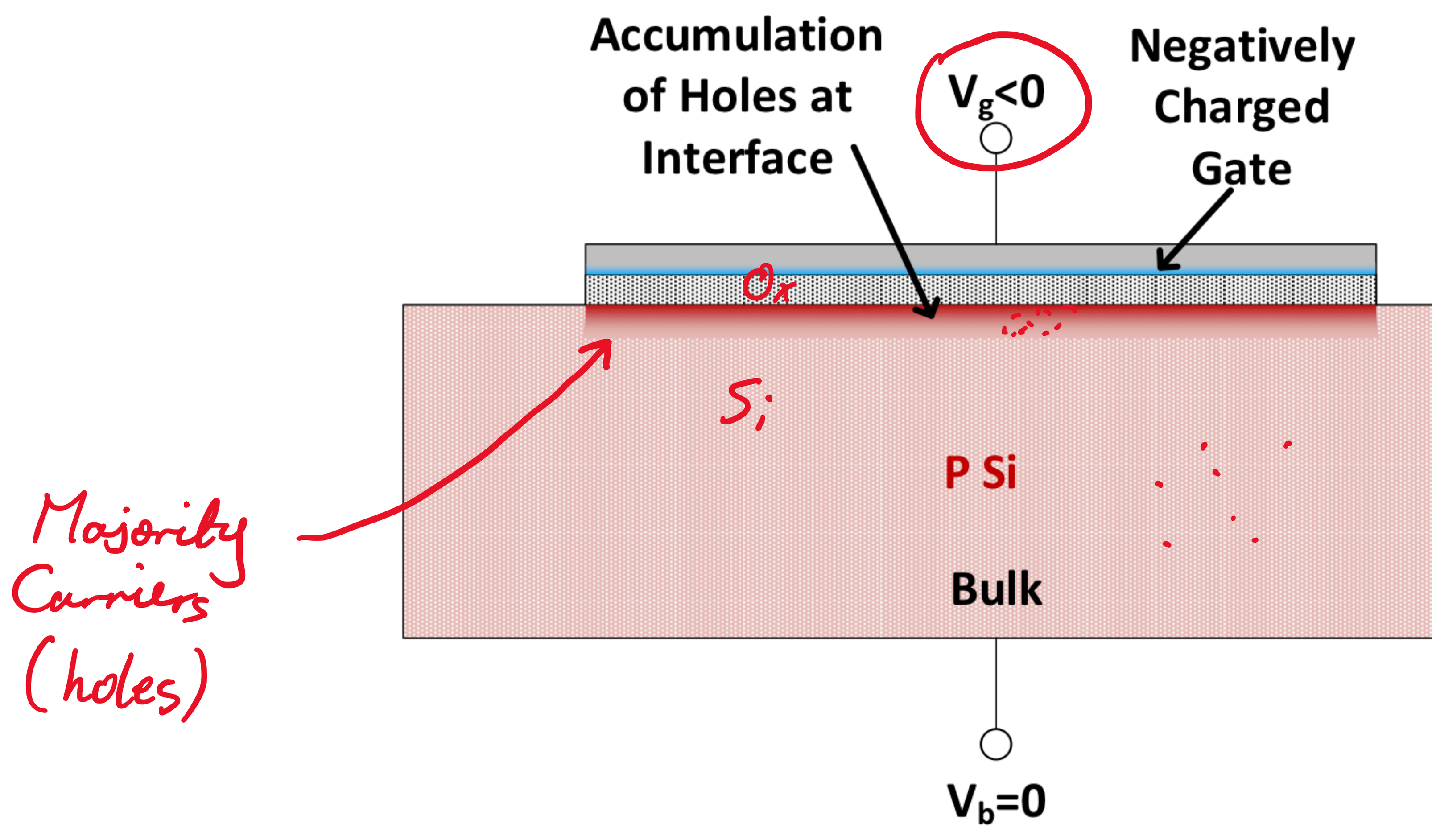
