Lecture4: Basic physics of semiconductor (4)

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GIST Lecture on March 11, 2015 (Internal use only)

Answers of review questions

- Two mechanisms
  - Drift & diffusion

- The electric field is 1 kV/cm.
  - The drift velocity is 10^6 cm/sec.

- The electron current density

$$\mathbf{J}_n = qn\mu_n\mathbf{E} + qD_n\nabla n$$

PN junction

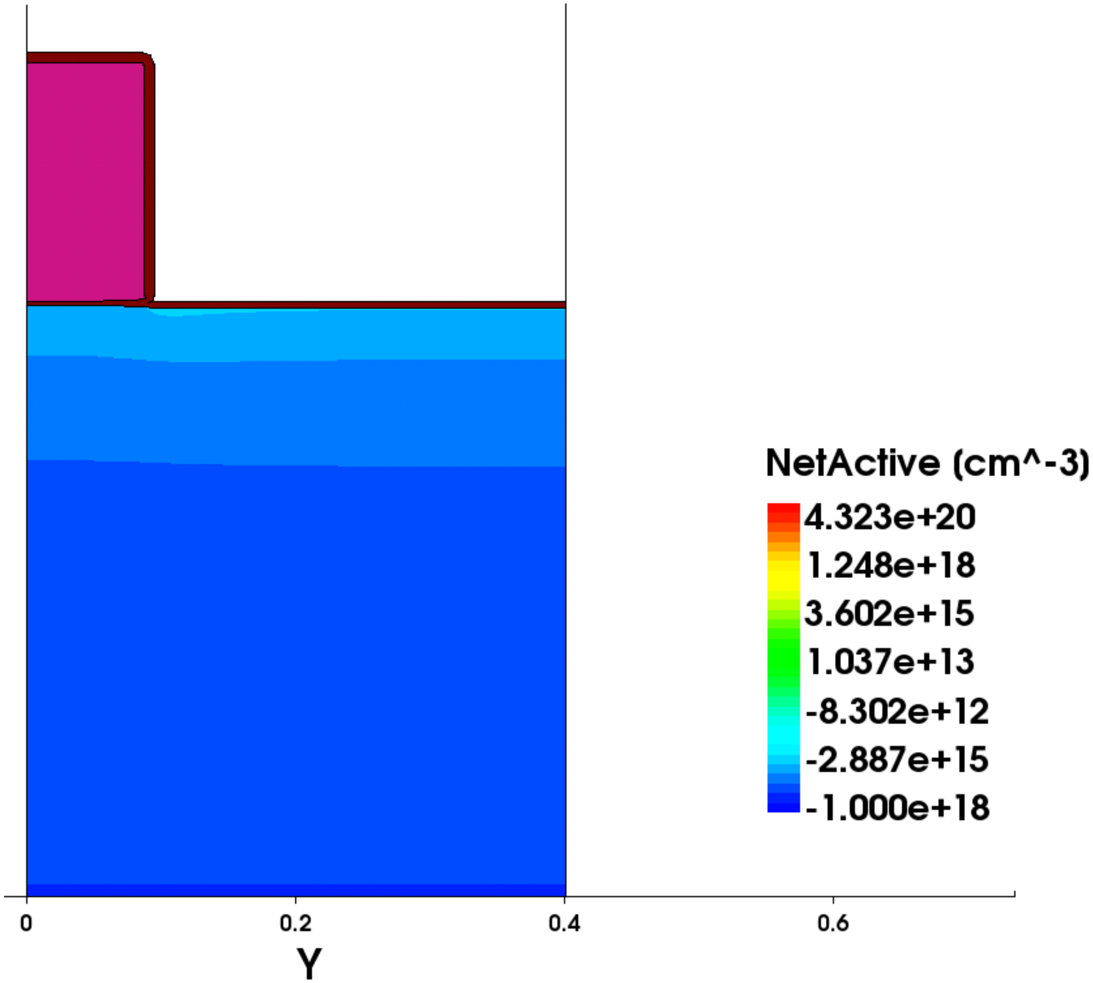
- What is it?
  - Junction of two different extrinsic regions

- Why do we study it?
  - It is a basic building block of electron devices.

- Today, only the equilibrium case will be discussed.
  - Nonequilibrium? Next lecture!

