Lecture2: Diode

Sung-Min Hong (smhong@gist.ac.kr)

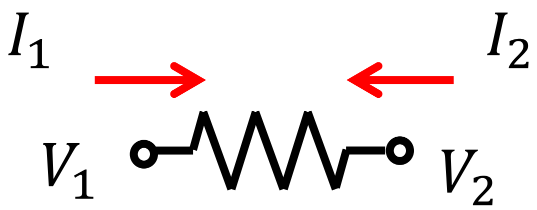
Semiconductor Device Simulation Lab.
School of Electrical Engineering and Coumputer Science
Gwangju Institute of Science and Technology

GIST Lecture on March 7, 2018 (Internal use only)

Two-terminal element

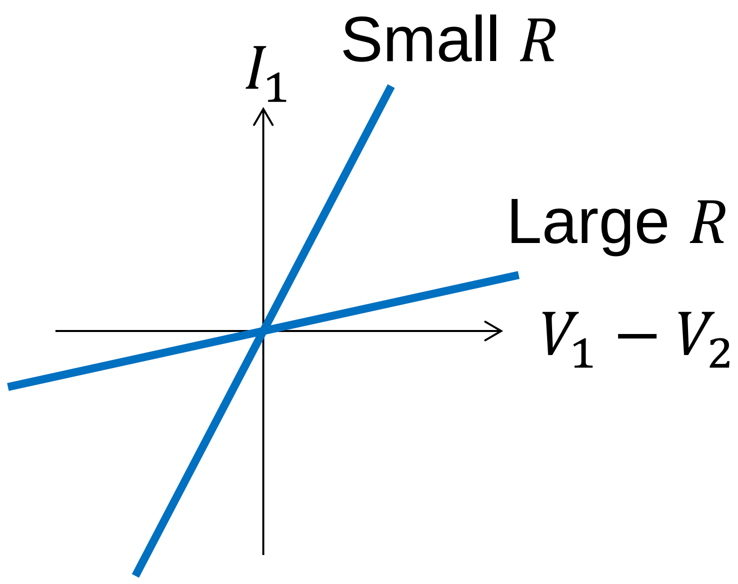
- How many terminal quantities?
  - Two for terminal voltages
  - Two for terminal currents
  - Then, how many independent ones?
  - Note that $I_1 + I_2 = 0$.
  - Note that a common change in V_1 and V_2 does not make a difference.
  - Therefore, I_1 and $V_1 - V_2$ can be regarded as independent variables.

  - Each type of a two-terminal element specifies the relation between I_1 and $V_1 - V_2$.



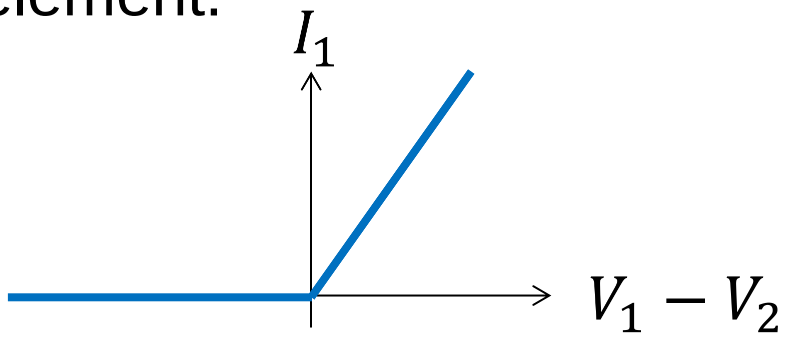
Current vs. voltage

- Sources
  - Voltage source: $V_1 - V_2 = \boldsymbol{V}$
  - Current source: $I_1 = -I_2 = \boldsymbol{I}$
- R, L, C
  - Resistor: $I_1 = \frac{V_1 - V_2}{\boldsymbol{R}}$
  - Capacitor: $I_1 = \boldsymbol{C}\frac{d(V_1 - V_2)}{dt}$
  - Inductor: $V_1 - V_2 = \boldsymbol{L}\frac{dI_1}{dt}$
  - They are linear. (When you scale the voltage, the current is scaled with the same factor.)
  - However, we need nonlinear elements!



Nonlinearity?

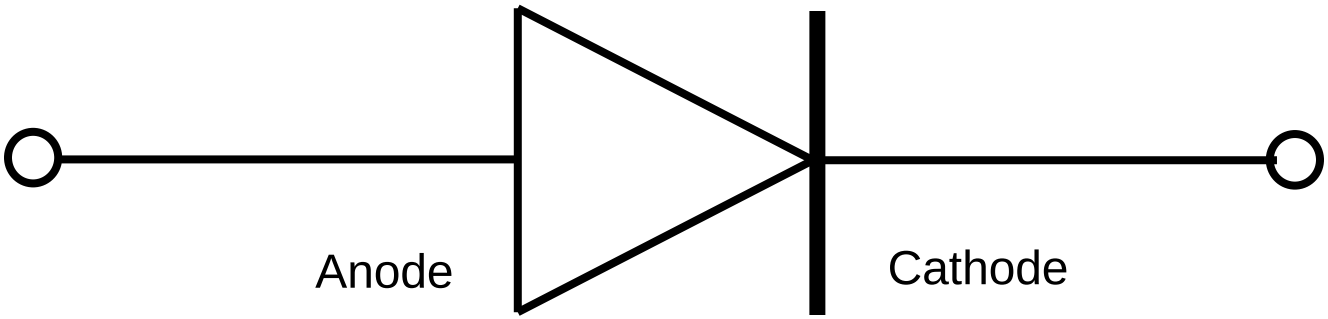
- My examples
  - Light switch?
  - A program language without `if … else` statement?
  - Alarm system?
  - (And so on)
- Assume a circuit element.



