Lecture6: Basic physics of semiconductors (6)

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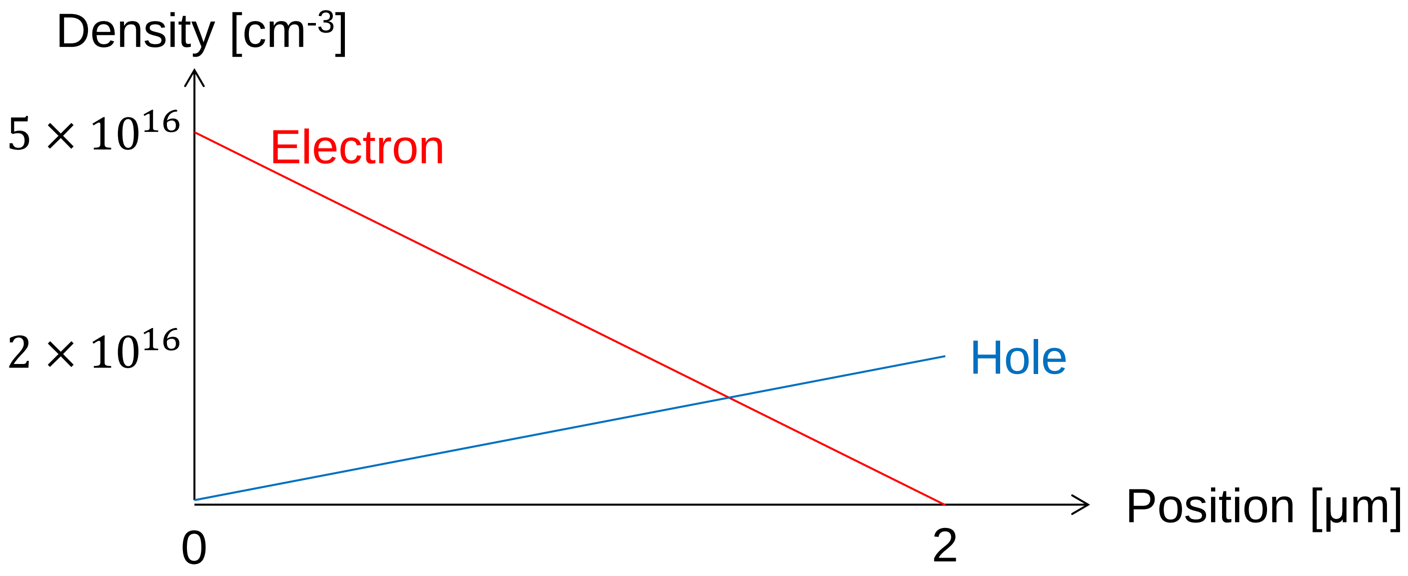
Homework#1 (1/5)

- In total, five problems.
- Due date: ***March 25 (Wed)***

- Problem1:
  - Consider three semiconductor materials, Si, Ge, and GaAs. Find the values of the intrinsic carrier density (at 300K) and the band gap energy. Specify the reference of values.

Homework#1 (2/5)

- Problem2:
  - The figure shows a p-type bar of silicon that is subjected to electron injection from the left and hole injection from the right. Determine the total current flowing through the device if the cross section area is equal to 1 μm X 1 μm.



Homework#1 (3/5)

- Problem3:
  - A junction employs $N_D = 5 \times 10^{17}$ /cm^3 and $N_A = 4 \times 10^{16}$ /cm^3. Consider three different temperatures, 250 K, 300 K, 350 K. For these cases, determine the majority and minority carrier concentration on both sides. Also calculate the built-in potential.

Homework#1 (4/5)

- Problem4:
  - In the textbook, you can find a derivation of the built-in potential formula:

$$V_0 = \frac{k_B T}{q} \ln \frac{N_A N_D}{n_i^2}$$

  - Derive the above formula with your own effort.

