VLSI Devices
Lecture 4

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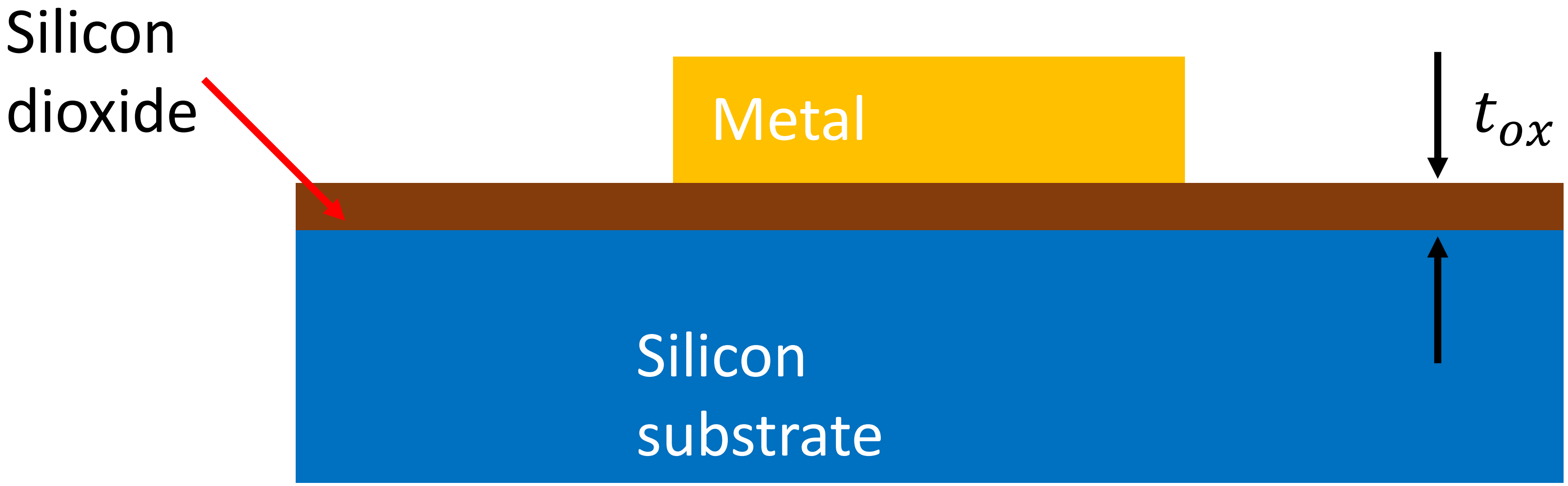
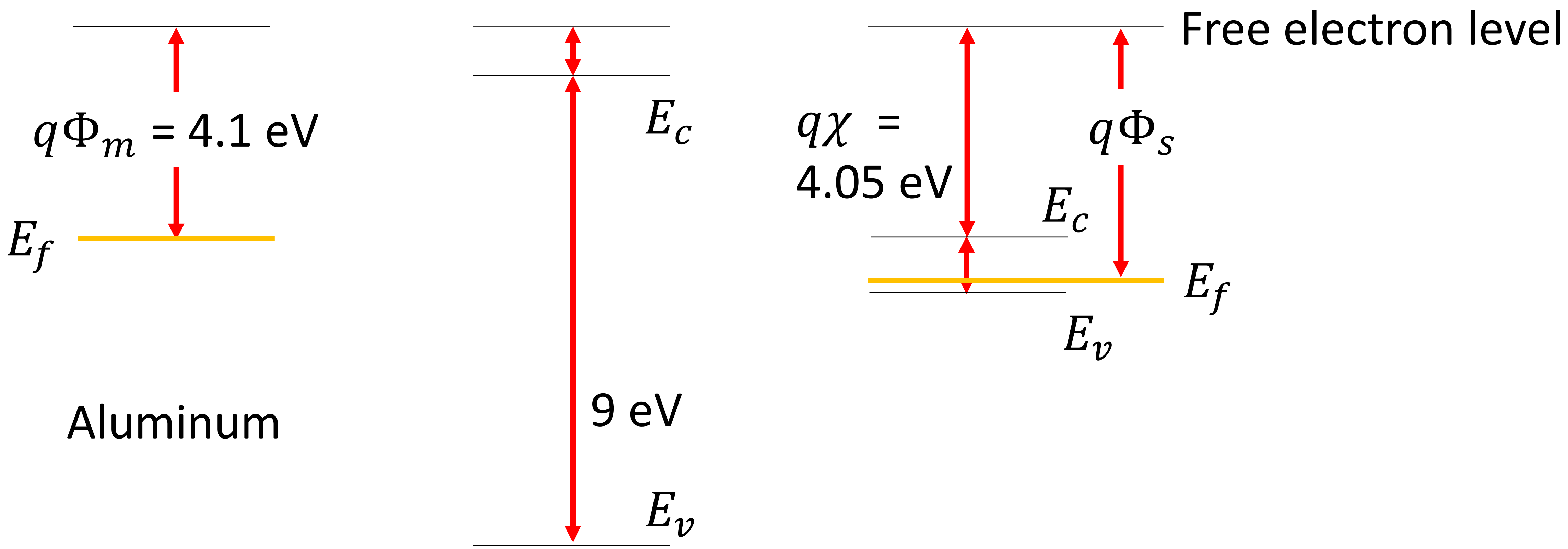
MOS capacitors

