$$

$$I_1 = f_1(V_1) \quad \}$$

Review from Last Time

Resistors are film devices since vertical dimensions small compared to lateral dimensions

Almost any layer can be (and is) used to form a resistor

Some have more attractive linearity or area requirements

Poly often material of choice for resistors

Voltage and Temperature performance characterized by VCR and TCR

$$\mathbf{VCR} = \left(\frac{1}{R}\frac{dR}{dV}\right)\Bigg|_{\text{ref voltage}}^{10^6} \qquad \text{ppm/V} \qquad R(T_2) \approx R(T_1)\left[1 + (T_2 - T_1)\frac{TCR}{10^6}\right]$$

$$TCR = \left(\frac{1}{R}\frac{dR}{dT}\right)\Bigg|_{\text{op. temp}}^{10^6} \qquad \text{ppm/°C} \qquad R(V_2) \approx R(V_1)\left[1 + (V_2 - V_1)\frac{VCR}{10^6}\right]$$

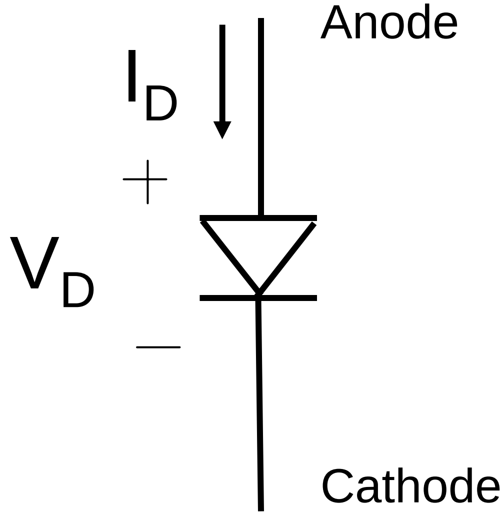
Conductivity of copper more attractive than that of aluminum