Homework#1 (5/5)

- Problem5:
  - Consider a pn junction at equilibrium.
  - Show that the width of the depletion region is given by:

$$W = \sqrt{\frac{2\epsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)V_0}$$

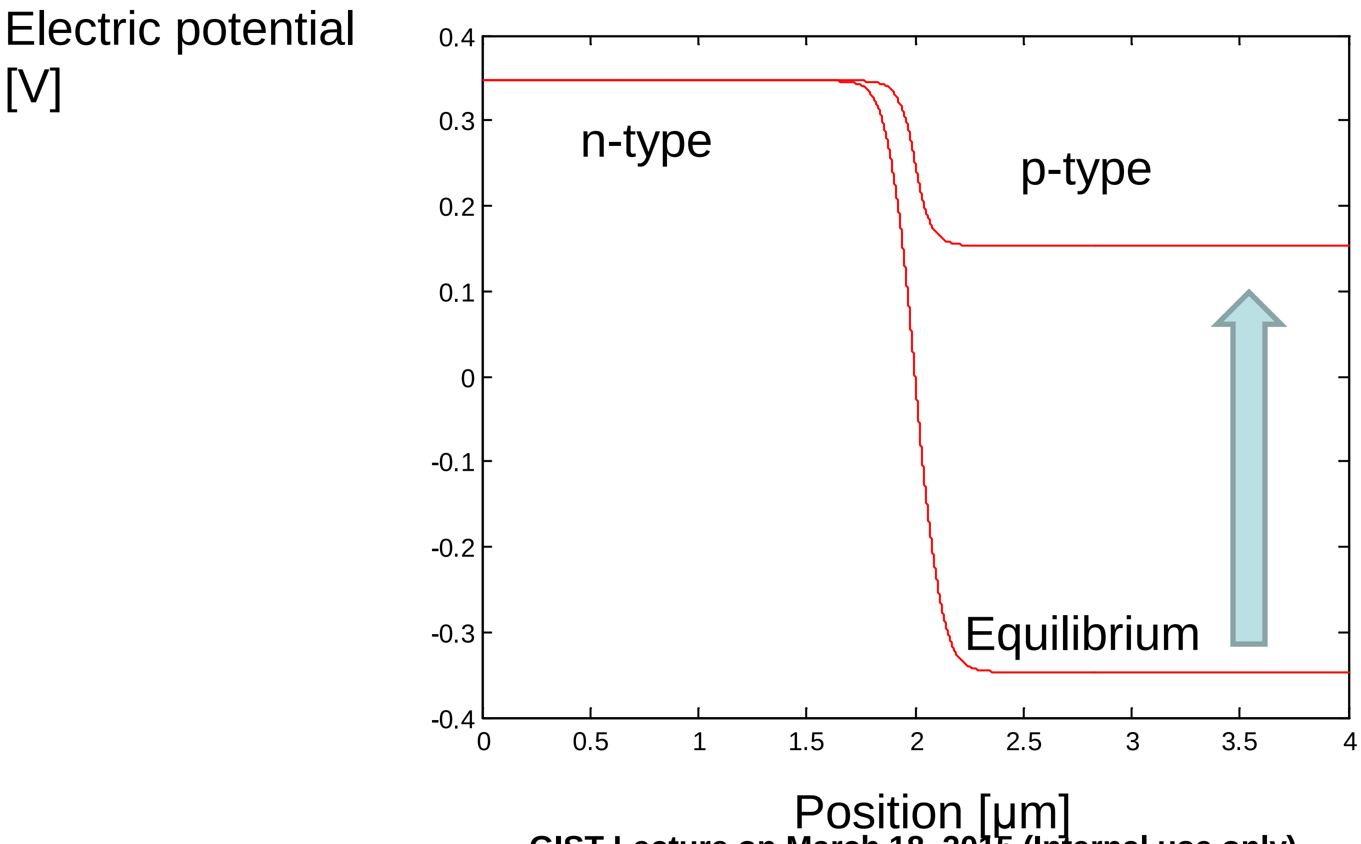
  - Show that the charge stored in a pn junction is given by:

$$Q = A\sqrt{2\epsilon_s q \frac{N_A N_D}{N_A + N_D} V_0}$$

  - (This problem can be a bit challenging.)

