Lecture5: Basic physics of semiconductors (5)

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GIST Lecture on March 16, 2015 (Internal use only)

Review question

- What is the V_T shown in the second question?
  - It is the thermal voltage, which is given by

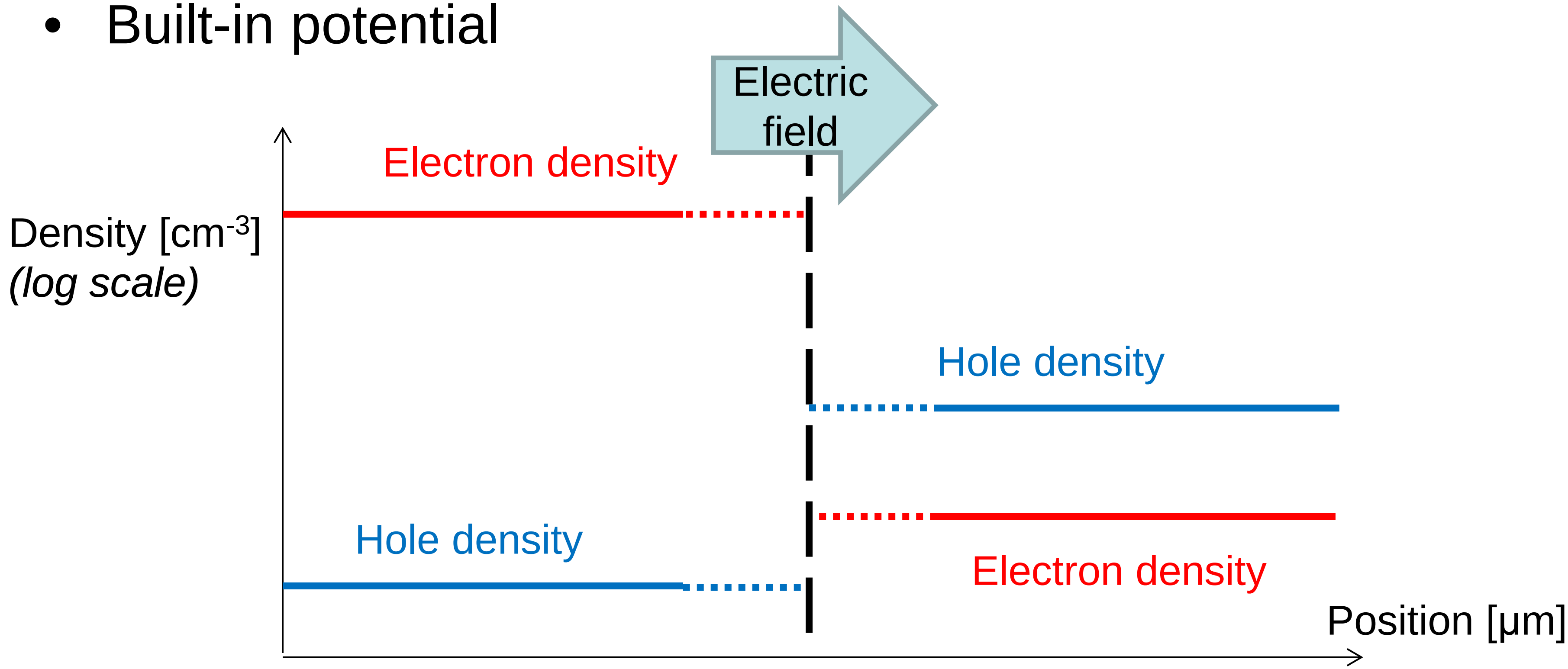
$$V_T = \frac{k_B T}{q}$$

  - At 300K, it is approximately 25.85 mV.

- Using the values in the problem,
  - $V_0 = 25\ mV \times \ln \frac{10^{16} \times 10^{18}}{10^{20}} = 805$ mV (close to 833 mV)

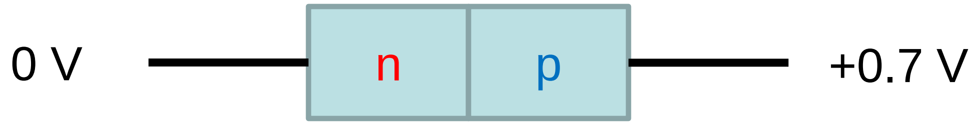
PN junction @ equilibrium

- No current
  - Because it is at equilibrium. ☺
- Depletion region
- Built-in potential



