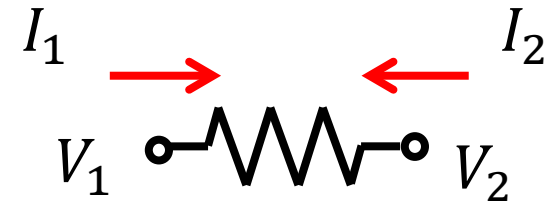

Lecture2: Diode

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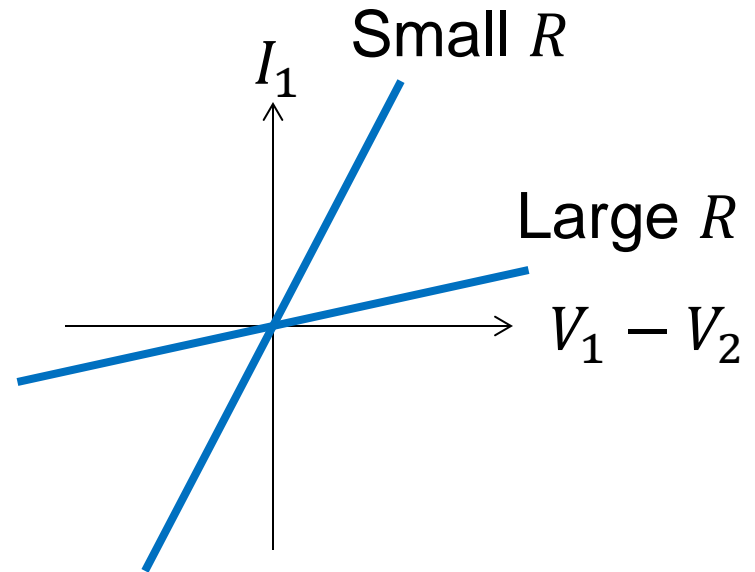
Two-terminal element

- 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 $V_1 - V_2$.



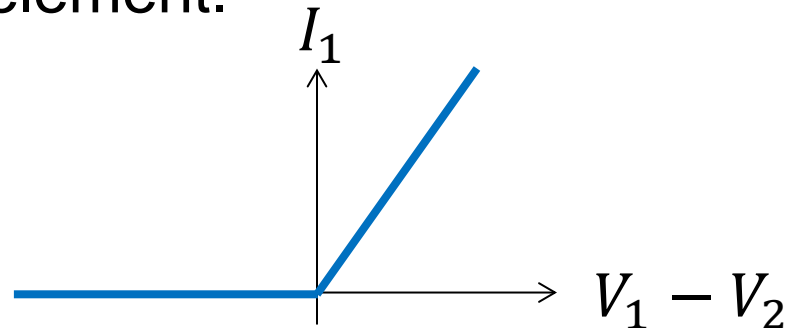
Current vs. voltage

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



Nonlinearity?

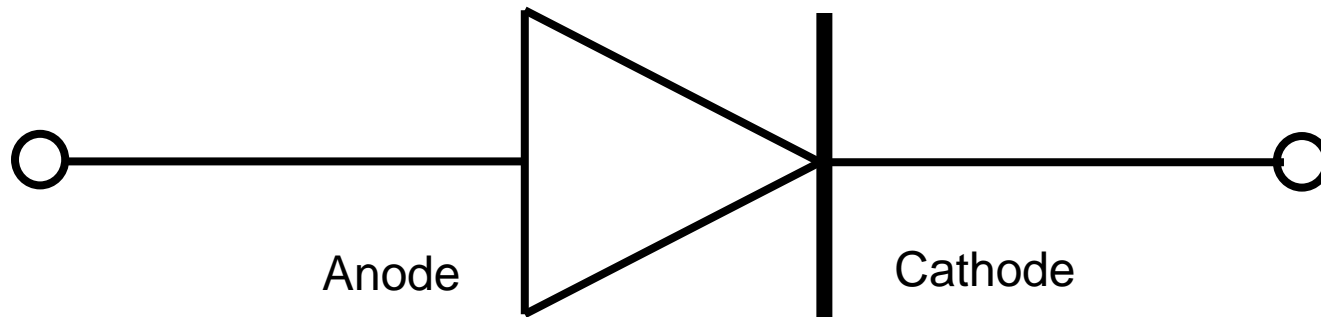
- My examples
 - Light switch?
 - A program language without `if ... else` statement?
 - Alarm system?
 - (And so on)
- Assume a circuit element.