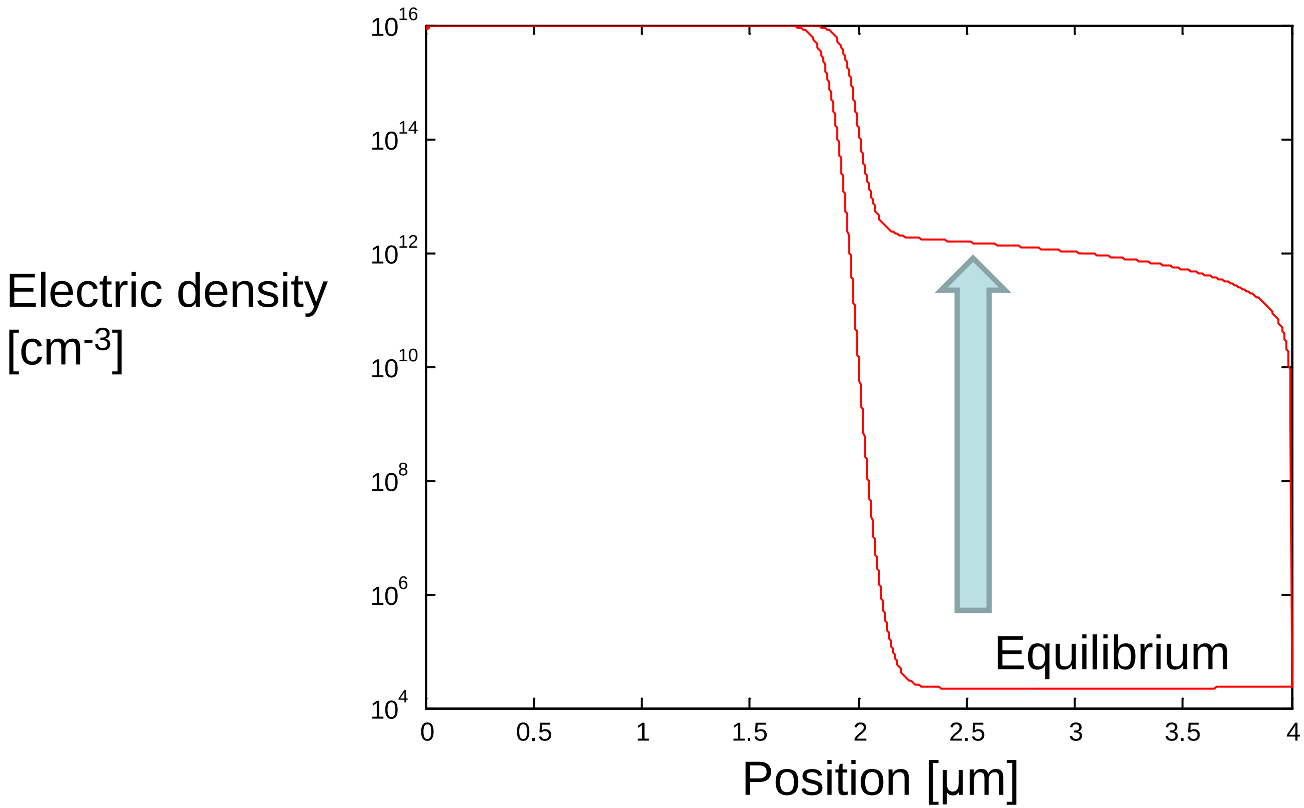
Forward bias

- Forward bias
  - We can easily guess that the depletion width will be reduced.
  - Potential barrier is lowered. (Equilibrium and 0.5 V)



Density @ forward bias

- Electron concentration (similar for hole concentration)
  - Equilibrium and 0.5 V
  - Exponential increase of electron density!



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.
- IV characteristics

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

  - 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.