- Basis of CMOS technology



Energy band diagram

- Three components
  - Metal, silicon dioxide, and p-type silicon

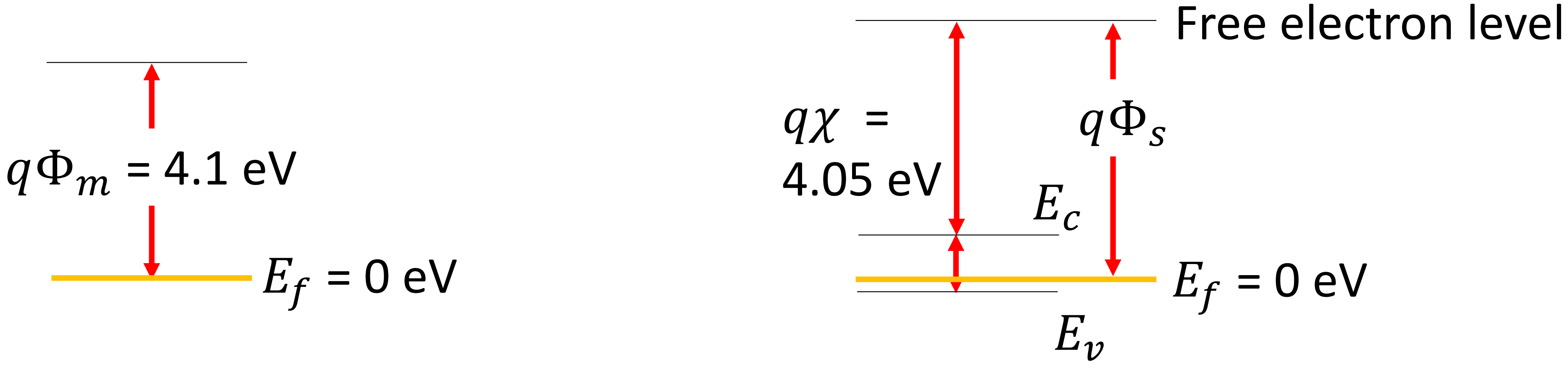


Consider $V_g = V_{sub} = 0$ V.