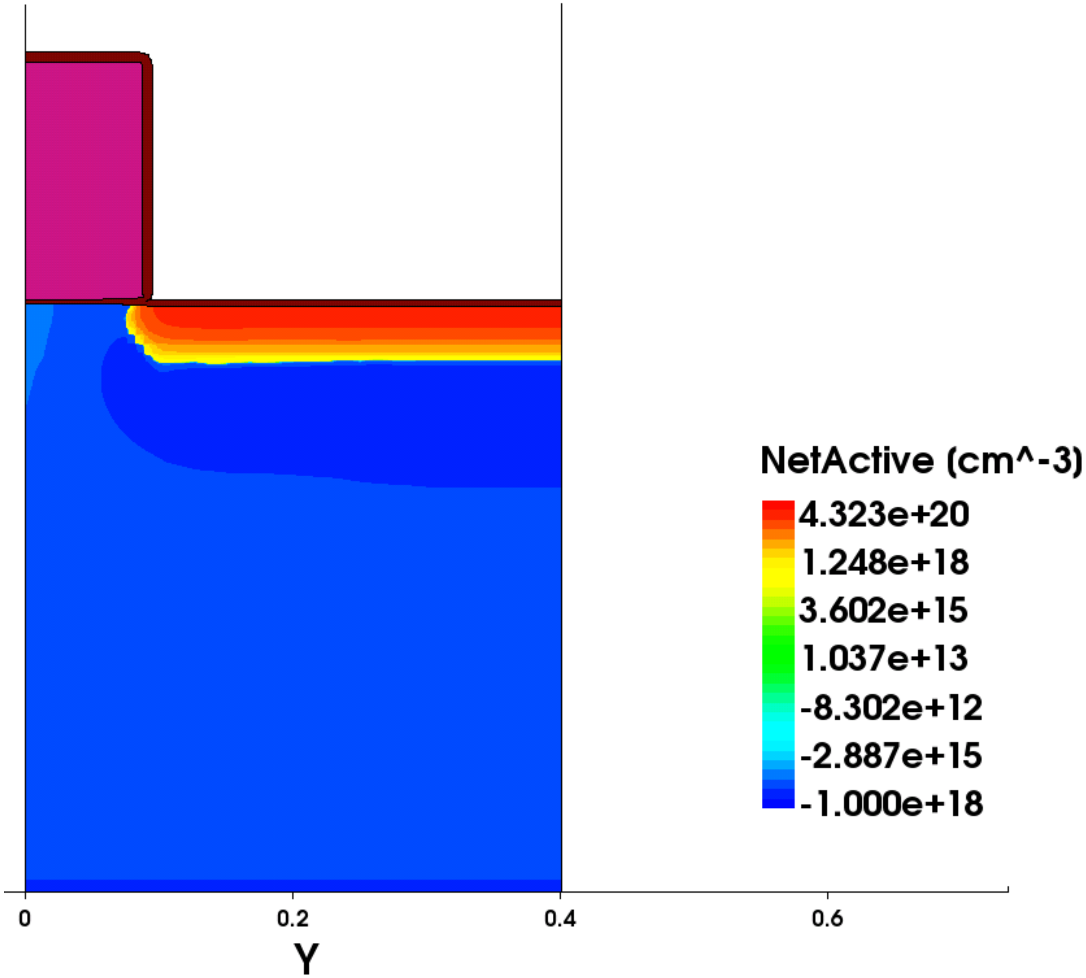
Fabrication (1/4)

- How to fabricate a pn junction
  - p-well and gate patterning



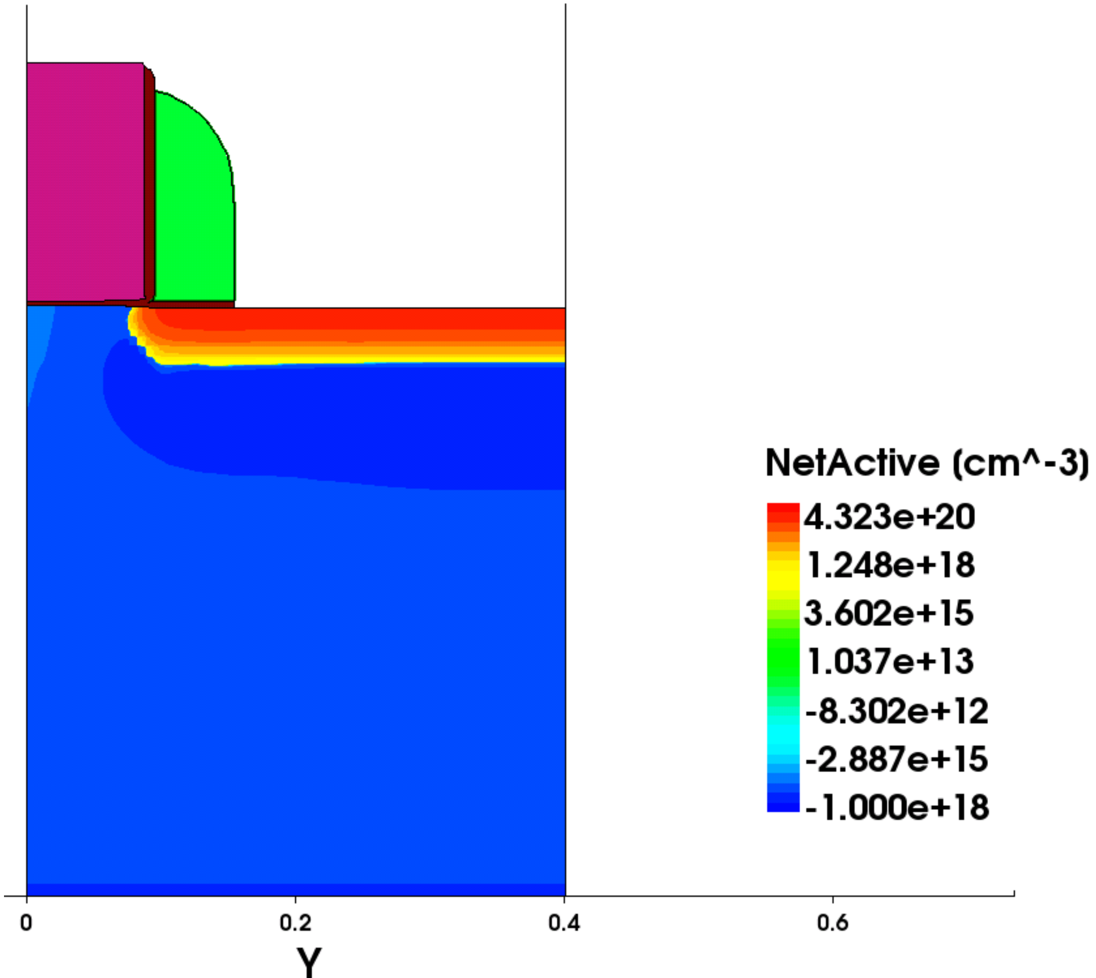
Fabrication (2/4)