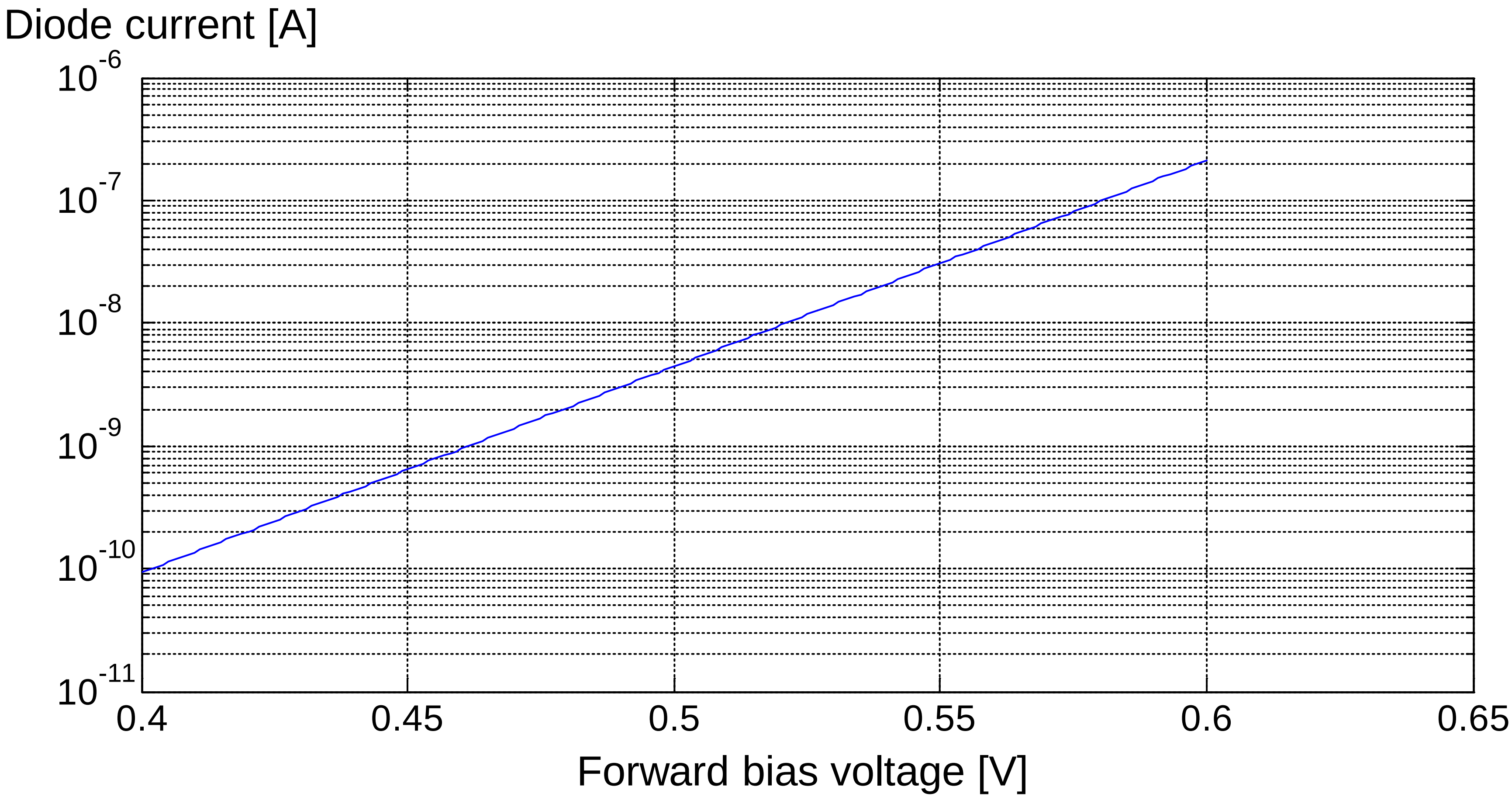
An example

- Determine I_S.
  - The cross section of 100 μm^2
  - L_n and L_p are 20 μm and 30 μm, respectively.
  - D_n and D_p are 34 cm^2 sec^{-1} and 12 cm^2 sec^{-1}, respectively.