- Rule: Align the Fermi level.
  - The energy difference is

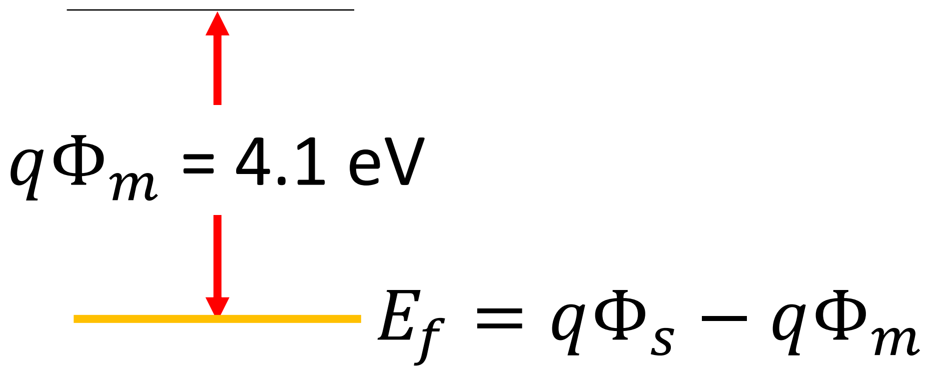
$$q\Phi_s - q\Phi_m$$

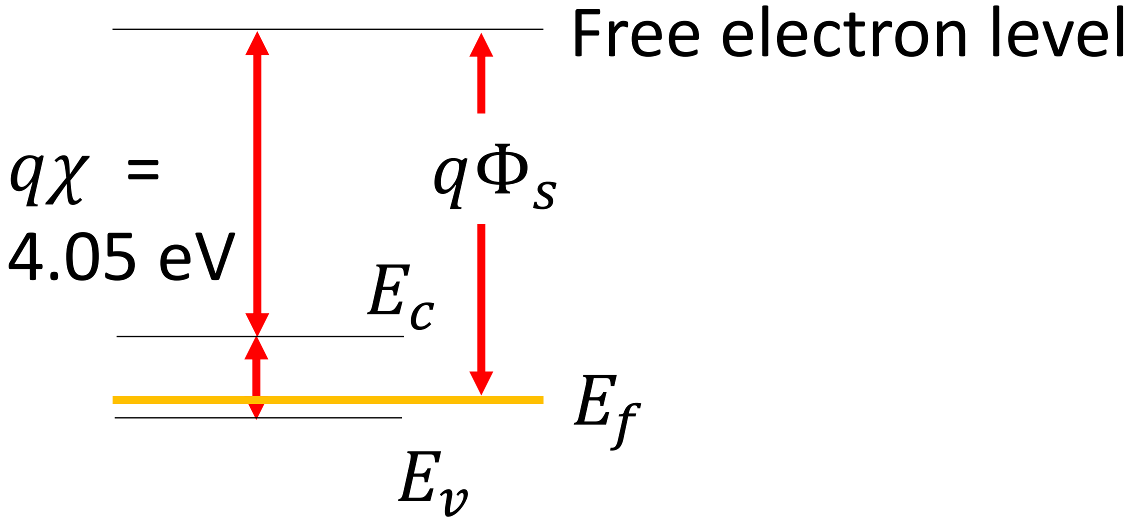
  - It means that a non-zero electric field is applied in the oxide layer.



When $V_g = \Phi_m - \Phi_s < 0$,

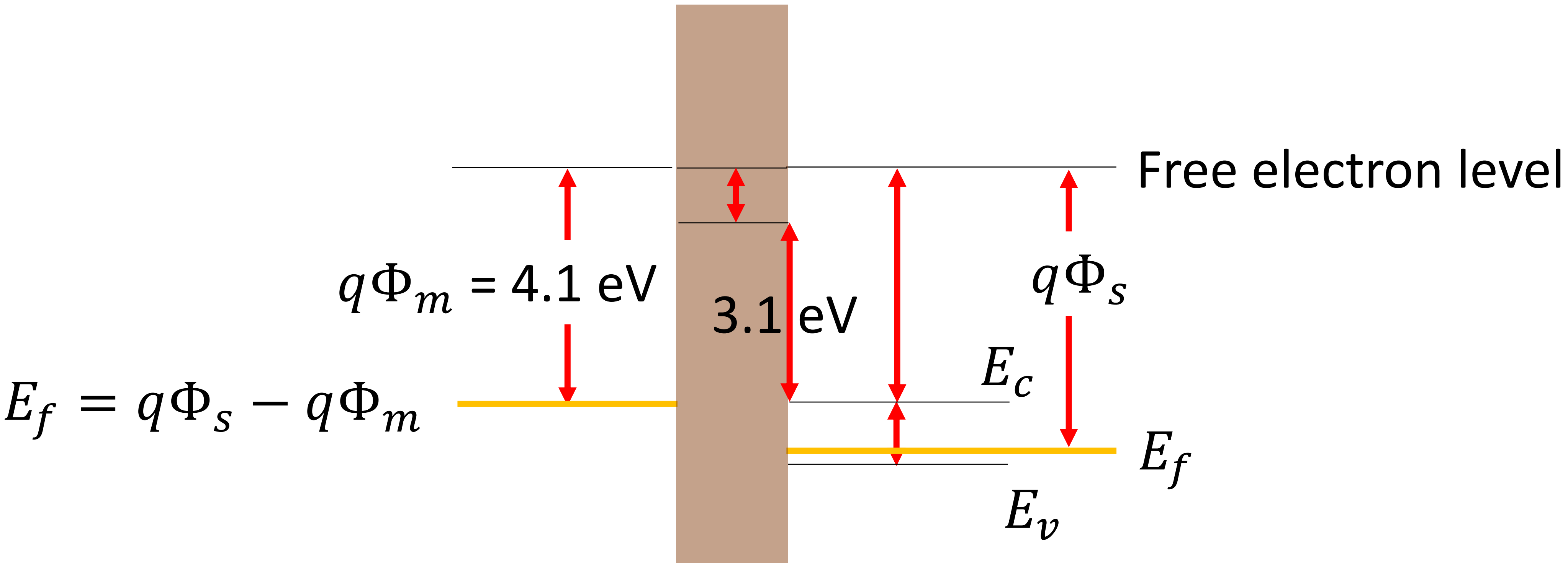
- The energy band at gate moves upward.
  - There is no energy difference.
  - It means that the energy band becomes flat.
  - This gate voltage is called the flatband voltage, V_{fb}.