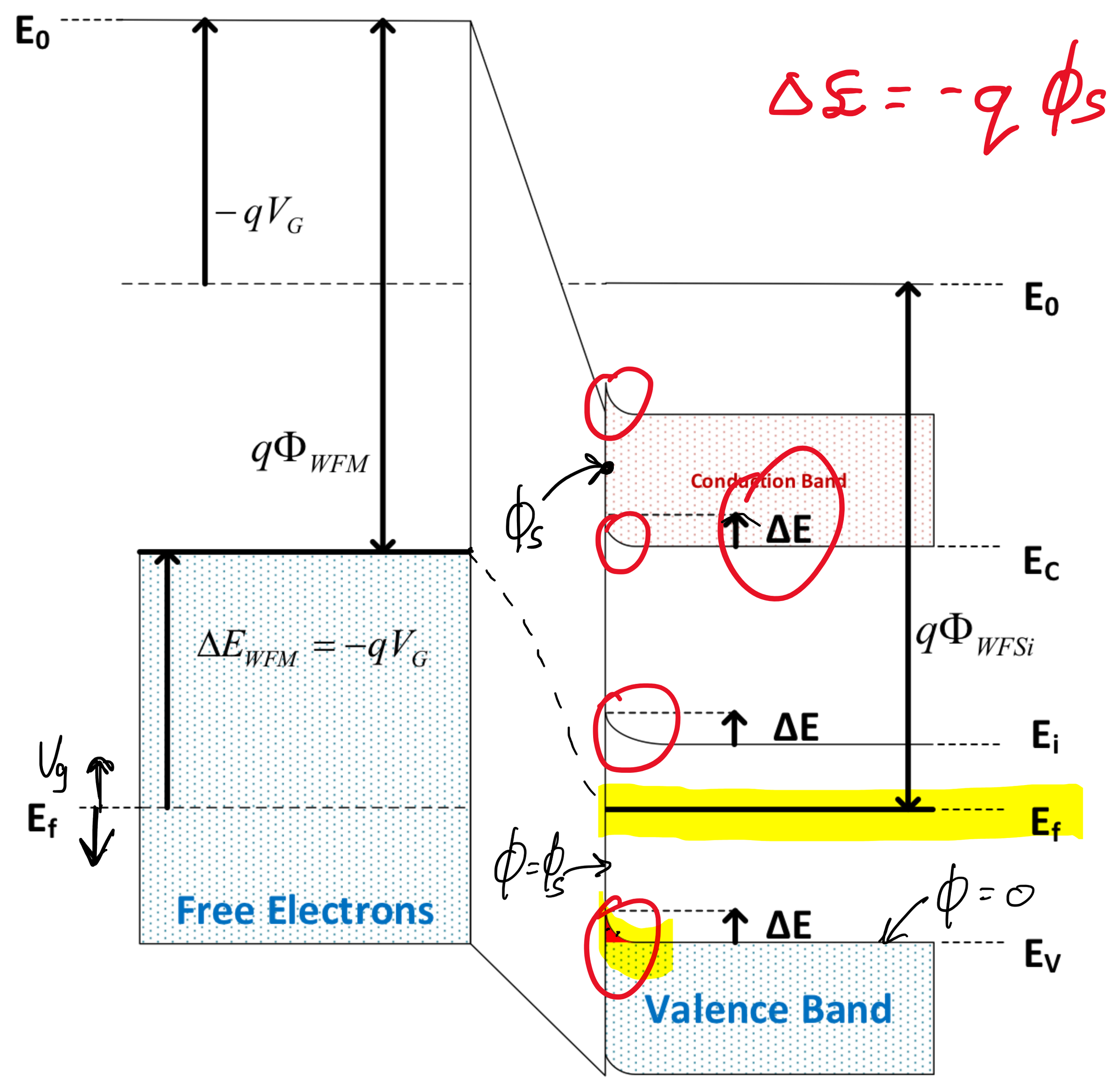
MOSFETS Part 6: Accumulation

