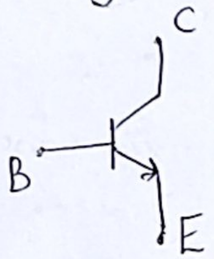
# Lec 13 MOS Capacitors

Why do BJTs make a bad switch?



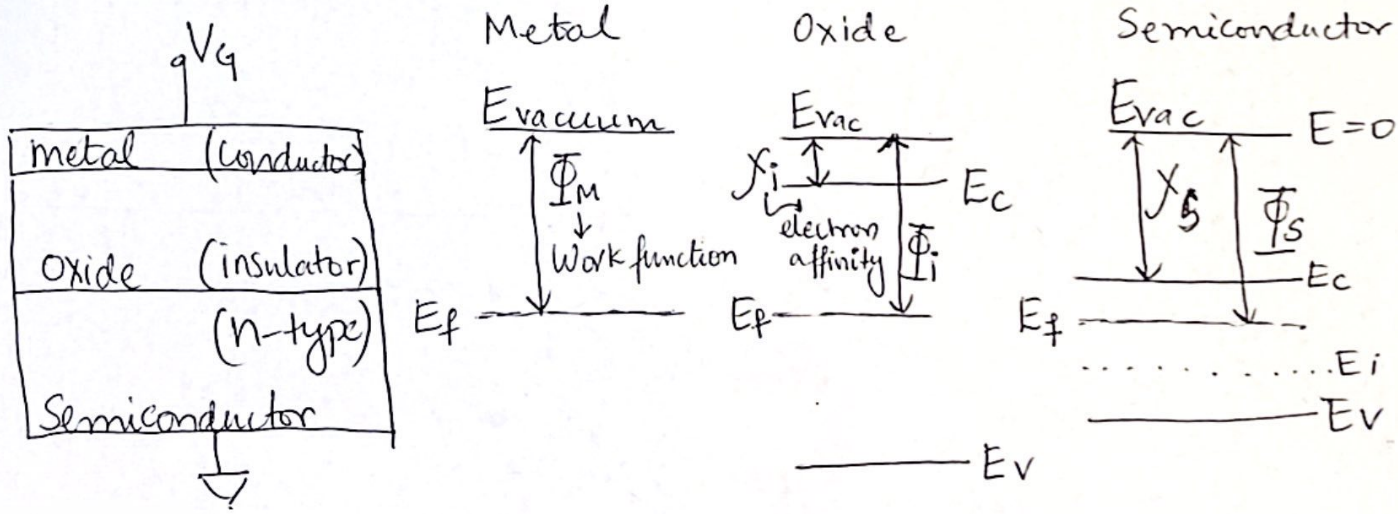

> B pulled up ⇒ Saturation; Current flows and a large number of minority carriers($e^-$) are injected into the Base.

> B pulled down ⇒ Cut-off; Both junctions are RB ⇒ no current flows & the electrons in base must be removed through recombination ⇒ slow & has a "leakage" current.

> The main problem is that BJT is a minority carrier controlled device.

> Today MOSFETs are the workhorse of all circuits. To understand them we must understand the MOS cap.

## Metal Oxide Semiconductor Capacitor



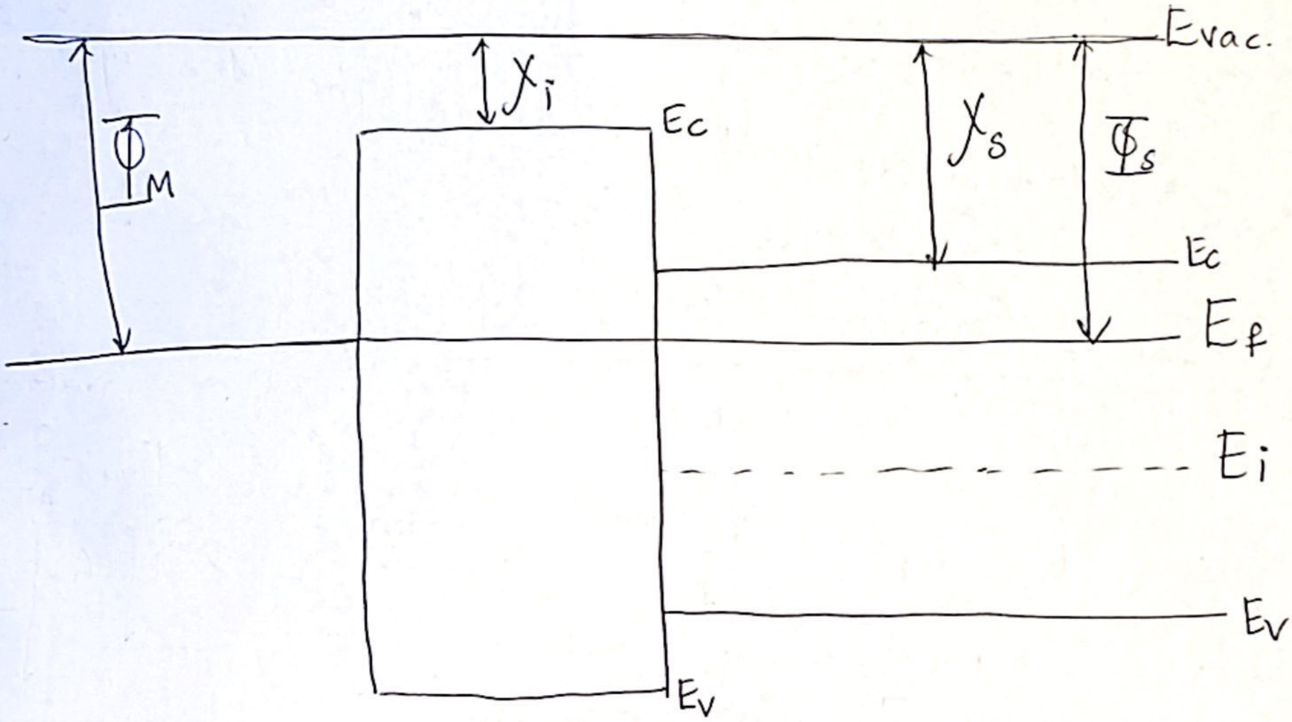
> $\chi$ does not depend on doping concentration but $\Phi$ does.