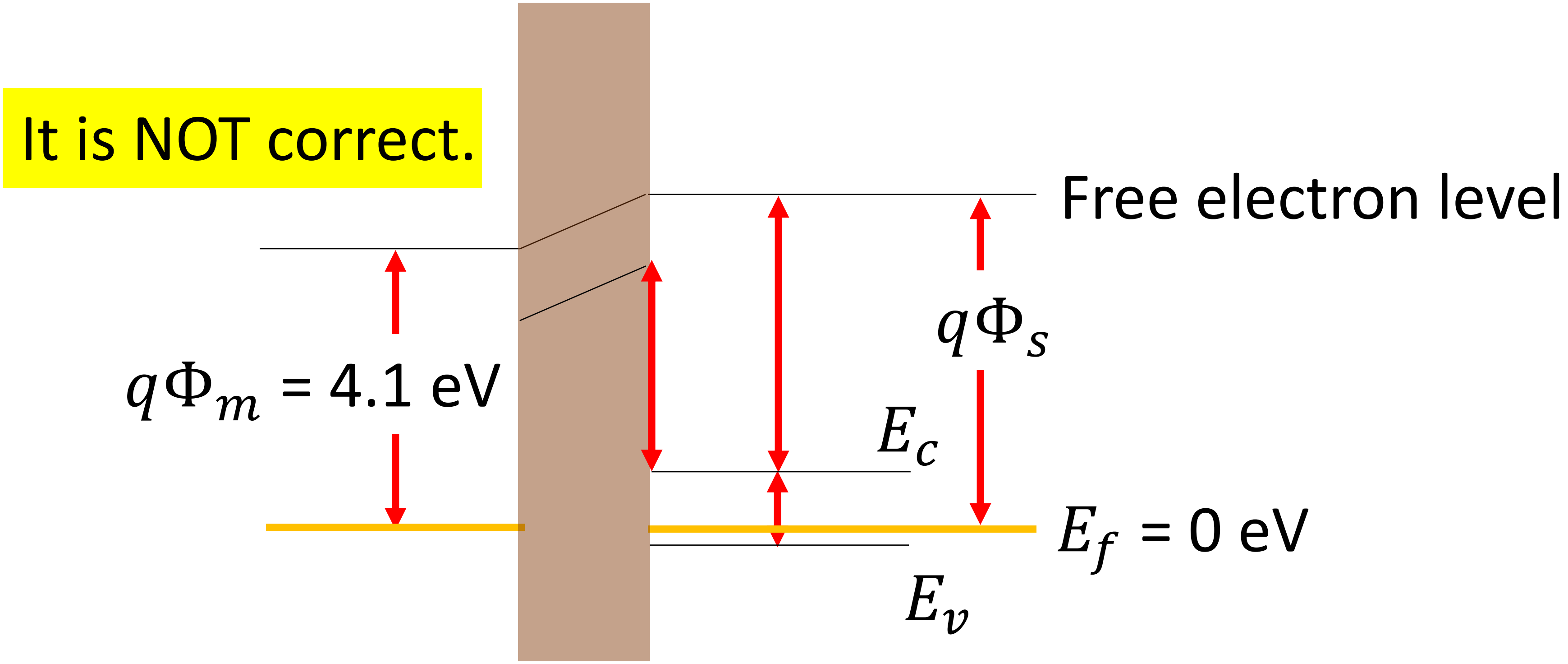
Draw the energy band diagram at $V_g = V_{fb}$.

- Since the energy band is flat, it is not difficult.
  - The electron energy barrier is 3.1 eV between the conduction bands of silicon and silicon dioxide.



Consider V_g = V_{sub} = 0 V, again.

- Non-zero electric field is found.
  - However, the energy difference, $q\Phi_s - q\Phi_m$, cannot be solely applied to the oxide layer. *Why?*