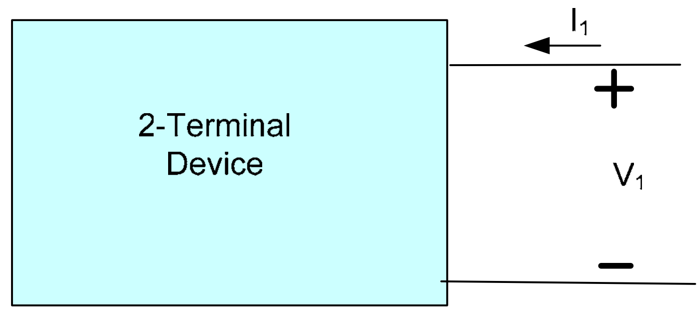
Basic Devices and Device Models

- Resistor
- Diode
- Capacitor
- MOSFET
- BJT

Diode Operation and Model

Goal: Obtain a mathematical relationship between the port variables of the diode

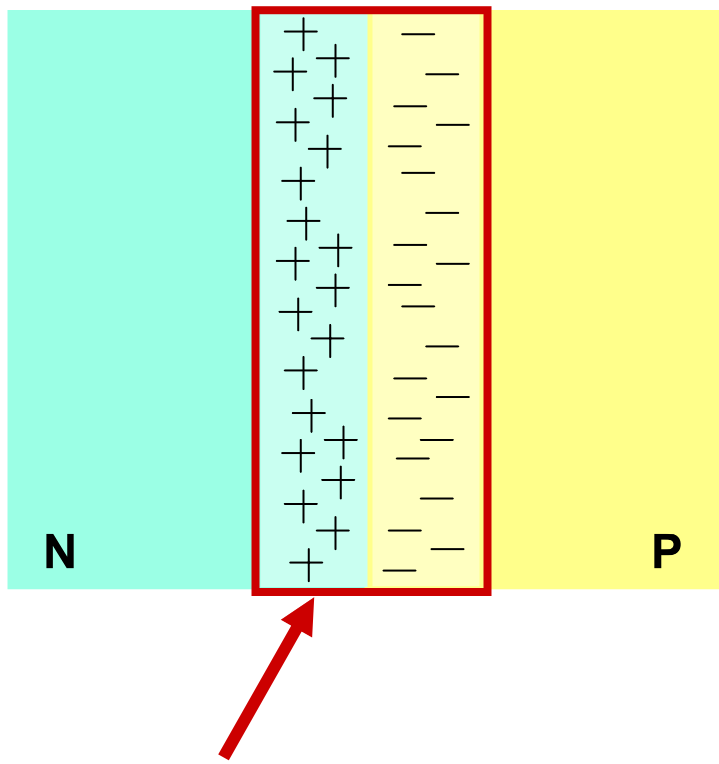




$$\mathbf{I_1 = f_1(V_1)} \quad \}$$

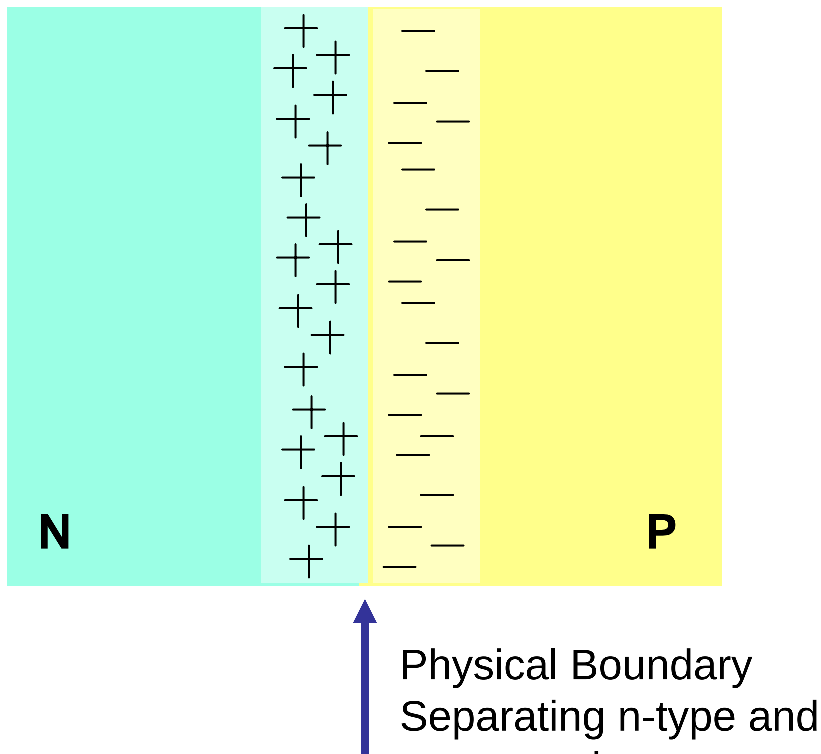
$$\mathbf{I_D = f_1(V_D)} \quad \}$$

Diodes (pn junctions)