- When $I_S = 1.77 \times 10^{-17}$ A,
  - Determine the forward bias current.
  - For $V_D = 300$ mV, $I_s\left(\exp\frac{V_D}{V_T} - 1\right)$ = 3.63 pA
  - For $V_D = 800$ mV, 820 μA

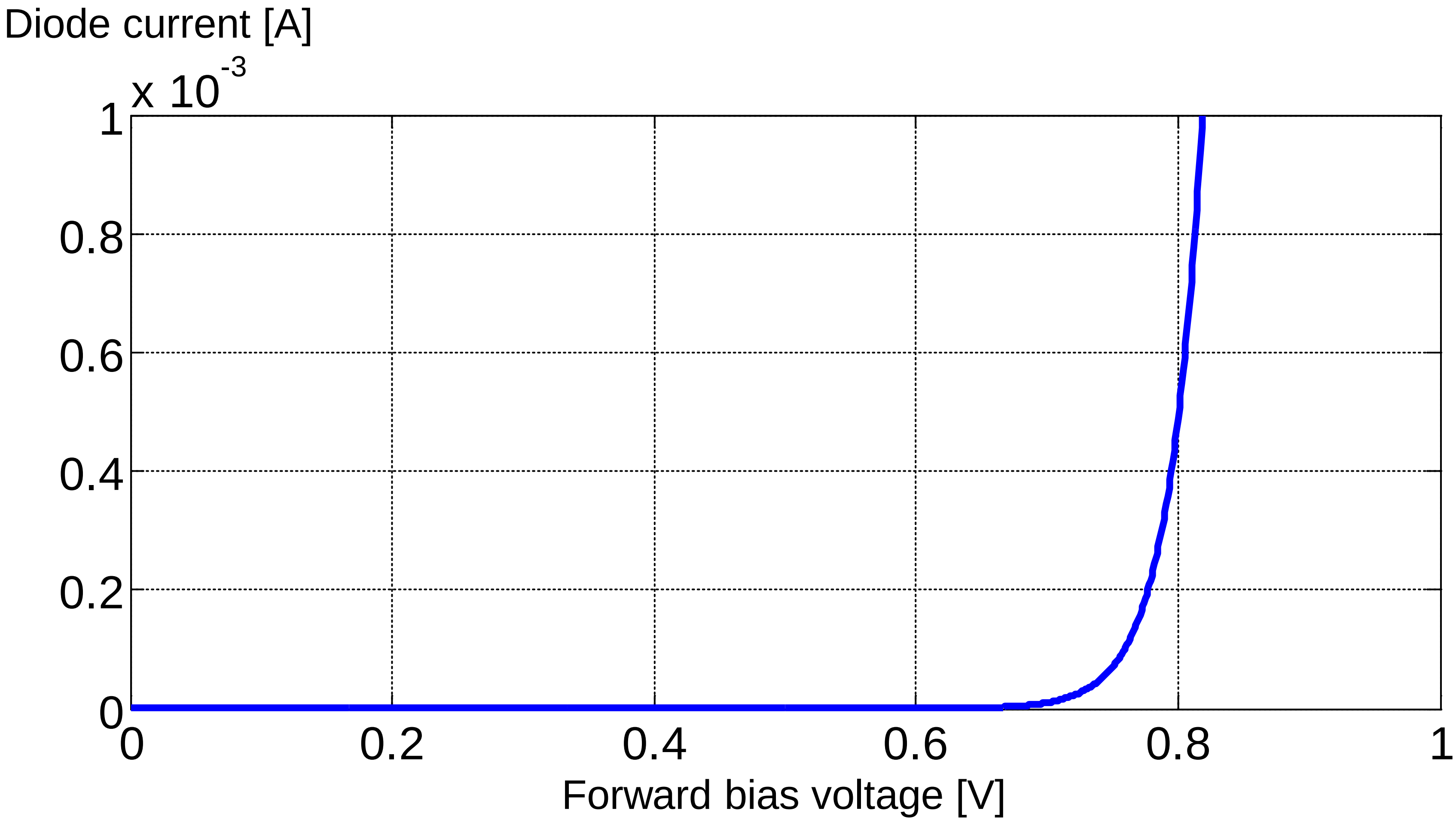
60 mV/dec, what is it?

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



Draw it!

- In the linear scale, very steep increase of current!



Constant-voltage model

- Idealized model