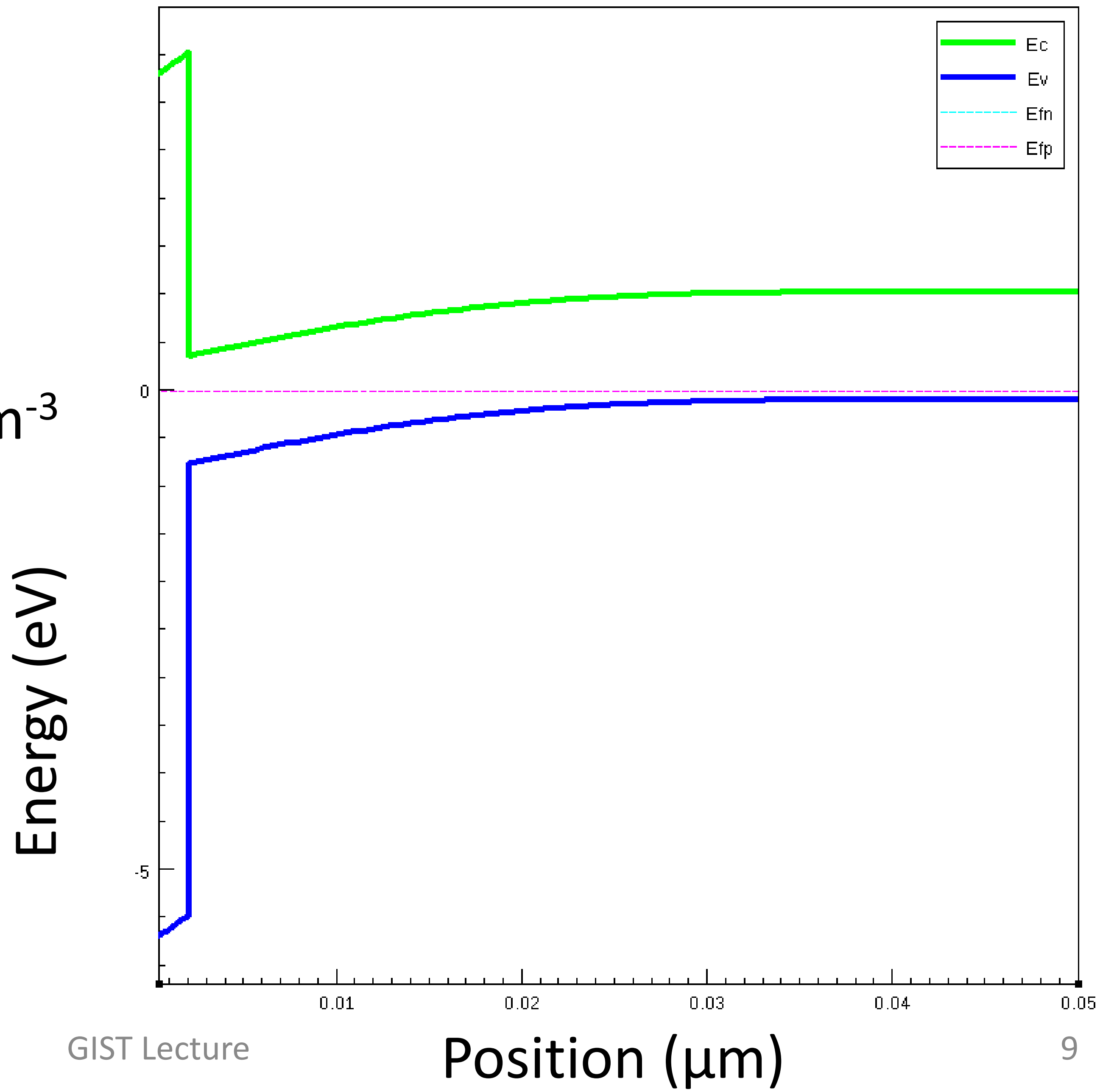


Surface potential, $\boldsymbol{\phi_s \equiv \phi(0) - \phi(\infty)}$

- A downward bending of bands in the p-type silicon near the surface
  - It is important to note that
$$V_g - V_{fb} = \phi_s + V_{ox} \qquad \text{Taur, Eq. (2.172)}$$
  - At the silicon-oxide interface,
$$\epsilon_{ox}|\mathbf{E}_{ox}| = \epsilon_{si}|\mathbf{E}_{si}| \qquad \text{Taur, Eq. (2.173)}$$
  - Since $\epsilon_{ox} = 3.9\epsilon_0$ and $\epsilon_{si} = 11.7\epsilon_0$,
$$|\mathbf{E}_{ox}| \approx 3|\mathbf{E}_{si}|$$