- Ion implantation for LDD formation
  - Arsenic, dose = 4e12<cm-2>, energy=10<keV>



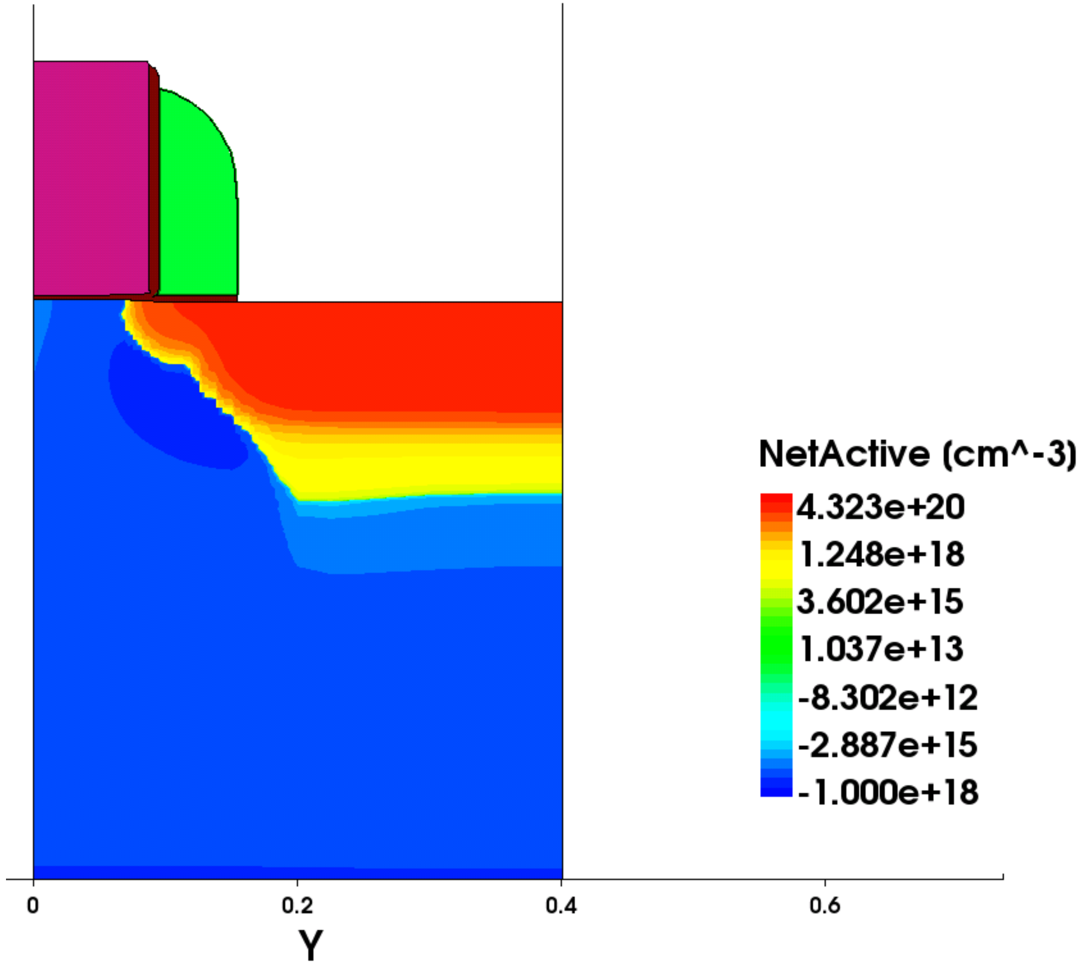
Fabrication (3/4)