Forward/reverse

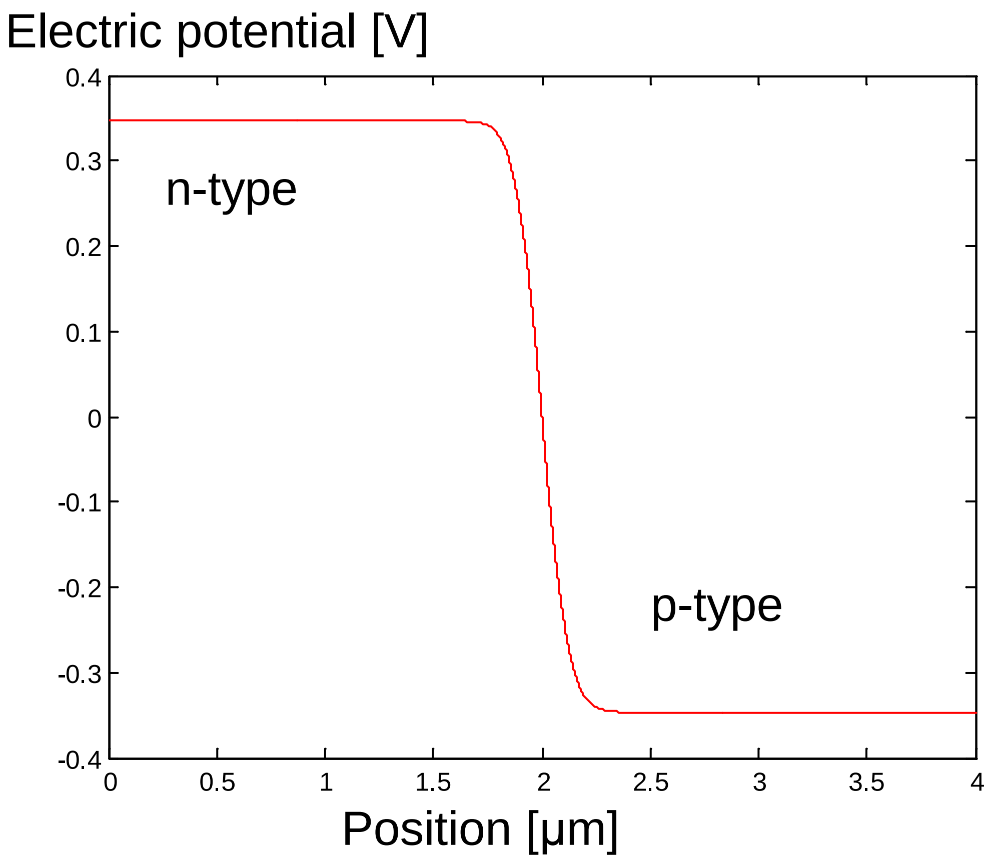
- A diode shows a strong polarity.
  - Does a resistor have a polarity?
  - In diodes, the following two cases are completely different.
- Forward bias
  - The voltage at the n-type side is higher than the p-type one.



- Reserve bias
  - The voltage at the p-type side is lower than the n-type one.

Reverse bias

- Electric field
  - Now, the magnitude of the electric becomes larger.



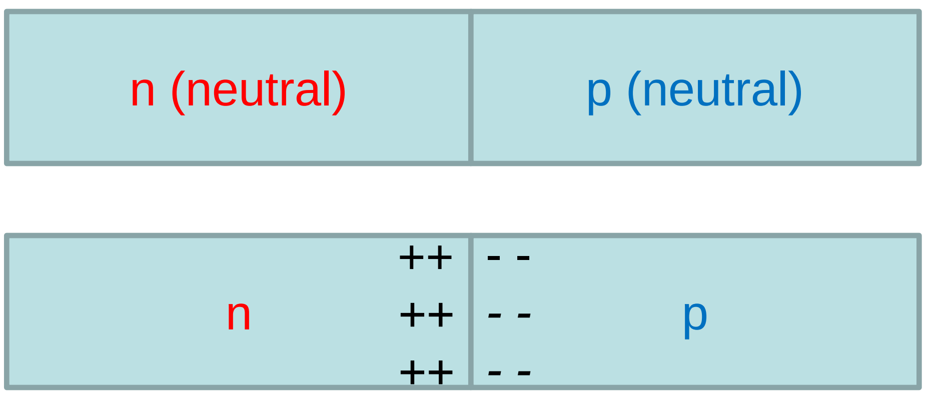
🡰 This is the equilibrium solution. What happens when the n-type region is positively biased?

Higher electric field?

- How can the pn junction generate the higher electric field?
  - At equilibrium, how did it generate the built-in electric field?

$$\nabla \cdot \mathbf{D} = \rho$$

  - Higher electric field means more space charges!



🡐 Which one can provide nonzero electric field?