Monday 16 March 2020 11:55



Accumulation Band View

- Set $V_g < 0$
- Results in Metal Fermi-Level shift of
  $\Delta \mathcal{E}_{FM} = -qV_G$
- Causes Si Bands to bend near interface
  - Bends by an amount $-q\phi_s$
    - Where ϕ_s is the potential at the interface
- Si Fermi Level Fixed by Doping
- Bent Valence band closer to $\mathcal{E}_f$
  - Hole conc. Higher
  - Higher accumulation of holes at the interface
- Holes because substrate is p-type
  - More correctly majority charge carriers



Potential $\phi(x)$ & Accumulation Thickness x_{acc}

- Bands tell us to expect more holes @ Interface
  - Due to some unknown potential gradient $\phi(x)$
- Let's calculate how many more holes: Poisson's Equation!

P-type

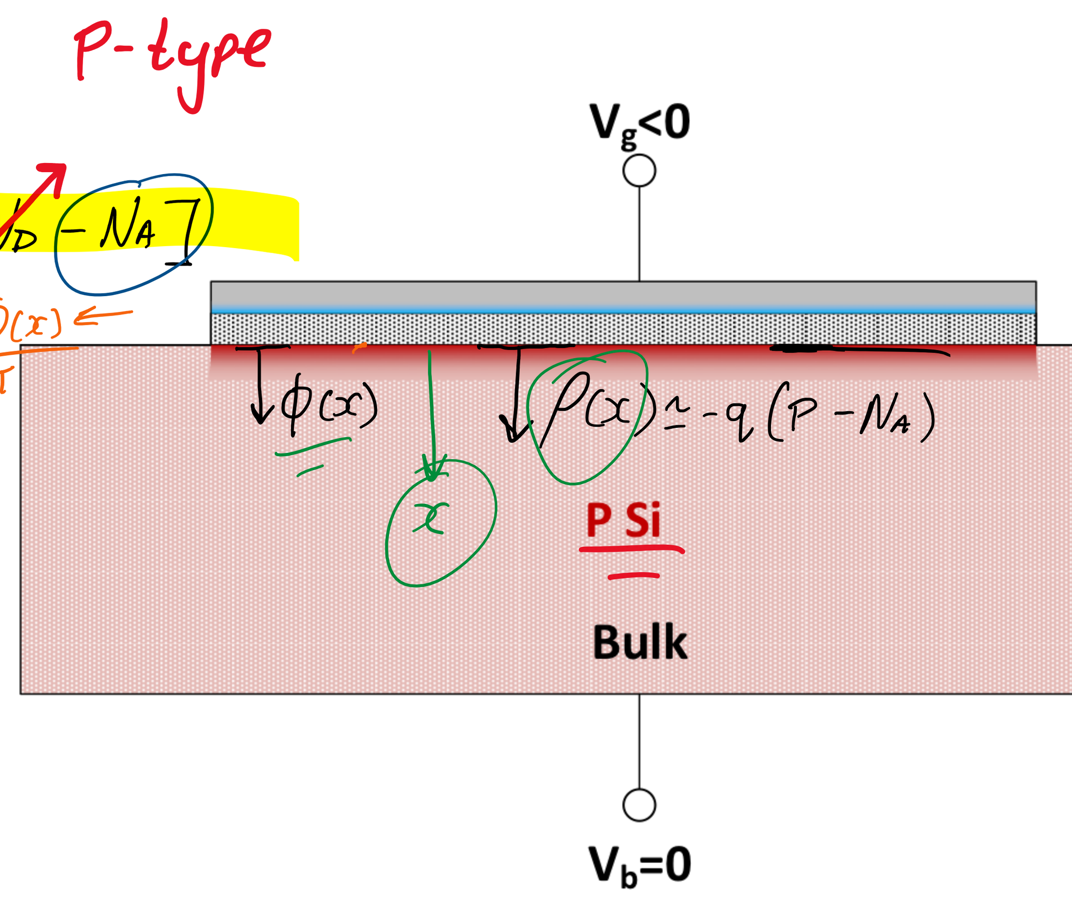
$$\frac{d^2\phi(x)}{dx^2} = \frac{-\rho(x)}{\mathcal{E}_{Si}} = \frac{-q}{\mathcal{E}_{Si}}\left[p - \cancel{n} + \cancel{N_D} - N_A\right]$$

$p = N_A e^{\frac{-q\phi(x)}{kT}}$

$n \;\&\; N_D \simeq 0$ Since p-type material

$p =$ Thermally Generated & Dopant Introduced Holes ← free

$N_A =$ Fixed Dopant Atoms (Ions)



- Poisson's Equation Simplifies:

$$\cancel{\frac{d^2\phi(x)}{dx^2} = \frac{-q N_A}{\mathcal{E}_{Si}}\left[e^{\frac{-q\phi(x)}{kT}} - 1\right]}$$

- If we know $\phi(x)$, we know $\rho(x)$
  - Thus accumulation charge!
- But solving Poisson's Eqn requires solving 2nd order differential Eqn