- Spacer patterning
  - Silicon nitride spacer for the source/drain doping



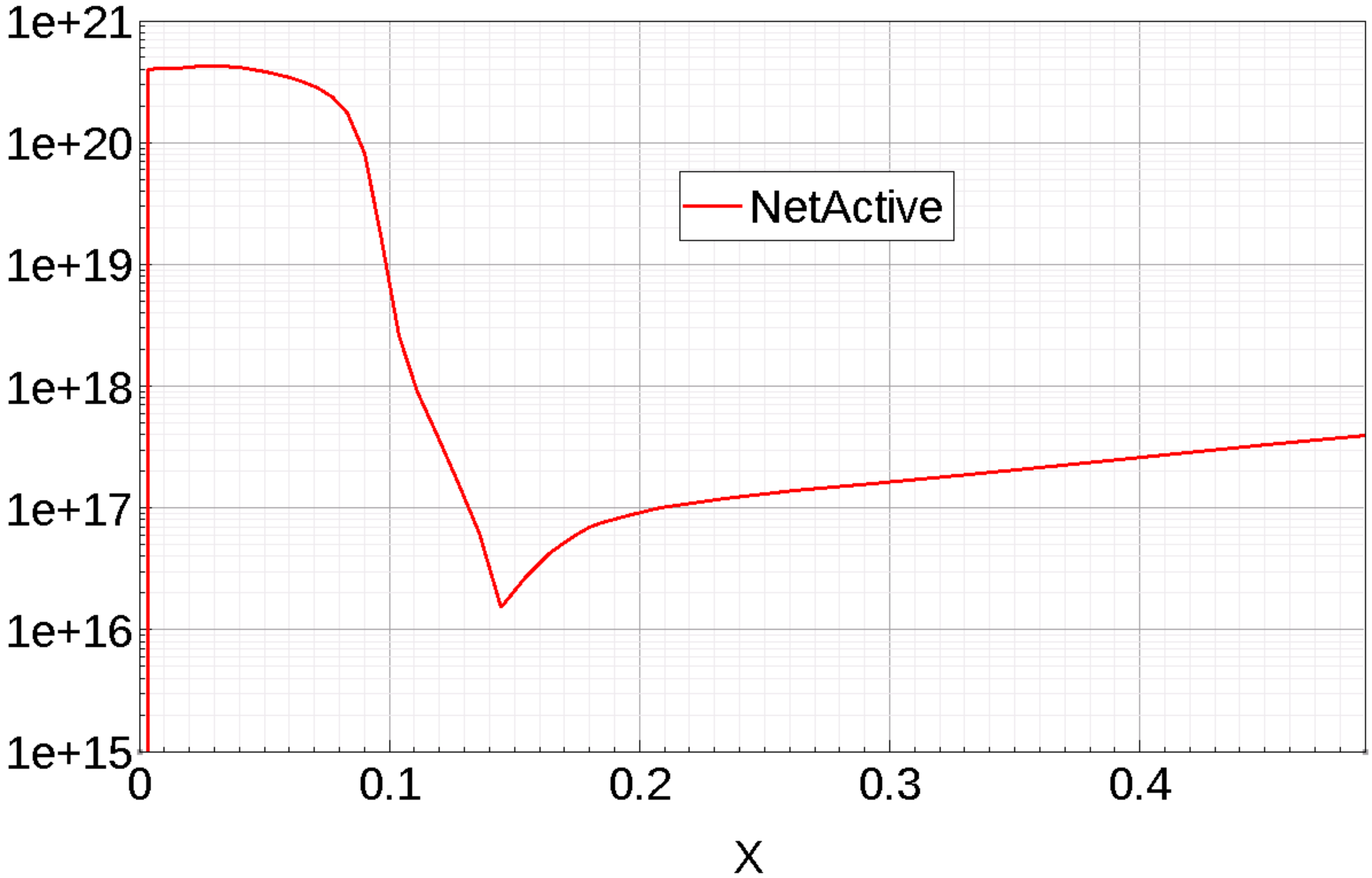
Fabrication (4/4)

- Ion implantation for source/drain formation
  - Arsenic, dose=5e15<cm-2>, energy=<40keV>