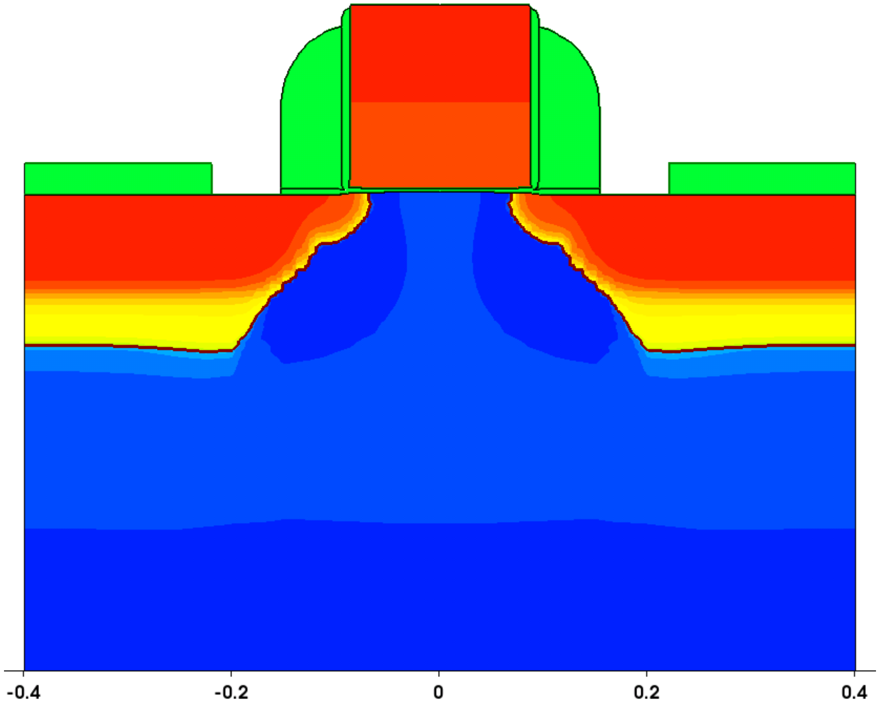
- Therefore, the depletion region becomes wider.
  - Even higher potential barrier!

Variable capacitance

- Capacitor? Why do we care about it?

$$Q = CV \text{ and } I = C\frac{dV}{dt}$$

  - Where can you find capacitance in the following structure?
  - Why is it important?



Doping profile of a typical planar MOSFET

Charge

- Charge stored in a pn junction

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

  - Then, what is the capacitance at a given value of the reverse bias, V_R?

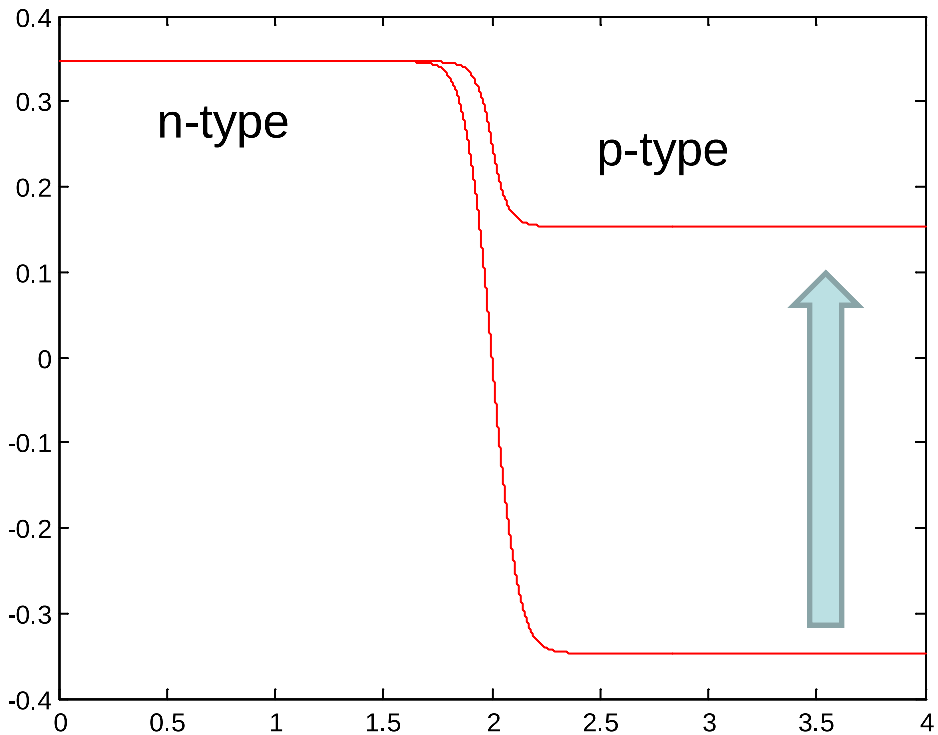
Summary of reverse bias

- Reverse bias
  - Larger electric field
  - Wider depletion region
  - (Almost) no current flow
  - Variable capacitance