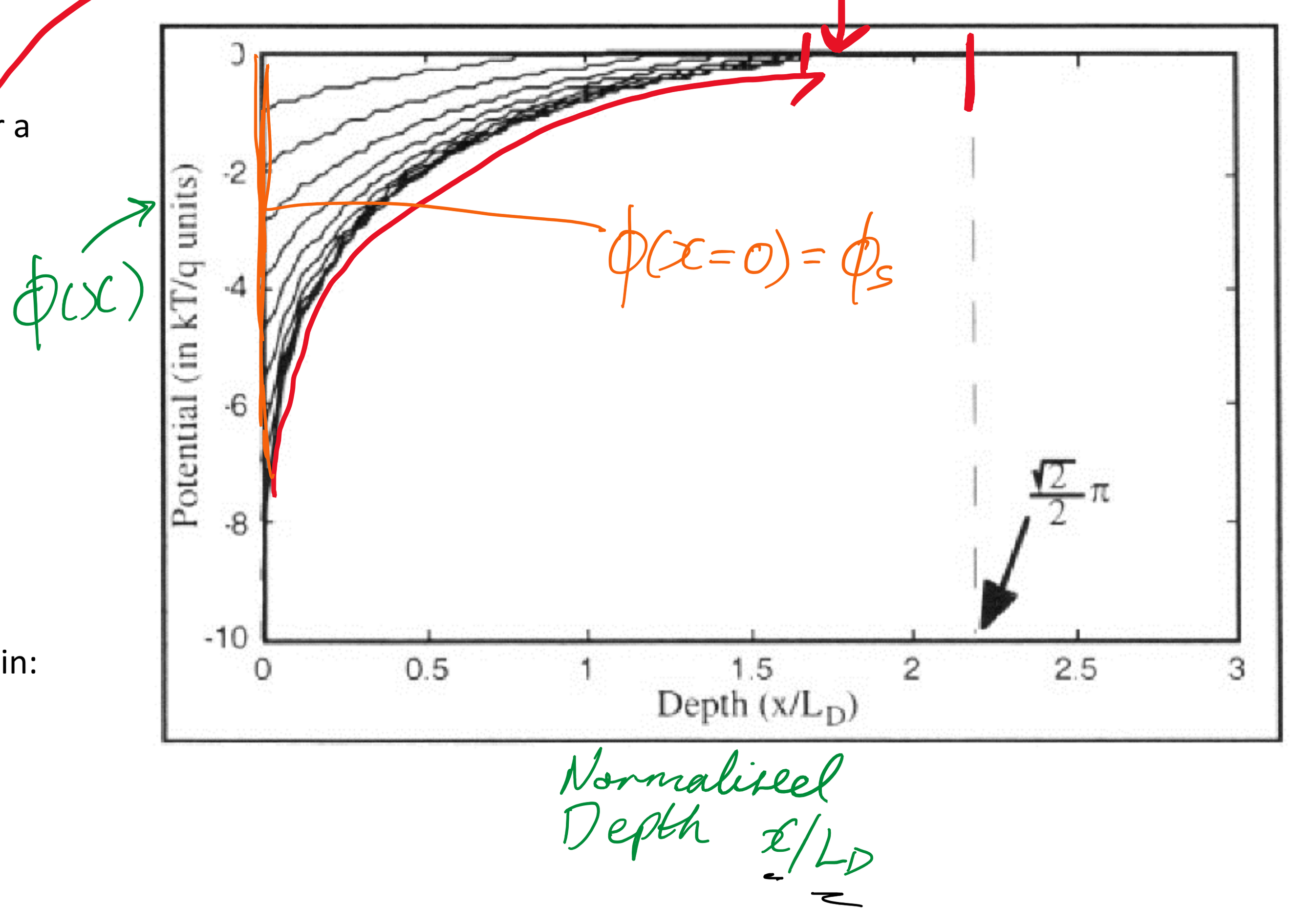
- Poisson would be a pain to solve
- Let someone else solve it and plot it instead
- Almost all the surface potential is dropped over a small distance regardless of surface potential!
- Normalise result to different Doping Concentrations with Debye Length:

$$L_D = \sqrt{\frac{\mathcal{E}_{Si}\, kT}{q^2 N_A}}$$

- All potential (thus all charge) accumulated within:

$$x < \frac{\pi}{\sqrt{2}} L_D = x_{acc}$$

- Usually very thin, a few nm



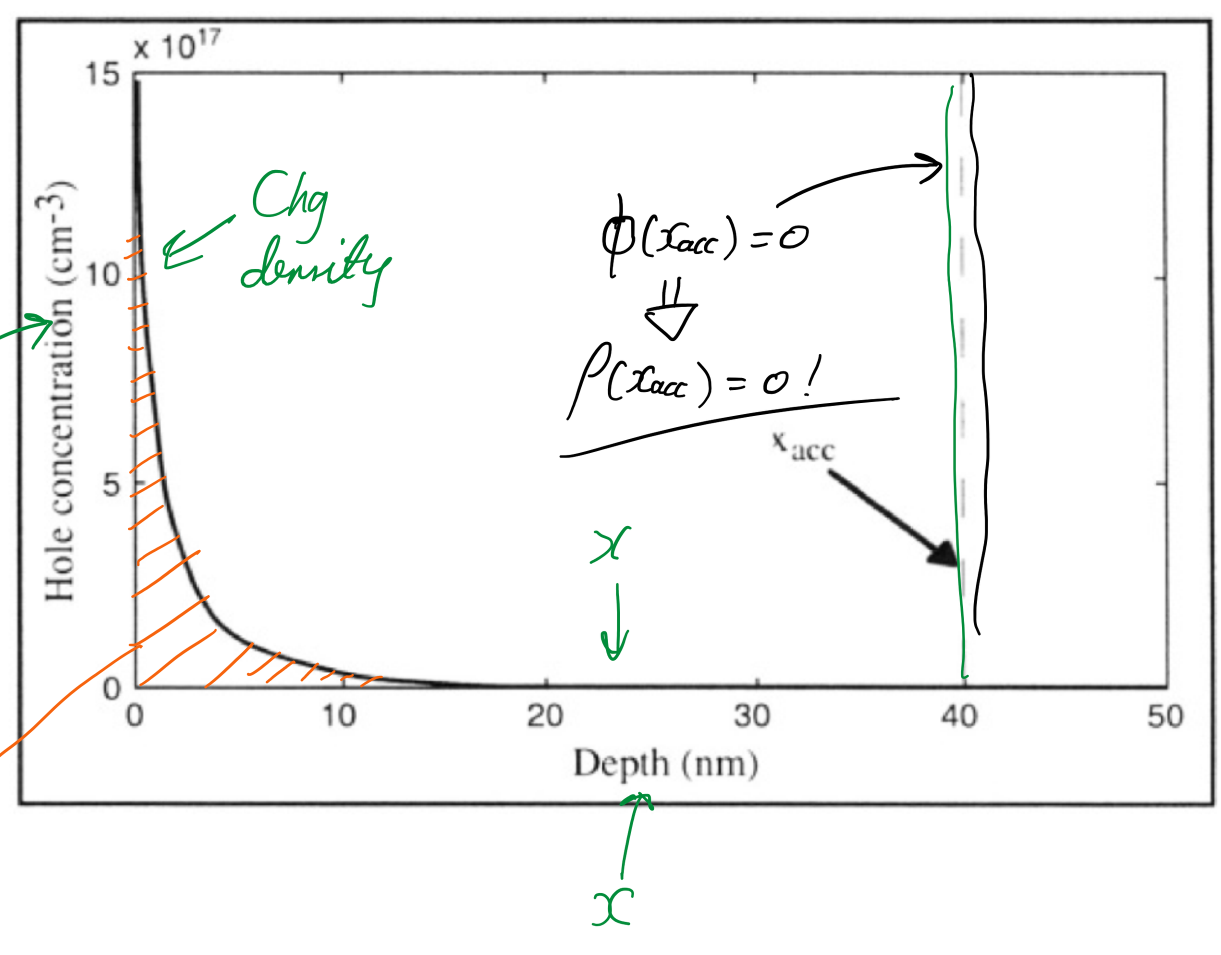
Accumulation Charge

- Charge Density as a function of depth given by:

$$\rho(x) = -q(p_{(x)} - N_A)$$

$$\rho(x) = -q N_A\left[e^{\frac{-q\phi(x)}{kT}} - 1\right]$$

- Charge Density $\rho(x)$ falls off exponentially with potential
  - Potential falls off within the thin x_{acc}
- All accumulation charge is contained within x_{acc}
- We want to know total accumulation charge Q_{acc}
- We know charge density $\rho(x)$
- We can integrate $\rho(x)$ to get Q_{acc}