- 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



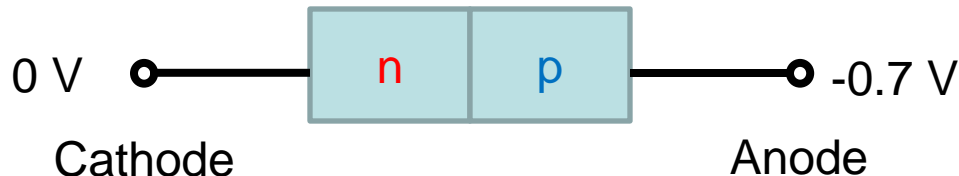
- Current → : Allowed
- Current ← : Not allowed

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 anode voltage.

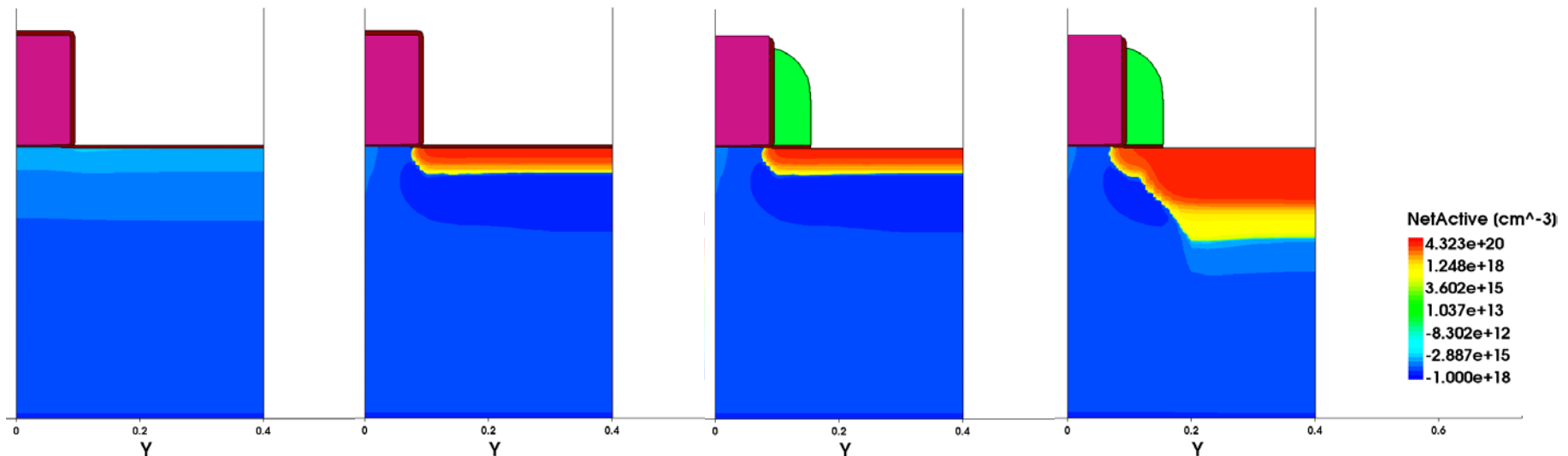


- Reverse bias
 - The voltage at the anode is lower than the cathode voltage.