  - For a negative voltage, it's electrically open.
  - For a positive voltage, it's resistive.
  - Is there such a circuit element? Yes!

Diode

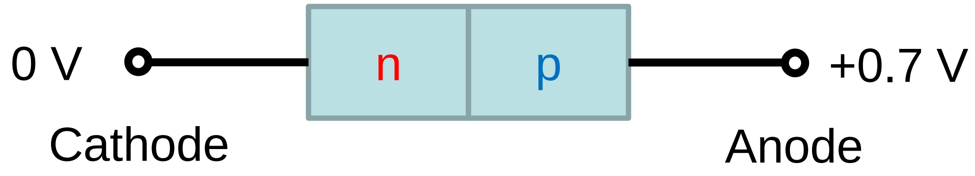
- Di(2) + ode(Electrode): Two-terminal device
  - Its symbol



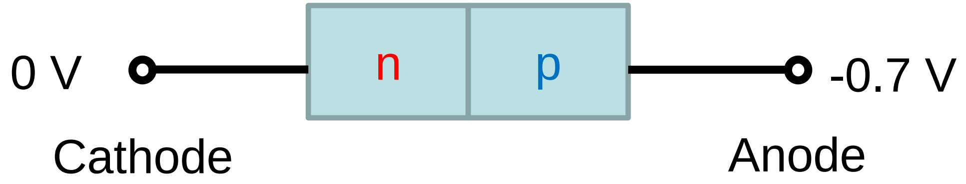
  - Current ➔ : Allowed
  - Current 🡐 : Not allowed

Forward/reverse

- A diode shows a strong polarity.
  - Does a resistor have a polarity?
  - In diodes, the following two cases are completely different.
- Forward bias
  - The voltage at the cathode is higher than the adode voltage.

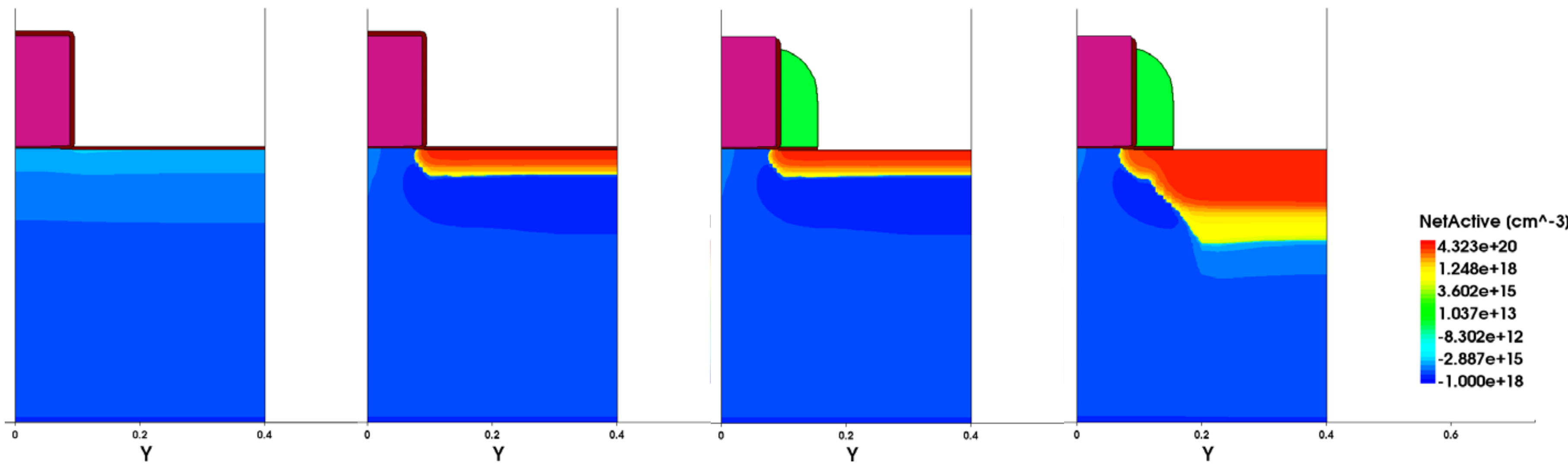


- Reserve bias
  - The voltage at the anode is lower than the cathode voltage.