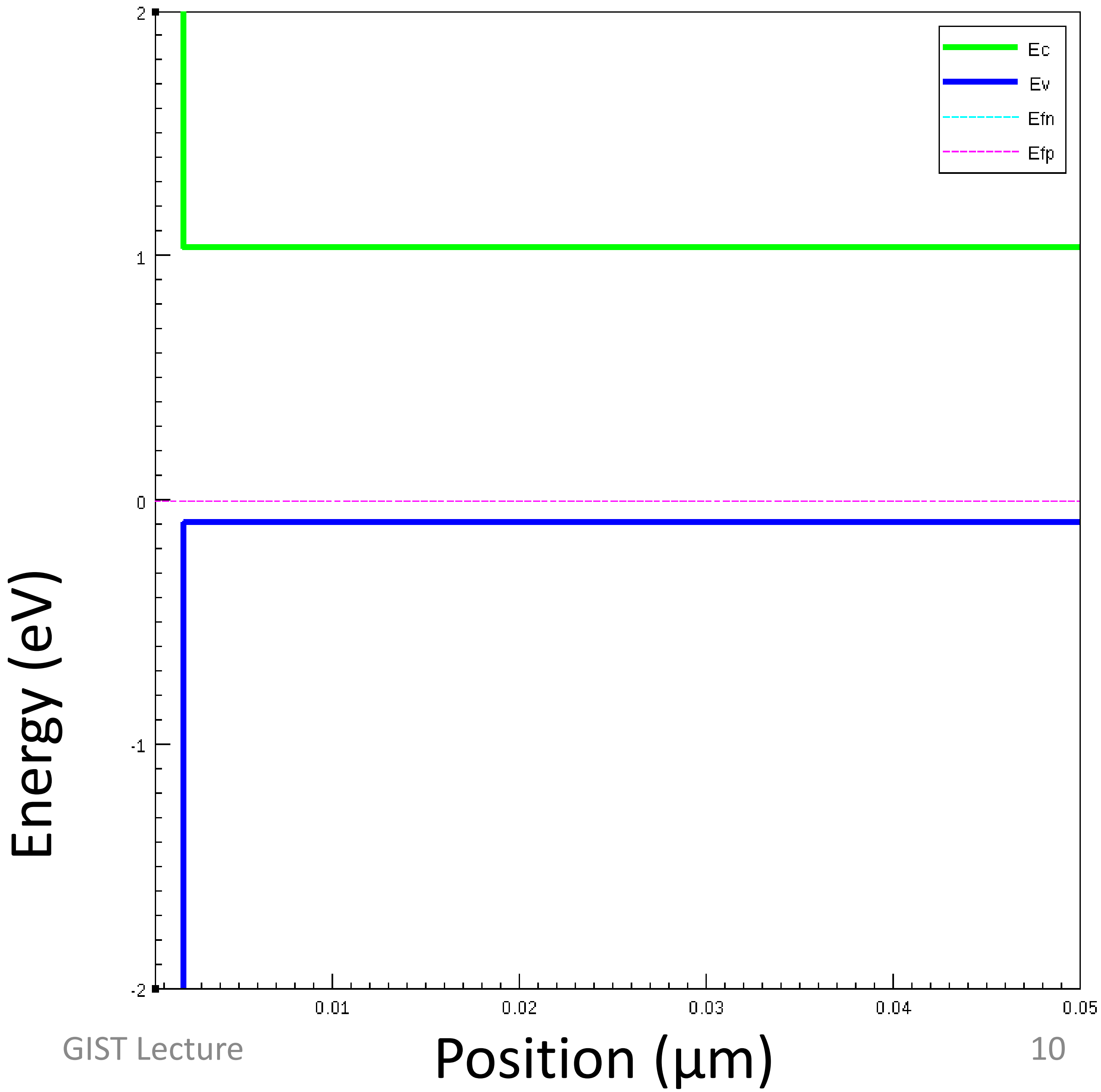
TCAD simulation

- Model parameter
  - Workfunction of 4.17 eV
  - Oxide thickness of 20 Å
  - P-type doping of 1×10^{18} cm^{-3}