How to realize(/fabricate) it

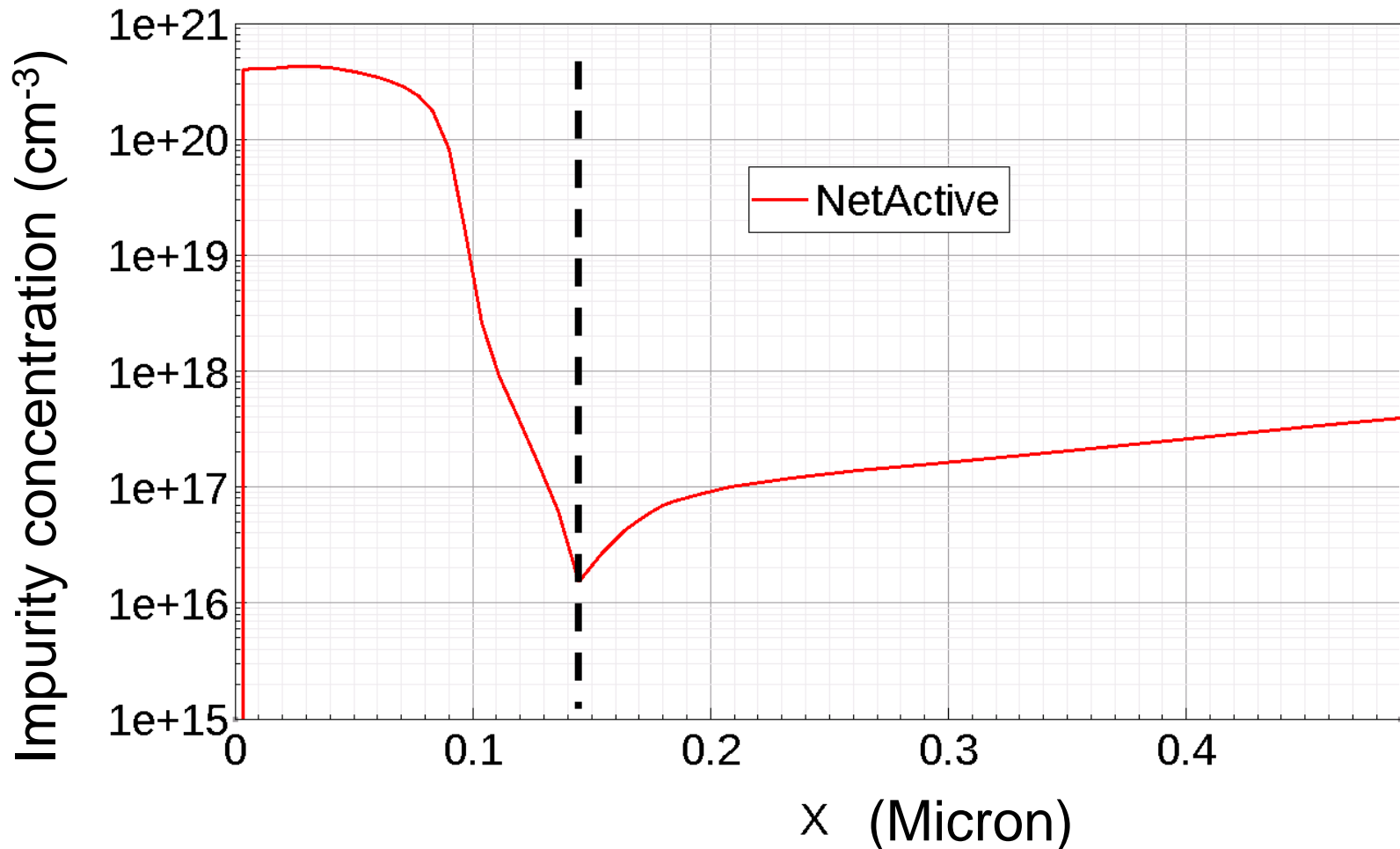
- PN junction
 - Results of the process simulation are shown.