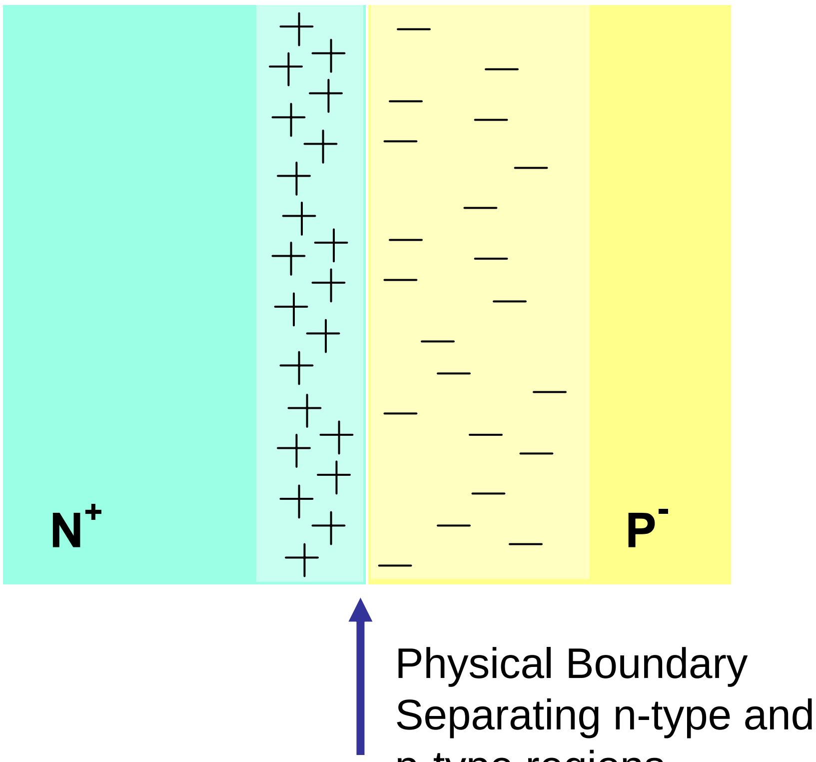
Depletion region created that is ionized but void of carriers

pn Junctions



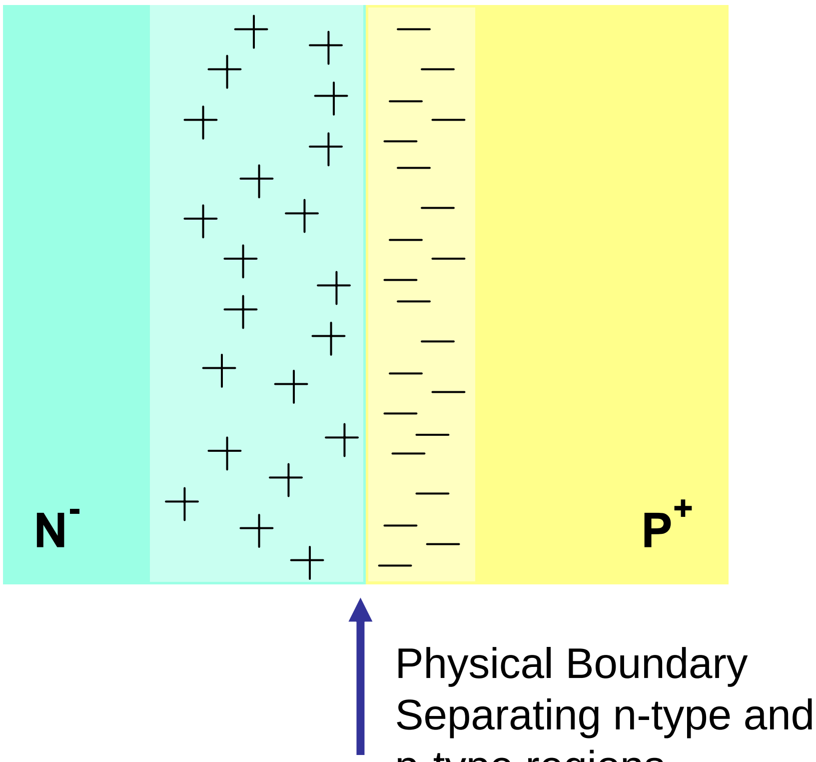
If doping levels identical, depletion region extends equally into n-type and p-type regions