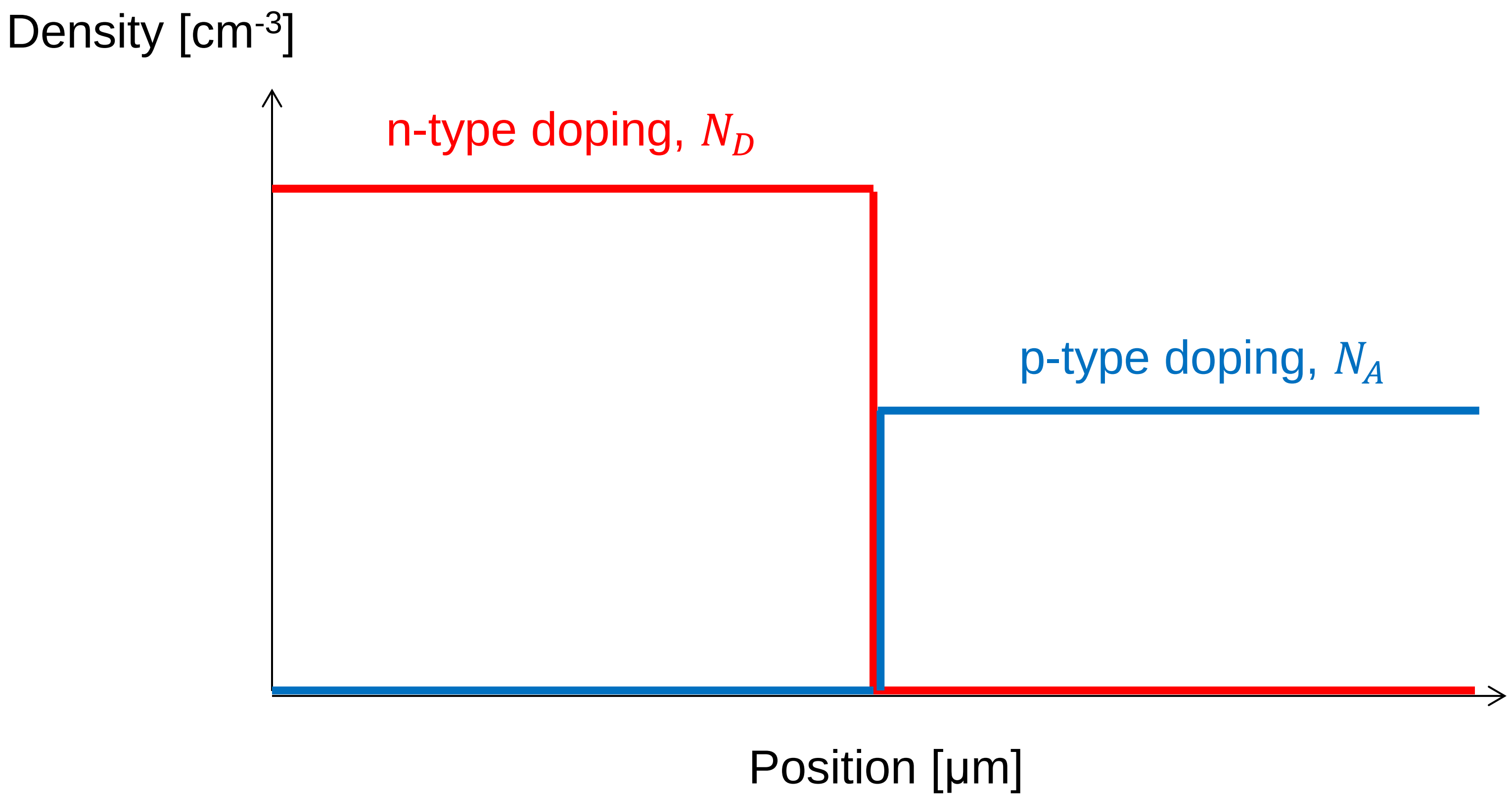
Vertical doping profile

- Ion implantation for source/drain formation
  - Arsenic, dose=5e15<cm-2>, energy=<40keV>



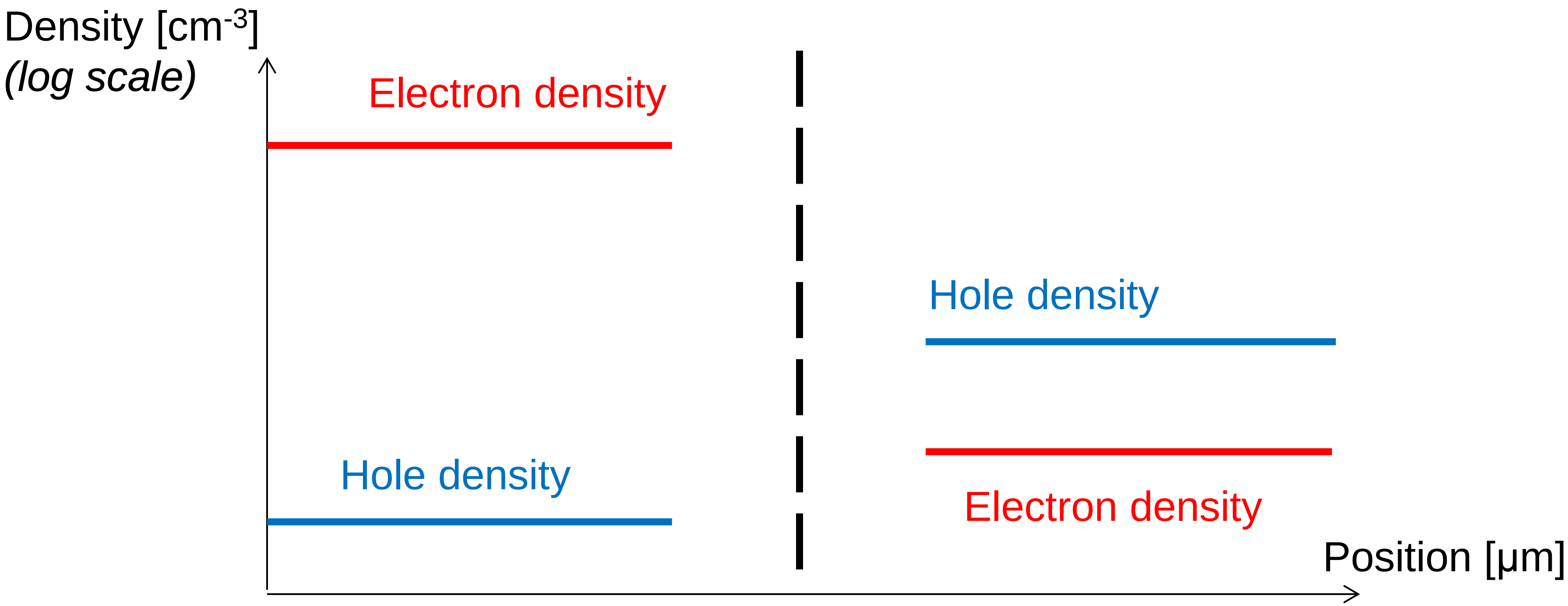
Simplified 1D structure

- For simplicity
  - An abrupt 1D junction is usually considered.