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

Vertical doping profile

- Ion implantation for source/drain formation



IV characteristics

- 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

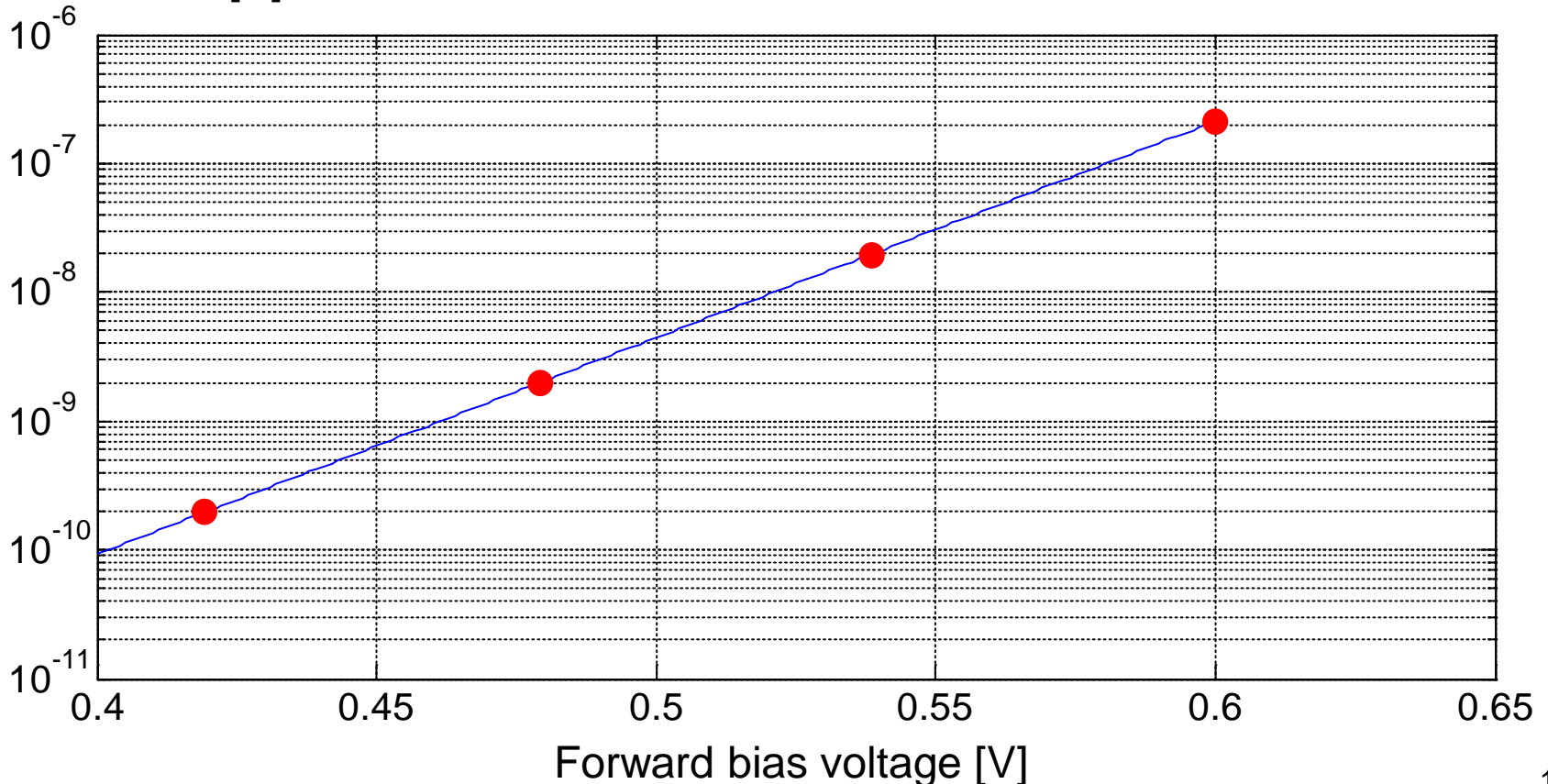
$$I_S = Aq n_i^2 \left(\frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p} \right)$$

- L_n and L_p are electron and hole “diffusion lengths,” respectively.