$$Q_{acc} = \int_0^{x_{acc}} \rho(x)\, dx$$

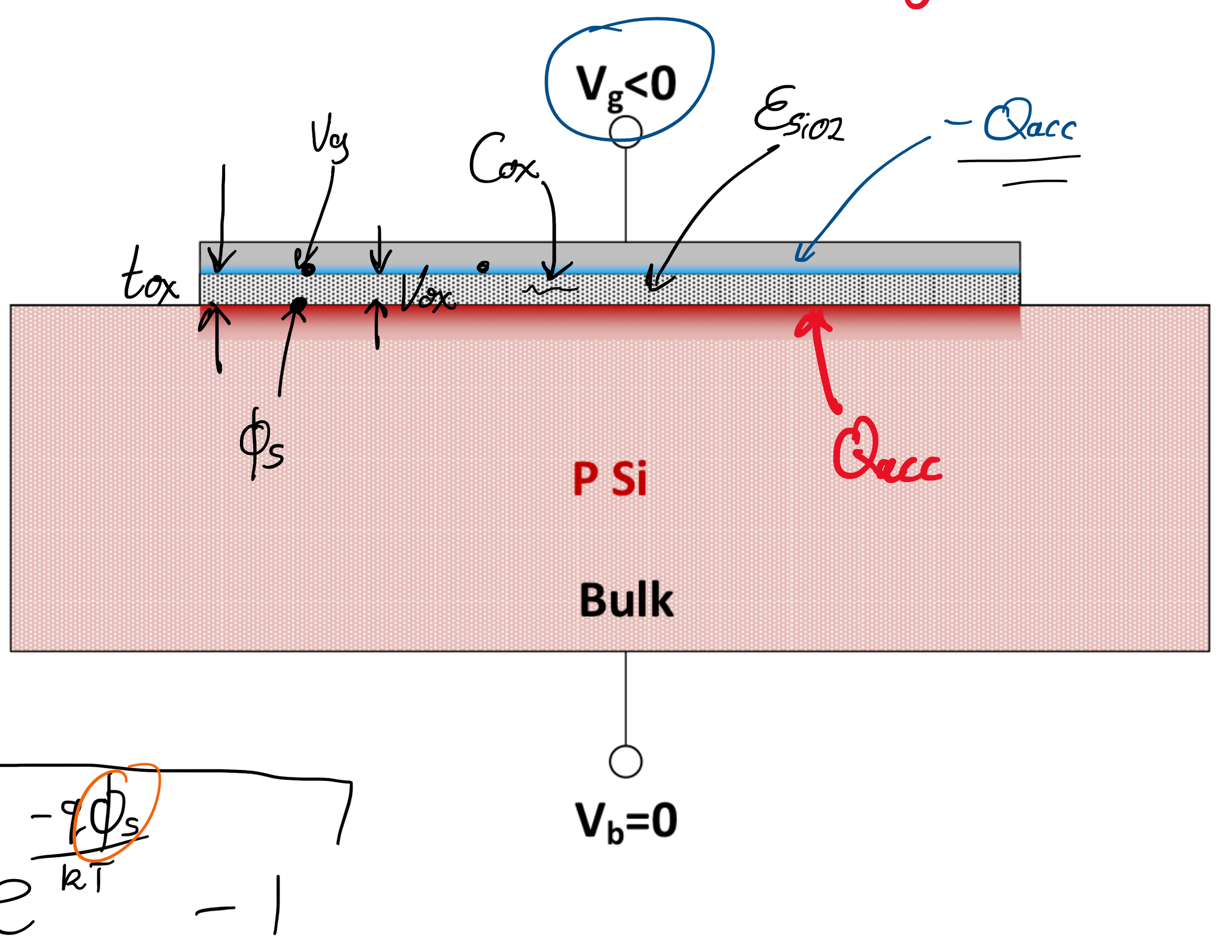
$$= \frac{-\mathcal{E}_{Si}\sqrt{2}}{L_D}\,\frac{kT}{q}\sqrt{e^{\frac{-q\phi_s}{kT}} - 1}$$

* Not Important *
↳ understand where we got it

Linking Gate Voltage to Accumulation Charge

- We want to link V_G to Q_{acc}
- We know: $Q = CV \longrightarrow V = \frac{Q}{C}$
- By KVL: $V_G = \phi_s + V_{ox}$

$$V_G = \phi - \frac{Q_{acc}}{C_{ox}}$$



- Approximate Parallel Plate Cap since $x_{acc} \rightarrow 0$

$$C_{ox} = \frac{\mathcal{E}_{SiO2}}{t_{ox}} \quad [F/m^2]$$

$$V_G = \phi_s + \frac{\mathcal{E}_S\sqrt{2}}{L_D\, C_{ox}}\,\frac{kT}{q}\sqrt{e^{\frac{-q\phi_s}{kT}} - 1}$$

→ Solve for ϕ_s → Use ϕ_s to find Q_{acc}