pn Junctions



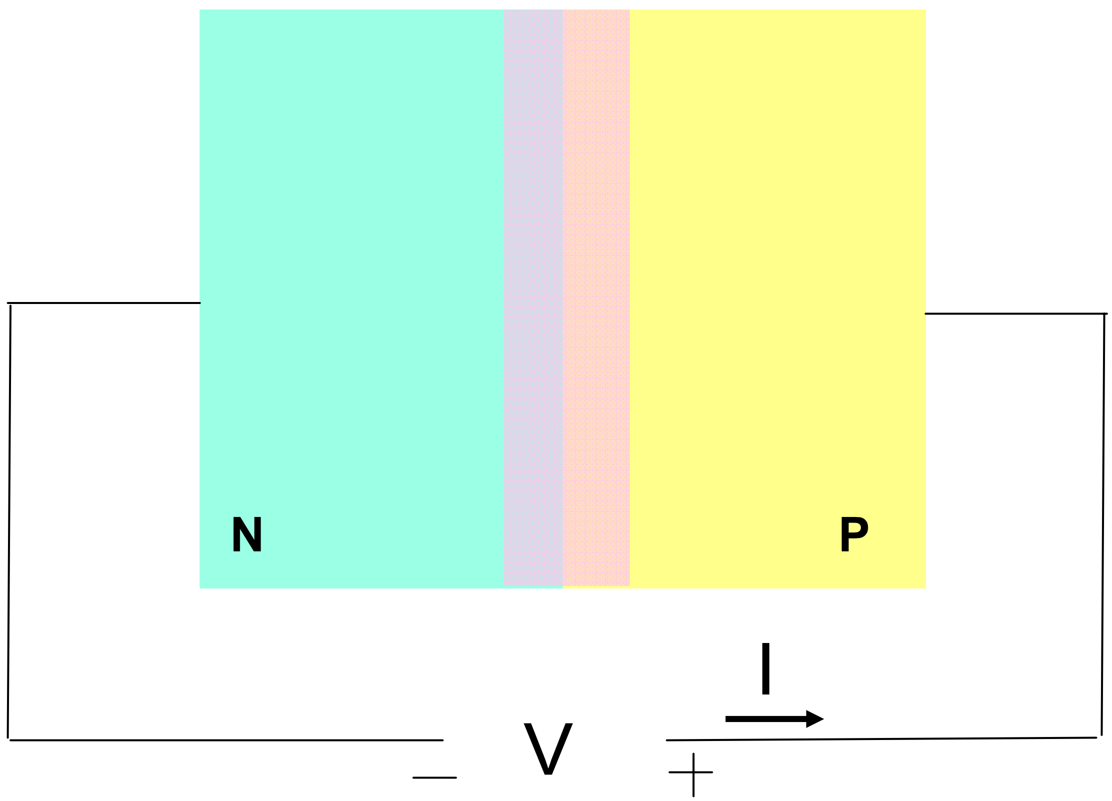
Extends farther into p-type region if p-doping lower than n-doping