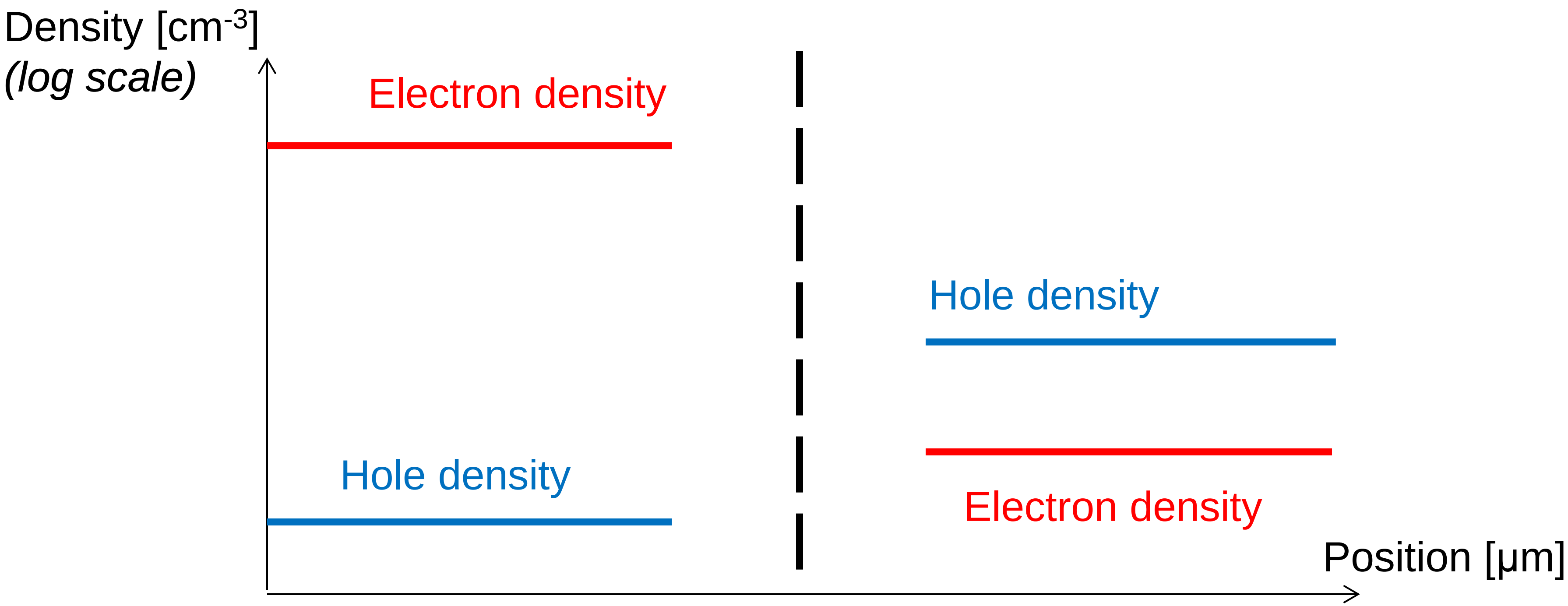
Away from the junction…

- No effect of junction!
  - In the n-type region, $n \approx N_D$ and $p \approx \frac{n_i^2}{N_D}$
  - In the p-type region, $p \approx N_A$ and $n \approx \frac{n_i^2}{N_A}$