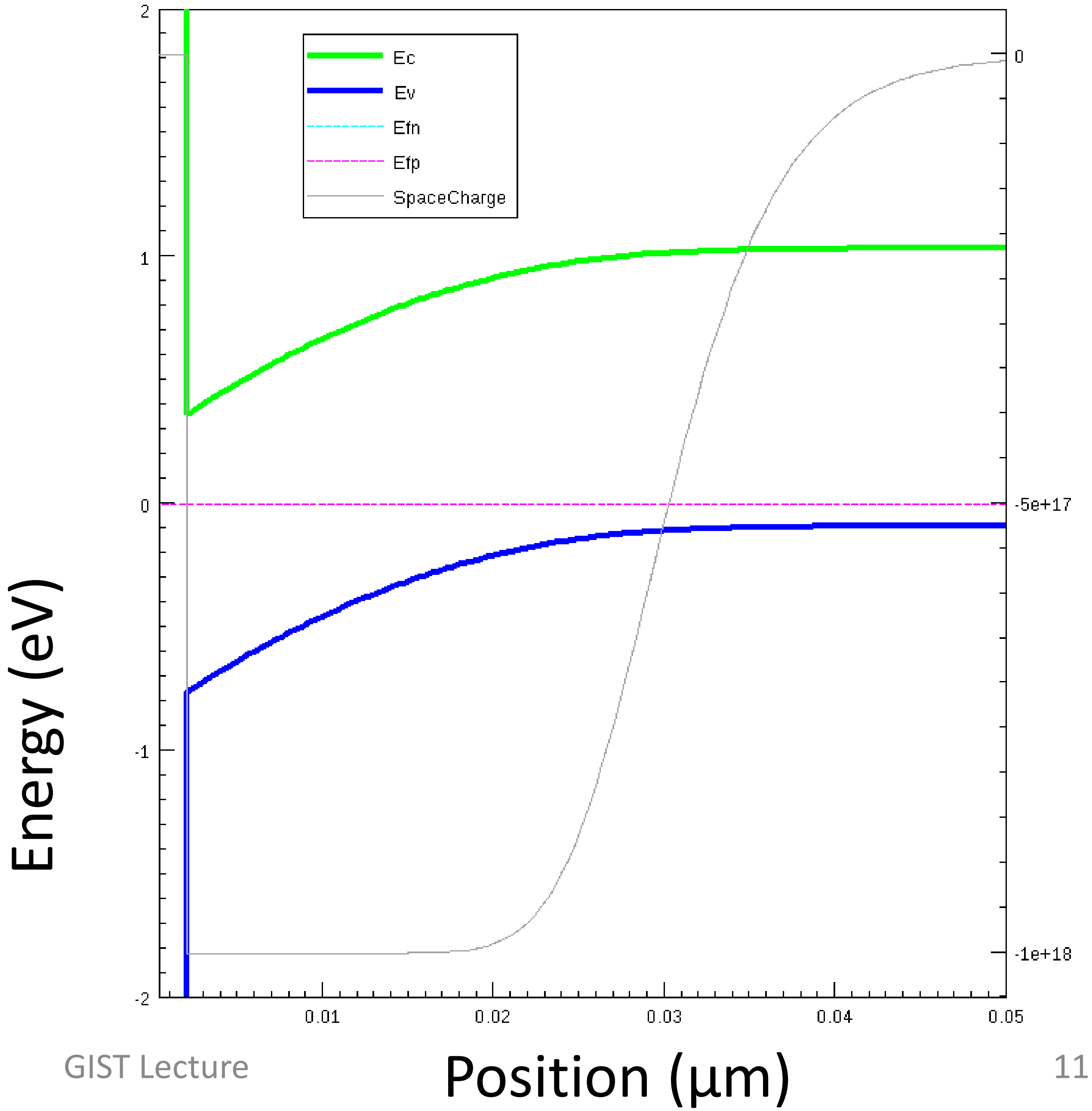
Case 1

- V_g = -0.94 V
  - Flatband condition



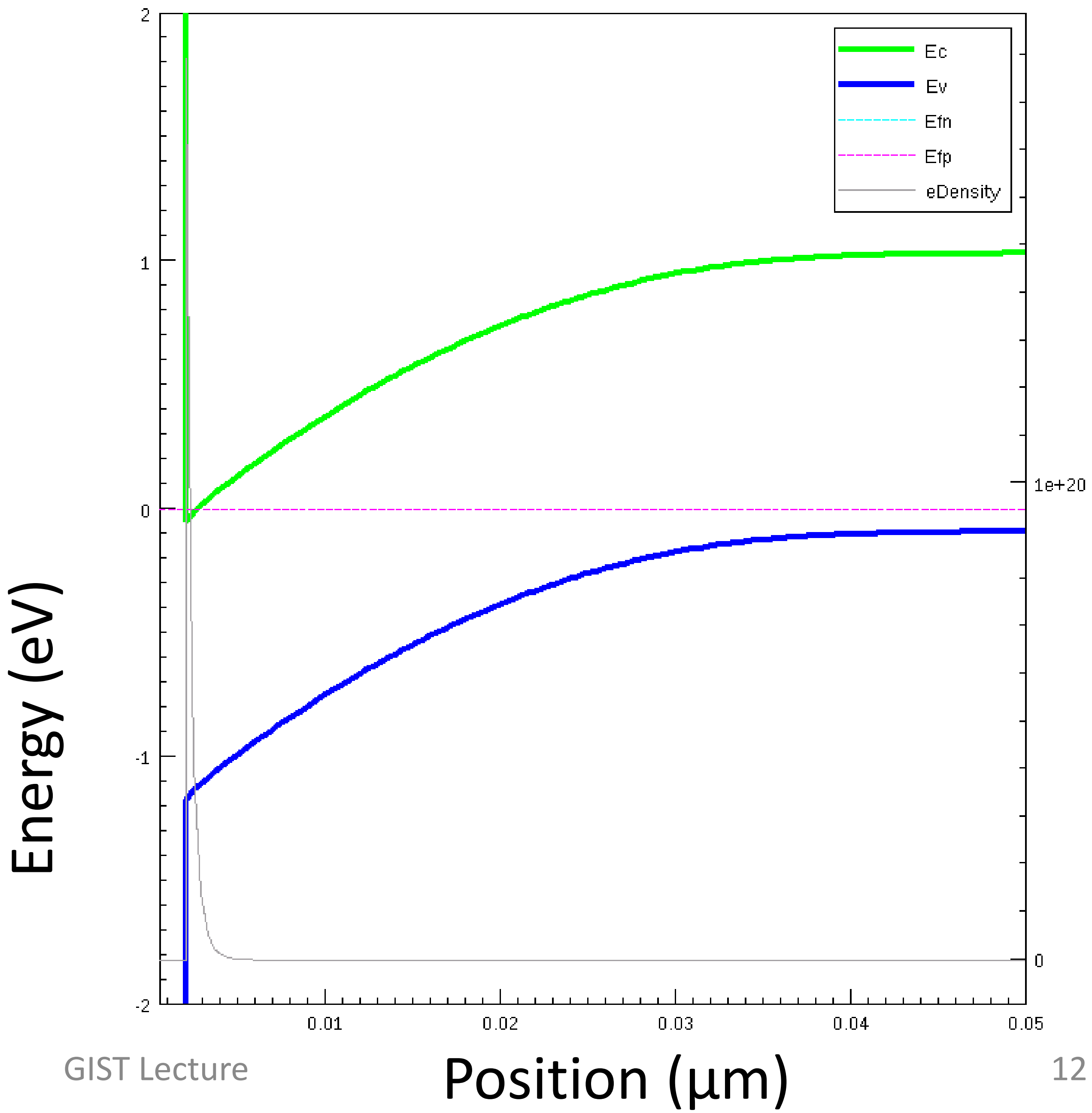
Case 2

- V_g = 0.0 V
  - Depletion