pn Junctions

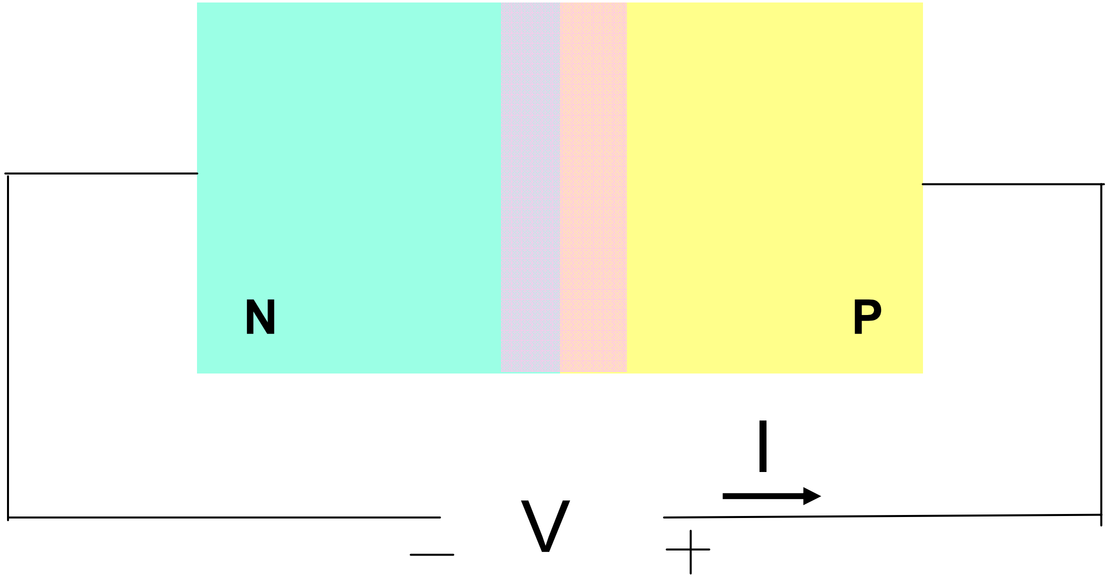


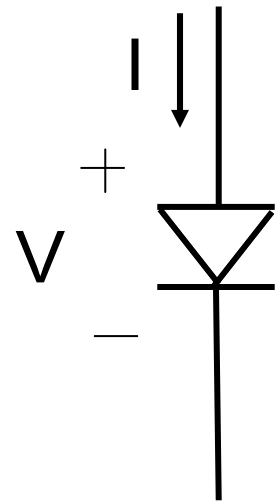
Extends farther into n-type region if n-doping lower than p-doping

pn Junctions



pn Junctions





Diode Equation:

$$I = \begin{cases} J_S A e^{\frac{V}{nV_T}} & V > 0 \\ 0 & V < 0 \end{cases}$$

J_S= Sat Current Density
A= Junction Cross Section Area
V_T=kT/q
n is approximately 1