How to realize(/fabricate) it

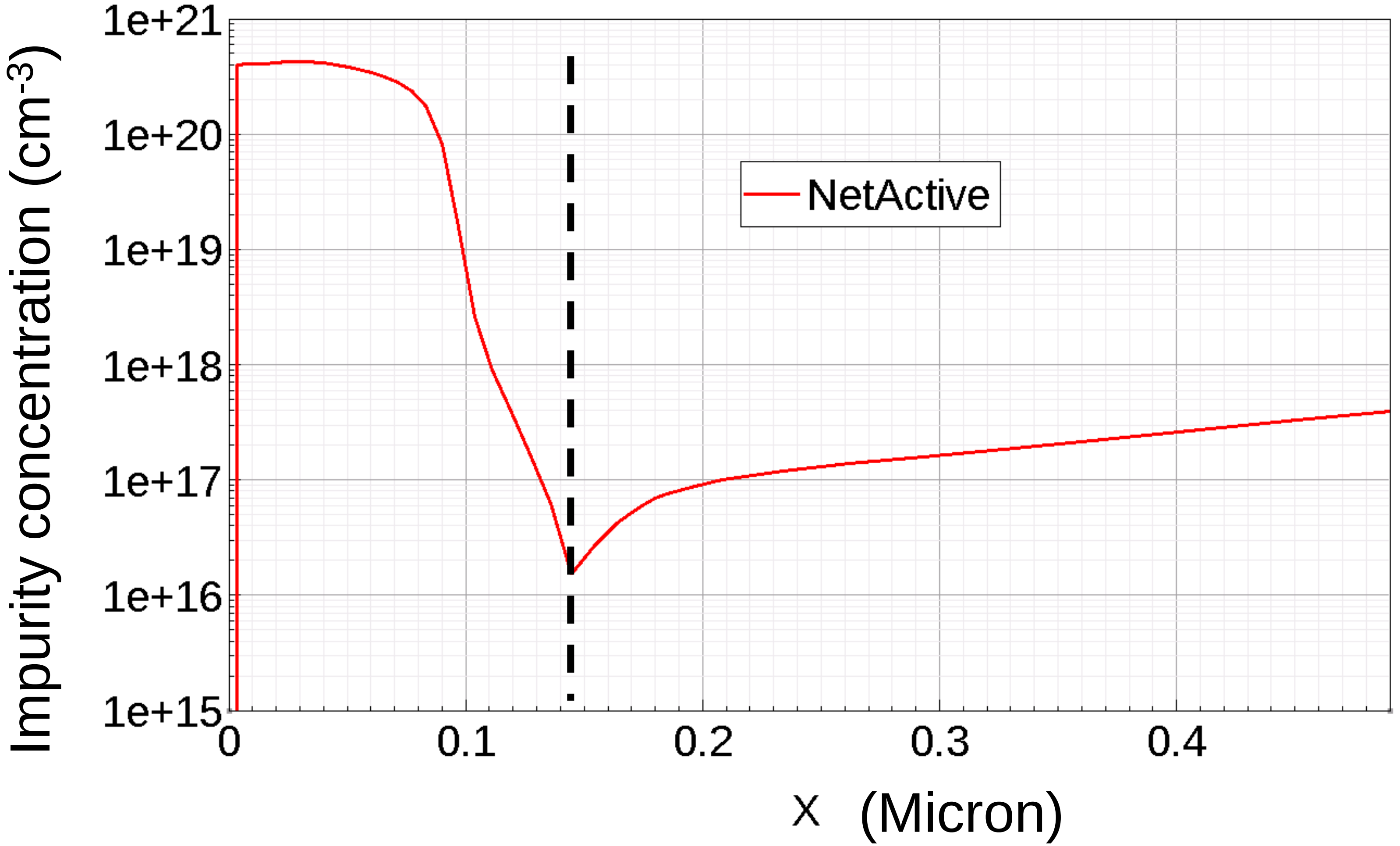
- PN junction
  - Results of the process simulation are shown.



  - Red: Silicon region with Arsenic ions
  - Blue: Silicon region with Boron ions

Vertical doping profile

- Ion implantation for source/drain formation



IV characteristics (1)

- In forward bias,
  - The external voltage opposes the built-in potential, raising the diffusion currents substantially.
- In reverse bias,
  - The applied voltage enhances the field, prohibiting current flow.
- In summary,

$$I_D = I_S\left(\exp\frac{V_D}{V_T} - 1\right)$$

  - Here, the "reverse saturation current" is given by

$$I_S = Aqn_i^2\left(\frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p}\right)$$

  - L_n and L_p are electron and hole "diffusion lengths," respectively.
  - Also, V_T is the thermal voltage.

IV characteristics (2)

- Some limiting cases:

$$I_D = I_S\left(\exp\frac{V_D}{V_T} - 1\right)$$

  – When V_D is close to zero,

$$I_D = I_S\frac{V_D}{V_T}$$

  – When V_D is negative and $V_D \ll -V_T$,

$$I_D = -I_S$$

  – When V_D is positive and $V_D \gg V_T$,

$$I_D = I_S\exp\frac{V_D}{V_T}$$