Forward bias

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

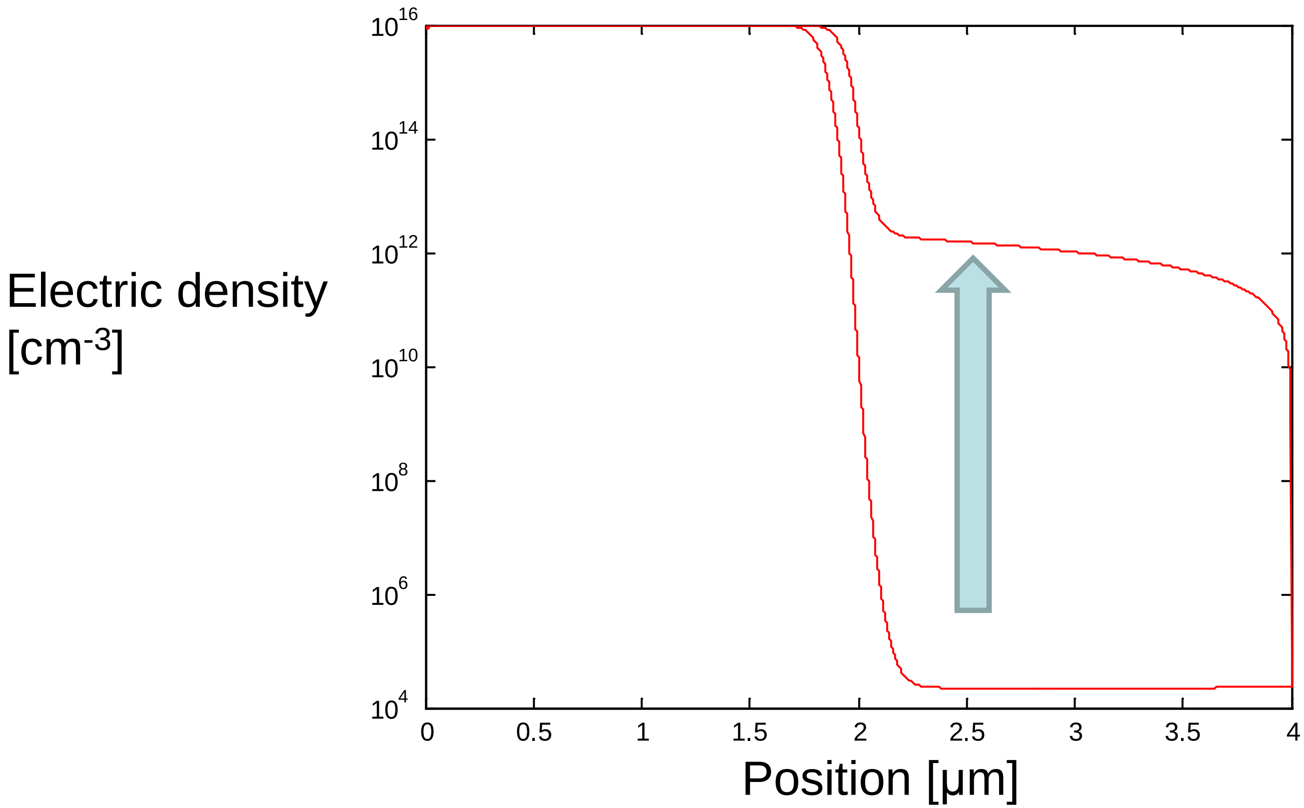
Electric potential [V]



Position [μm]

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.

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

  - 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.
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- 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

Homework#1

- In total, five problems.
- Due date: March 23 (Mon)

- Problems will be announced shortly.

Office hour

- In this semester, you have to visit my office (at least) once.
- In this week, I will provide the following sessions.
  - March 16 (Mon) PM 09:00~PM11:00
  - March 17 (Tue) PM 09:00~PM11:00
  - March 18 (Wed) PM 09:00~PM11:00
  - March 19 (Thu) PM 09:00~PM11:00
- Please send me a reservation e-mail in advance.

	3/16, Mon	**3/17, Tue**	**3/18, Wed**	**3/19, Thu**
09:00~	Booked	Booked		
09:30~				
10:00~		Booked	Booked	
10:30~				