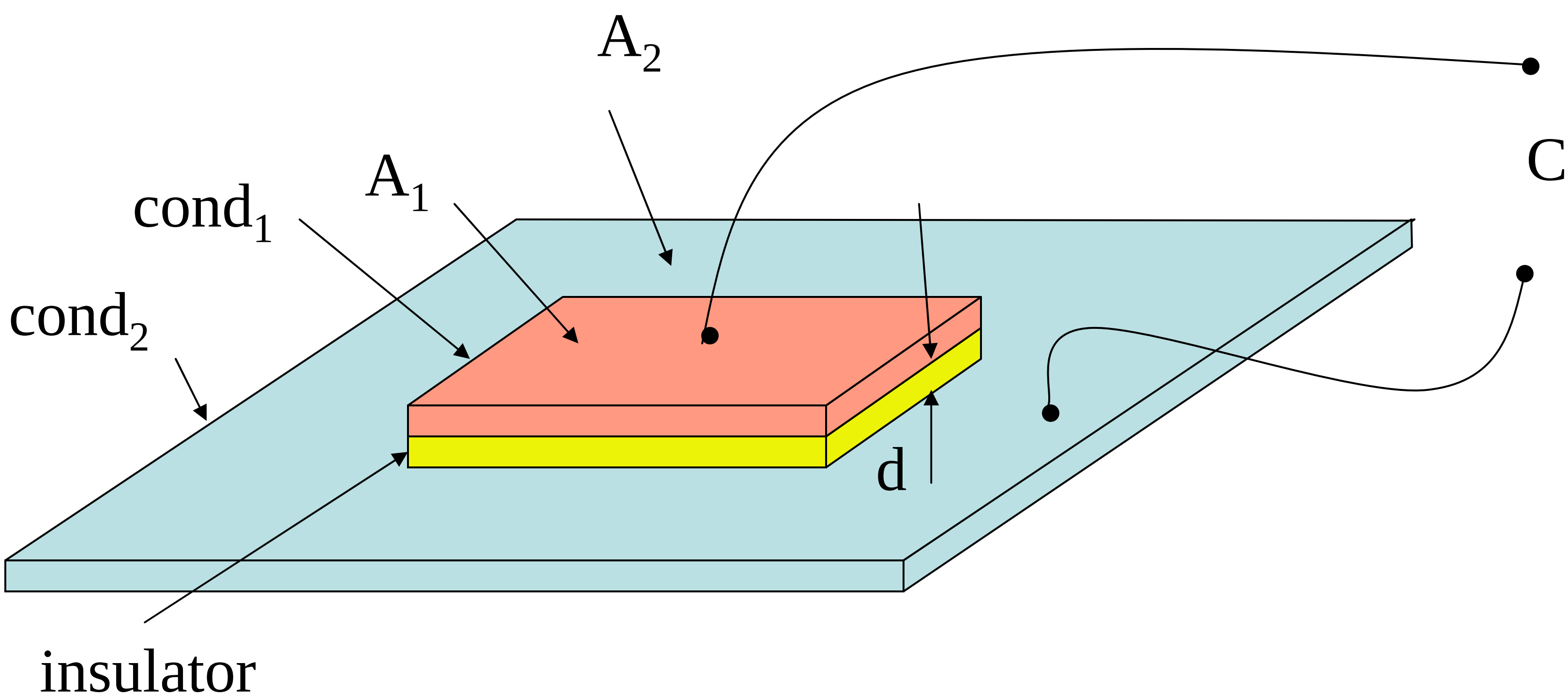
Basic Devices and Device Models

- Resistor
- Diode
- ➡ Capacitor
- MOSFET
- BJT

Capacitors

- Types
  - Parallel Plate
  - Fringe
  - Junction

Parallel Plate Capacitors



A = area of intersection of A_1 & A_2

One (top) plate intentionally sized smaller to determine C

$$C = \frac{\in A}{d}$$

ε: Dielectric constant

Parallel Plate Capacitors

$$\text{If } C_d = \frac{\text{Cap}}{\text{unit area}}$$

