Intro to ECSE : Class 11 2/14/23

1) Overview of Lab02: Parts A & B

Purpose : 1) Introduce you to linearity (extremely important)
2) Give you more tools for designing & solving circuits (nodal analysis & some linear algebra)
3) Provide examples of non-linearity as a comparison (diodes & op-amps)

Part A: Defining Linear/Non-Linear Device Characteristics

today {
a) Resistors : draw, simulate, and measure IV characteristic
b) Diodes : draw, simulate, and measure IV characteristic
c) Resistance vs. Differential Resistance
↘ same for all I and V ↘ R depends on I and V

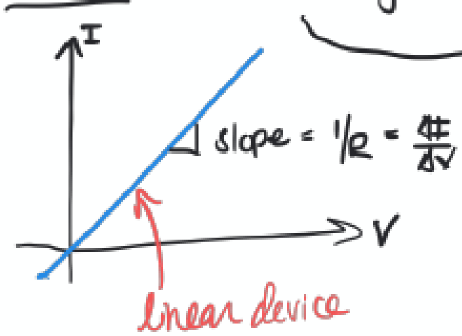
Part B : Solving Linear Resistive Networks Using Nodal Analysis

Friday {
a) Nodal Analysis: solve for the unknown nodal voltages in a circuit by summing currents at nodes (KCL)
b) Design circuits using nodal analysis

2) Linear and Non-Linear Current-Voltage (IV) Characteristics

i) Resistor : $V = IR$ $y(x) = mx$ → $I(V) = V/R$

$$\frac{\Delta I}{\Delta V} = 1/R$$



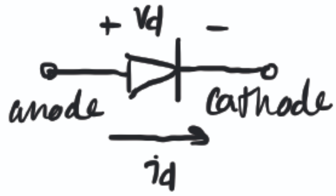
- slope is the same at all values of V and I (R is constant)

$R \neq R(I) \neq R(V)$

ii) Diode : allows current to pass in one direction, but not in the other

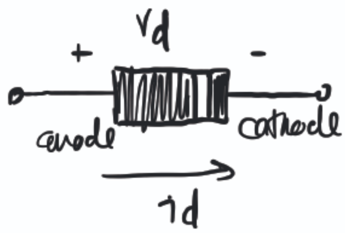
a) Simple ideal diode model

circuit symbol:

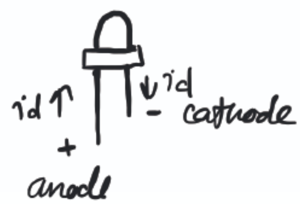


actual appearance:

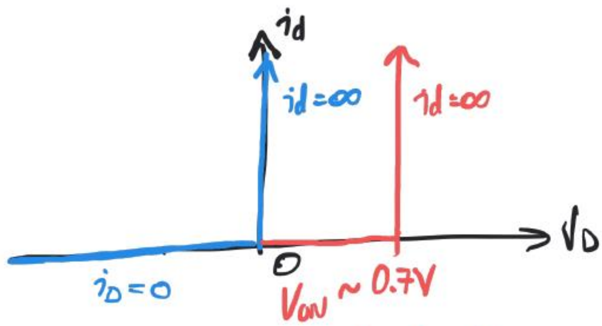
Si diode



LED



IV Characteristic (simple ideal)



$$i_d = \begin{cases} 0 & \text{for } V_D \leq 0 \\ \infty & \text{for } V_D > 0 \end{cases}$$

- acts like a voltage-controlled switch:
  - open circuit when $V_D \leq 0$
  - short circuit when $V_D > 0$

- In reality, diodes have a "turn-on" voltage (V_{ON}) - current starts flowing when $V_D > V_{ON}$

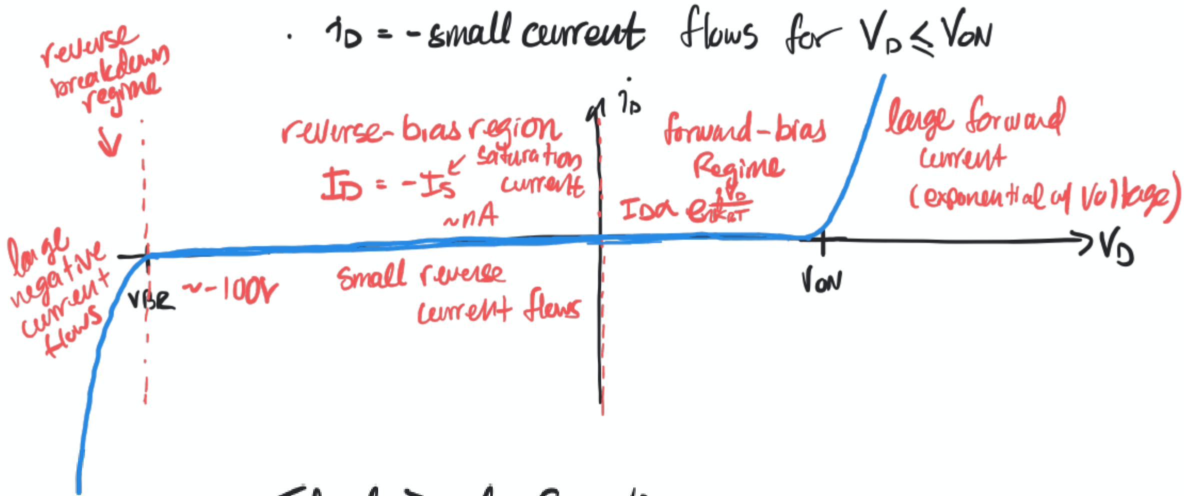
$$i_d = \begin{cases} 0 & \text{for } V_D \leq V_{ON} \\ \infty & \text{for } V_D > V_{ON} \end{cases}$$