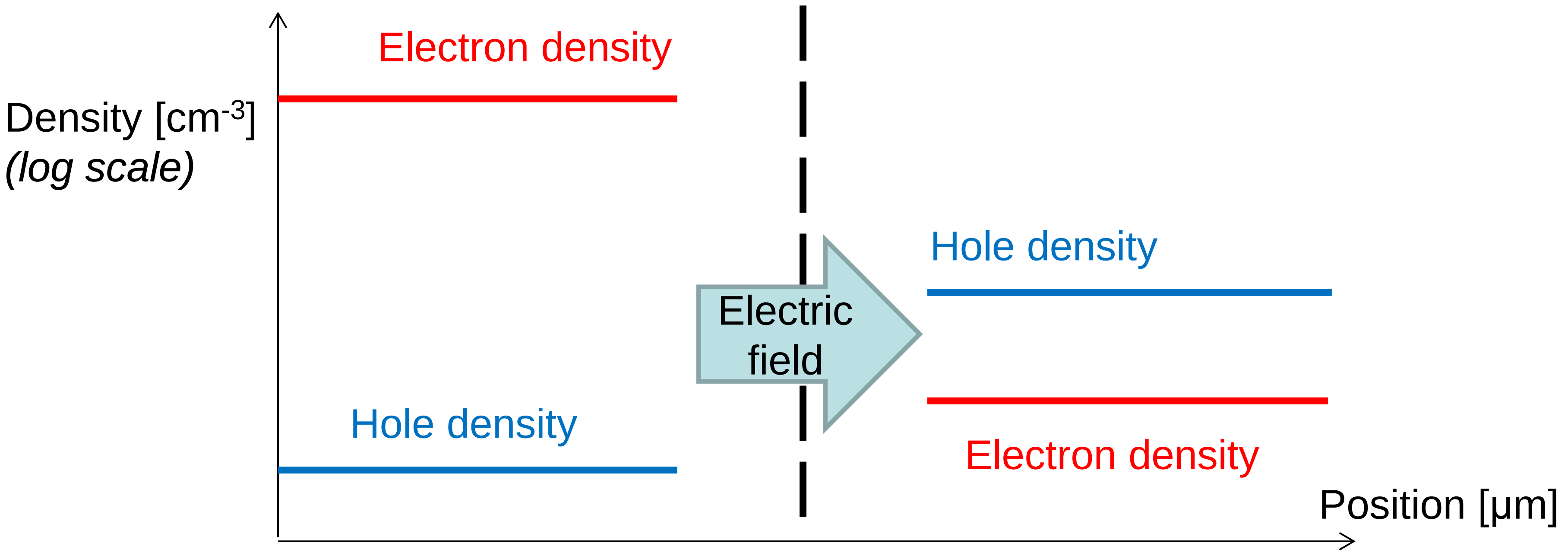
Example

- $N_D = 10^{16}$ cm^{-3} and $N_A = 5 \times 10^{15}$cm^{-3}



Across the junction…

- Large diffusion currents:
  - Electrons flow from the n side to the p side
  - Holes flow from the p side to the n side
- However, the net flux of electrons and holes is not allowed.
  - Equilibrium! Compensated by the drift current!

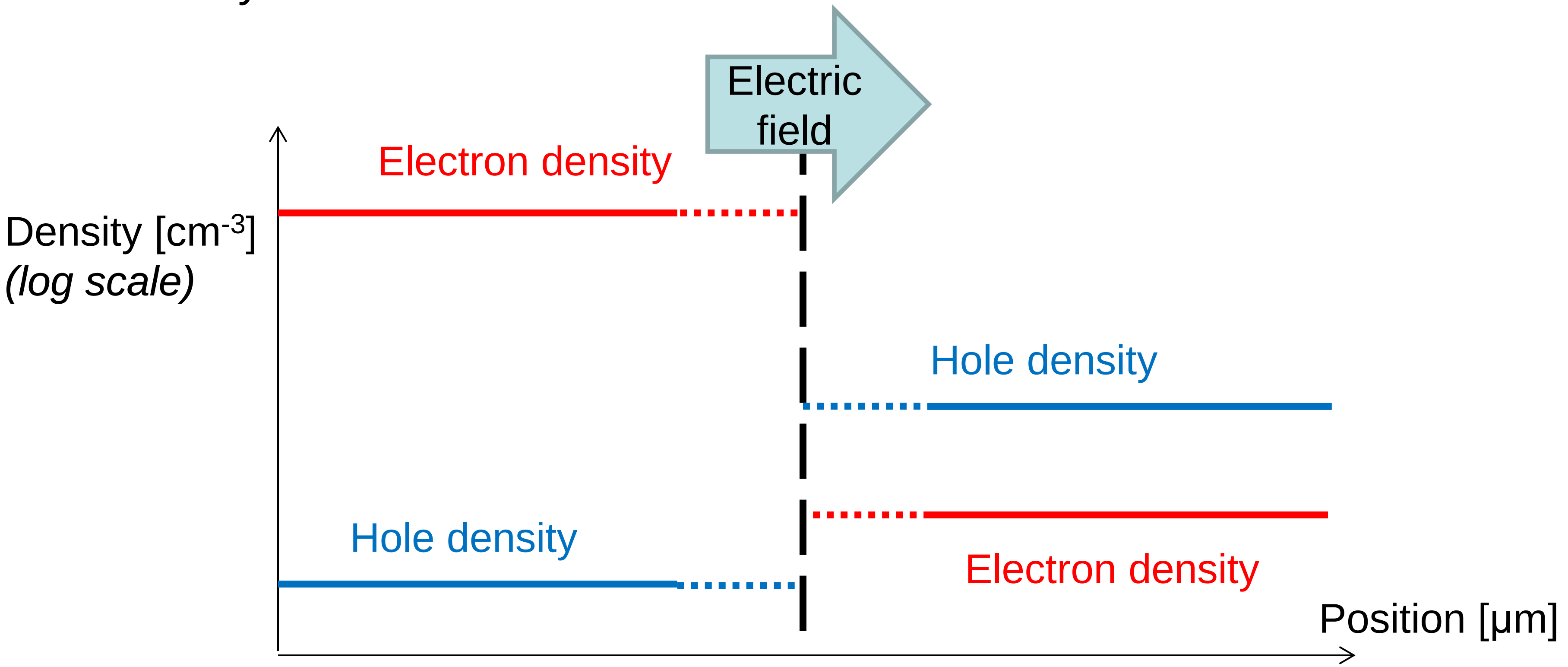


How can we have $\mathbf{E}$?