60 mV/dec, what is it?

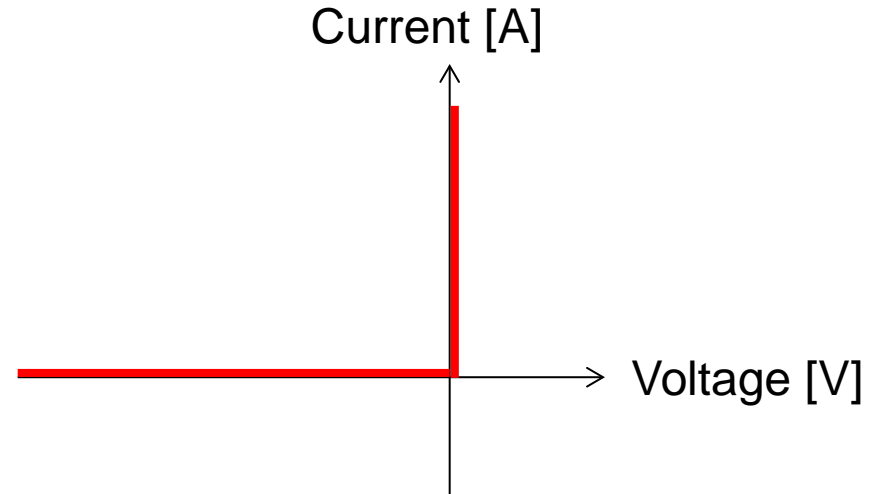
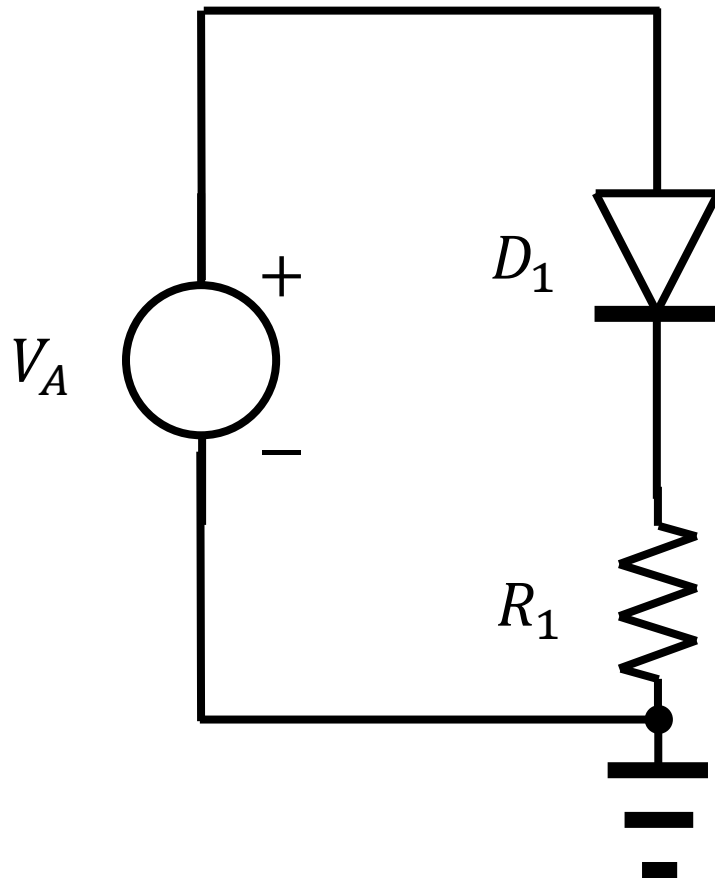
- Calculate $V_T \ln 10$ at 300K.
 - Approximately 60 mV!

Diode current [A]



Idealization

- Assume a perfect rectifier.
- A diode-resistor combination



- ← Consider two cases, $V_A > 0$ and $V_A < 0$.
- ← Draw the IV curve.