- Space charge



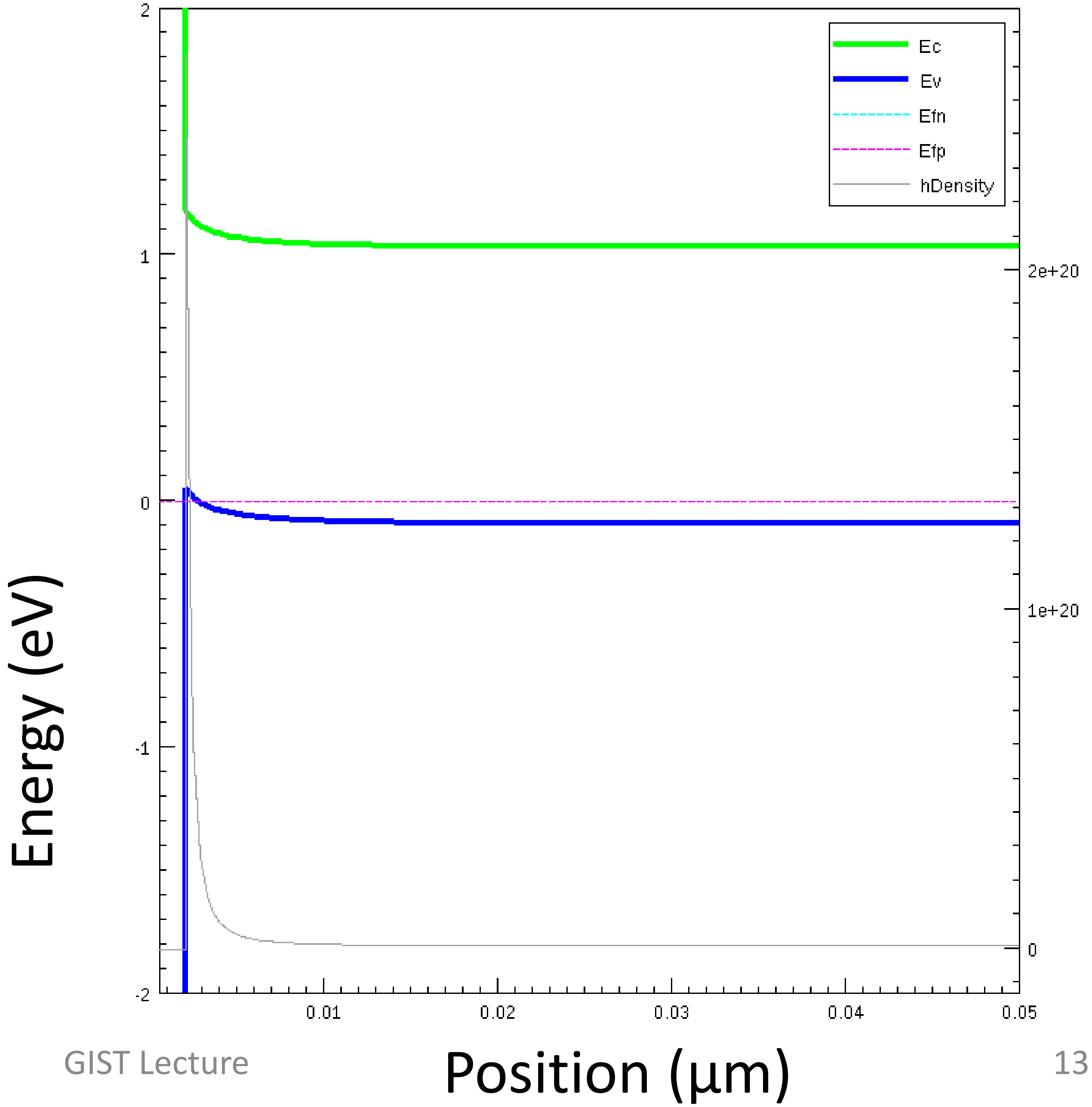
Case 3

- V_g = 1.0 V
  - Inversion
- Electron density



Case 4

- V_g = -2.0 V
  - Accumulation
- Hole density



Thank you!