- Poisson's equation

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

  – When the net charge density does not vanish, the electric field can vary.

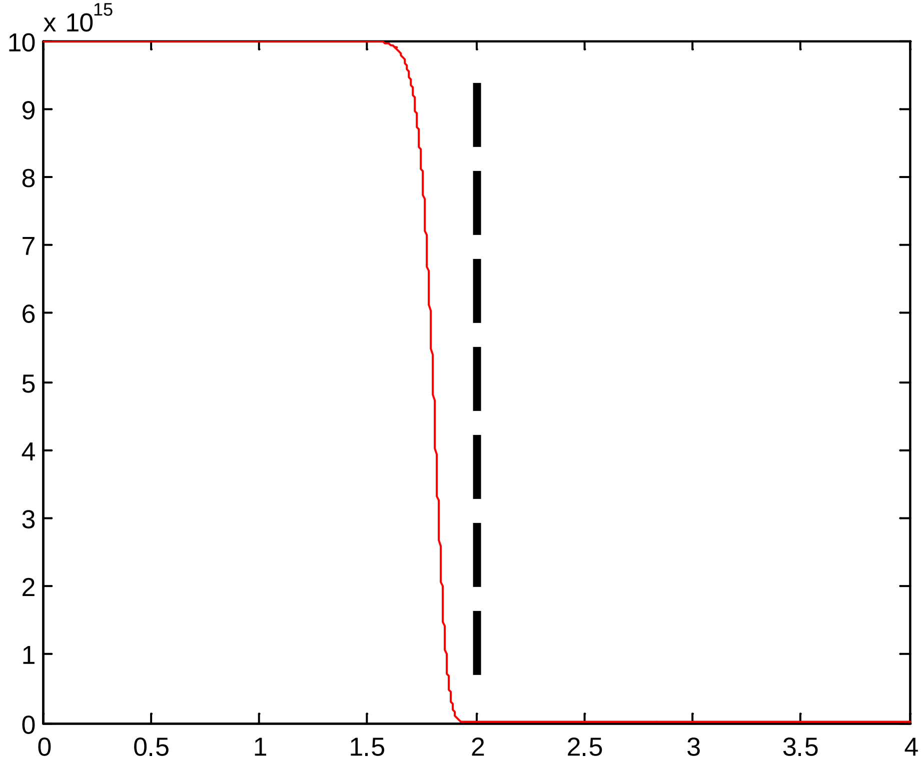


Depletion region

(Google image)

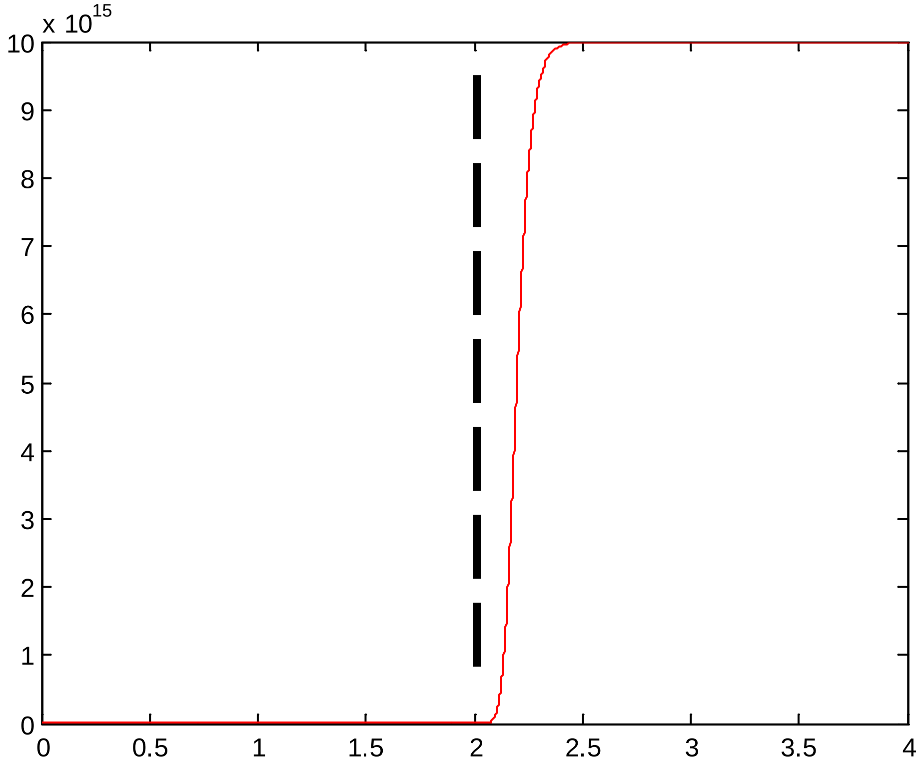
- Depletion region causes **E**.
  - A symmetric pn junction with 10^{16} cm^{-3} doping density.

Electron density [cm^{-3}]



Position [μm]

Hole density [cm^{-3}]



Position [μm]

Built-in potential

- The potential difference across the junction
  - A simple expression is available.

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