V_{ON}: for Si diodes: 0.7V

for LEDs: 1.8V +

b) model #2: real diode

- Differences:
  - $i_D \neq \infty$ for $V_D > V_{ON}$ (curve: resistance is not 0)
  - if $V_D < V_{BR}$ (breakdown voltage) a large negative current will flow
  - i_D = - small current flows for $V_D \leq V_{ON}$



Ideal Diode Equation

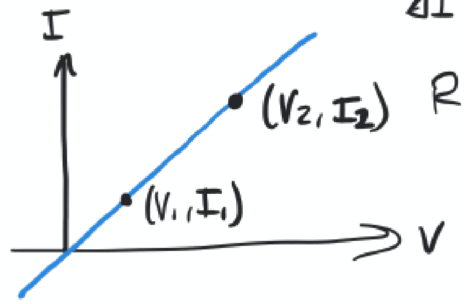
$$I_D = I_S\left(e^{\frac{qV_D}{nk_BT}} - 1\right)$$

- q → charge
- V_D → diode voltage
- T → temperature of diode material
- I_S → saturation current
- n → ideality factor 1-2
- k_B → Boltzmann's constant

- if $V_D < 0$, $I_D = I_S(0-1) = -I_S$
- if $V_D \geq V_{ON}$, $I_D \sim I_S e^{\frac{qV_D}{nk_BT}}$
- Note: this equation does not treat reverse breakdown

iii) Differential Resistance

Via Ohm's law : $R = \frac{\Delta V}{\Delta I}$



$R = \frac{V_2 - V_1}{I_2 - I_1}$ - This only works for a straight line

· Calculus: if ΔV and ΔI are very small:

$\Delta V \to dV$, $\Delta I \to dI$ } Infinitesimal change in V and I → defines slope at a single point
→ we can find slope of any curve

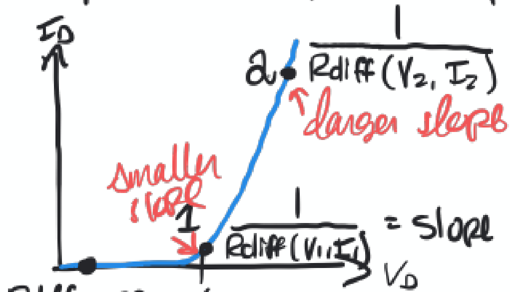
· For a general IV curve:

If $R = \frac{\Delta V}{\Delta I} \to R_{diff} = \frac{dV}{dI}\Big|_{(V_0, I_0)}$ ← differential resistance at a point (V_0, I_0)

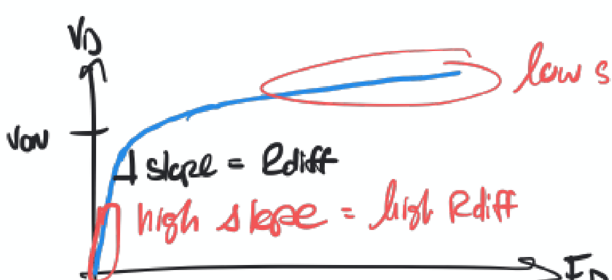
· Rdiff : local measure of resistance : how much does voltage change (dV) for a change in current (dI)?

$dV = R_{diff} \cdot dI$ at a point (V_0, I_0)

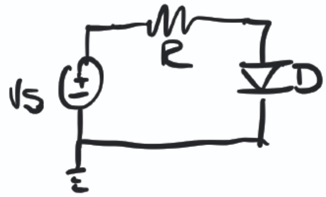
Forward-bias regime



· which point has lower Rdiff? Rdiff(2) < Rdiff(1)



iv) Current - Limiting Resistor : R in series with a diode.



why · If current is too high, it will damage the diode. Heat from current destroys the materials. ALWAYS use a resistor in series with a diode

· Diode voltage is insensitive to current changes in forward-bias → easier to control a diode using current