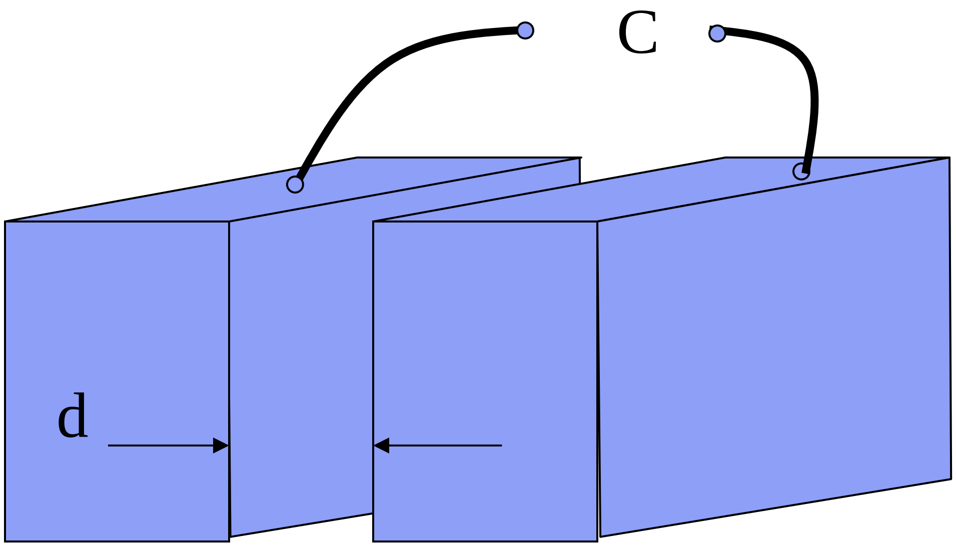
$$C = \frac{\varepsilon A}{d}$$

$$C = C_d A$$

where

$$C_d = \frac{\varepsilon}{d}$$

Fringe Capacitors

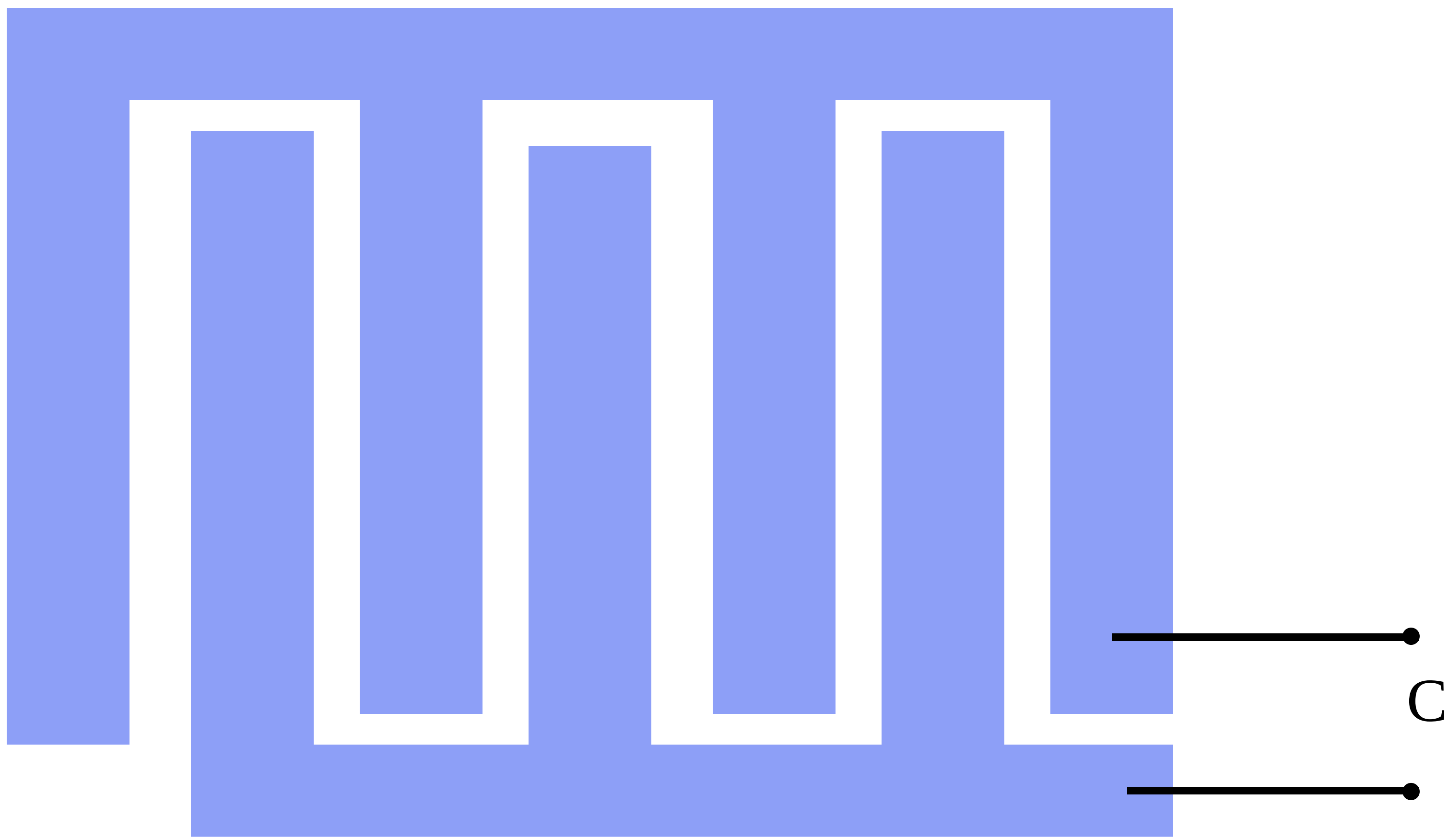


$$C = \frac{\varepsilon A}{d}$$

A is the area where the two plates are parallel

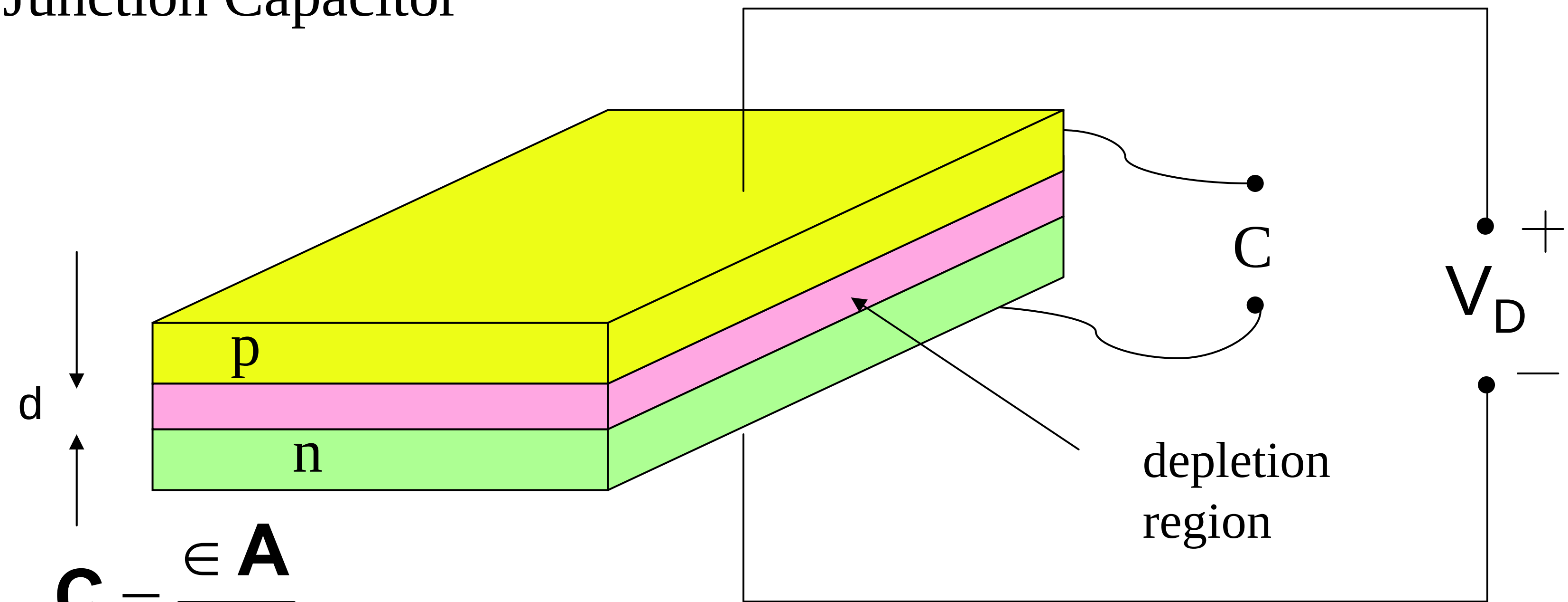
Only a single layer is needed to make fringe capacitors

Fringe Capacitors



Capacitance

Junction Capacitor



$$C = \frac{\in A}{d}$$

Note: d is voltage dependent
-capacitance is voltage dependent
-usually parasitic caps
-varicaps or varactor diodes exploit
voltage dep. of C

$$C = \frac{C_{jo}A}{\left(1 - \frac{V_D}{\varphi_B}\right)^n} \quad \textit{for} \quad V_{FB} < \frac{\varphi_B}{2}$$

$$\varphi_B \cong 0.6V$$

C_{j0}: junction capacitance at $V_D = 0V$

φ_B: barrier or built-in potential

End of Lecture 14