$$\Phi_s = \chi_s + (E_c - E_f)$$

> **Assumptions** (We will revisit later).

1) No net charge centers in the oxide or at the oxide-sc junction
2) Flat band condition exists $\Phi_M = \Phi_s = \chi_s - (E_c - E_f)$

$V_G = 0$



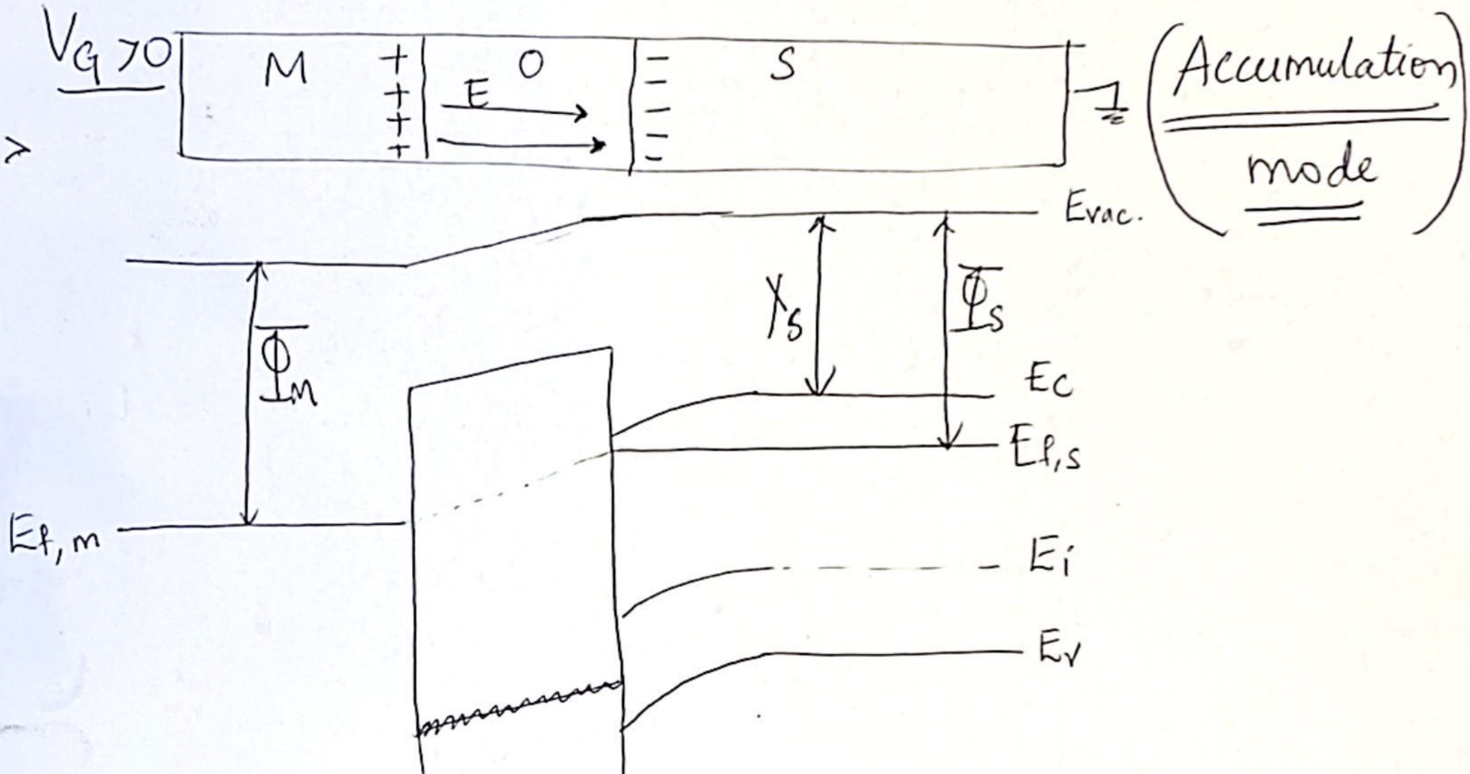
> When $V_G \neq 0$ due to insulator no current can flow ⇒ $E_{f,s}$ remains constant within the semiconductor. $E_{f,m}$ is also constant.

$\nabla \cdot E = \frac{\rho}{\epsilon}$

$V = -\int \bar{E} \cdot d\bar{l}$

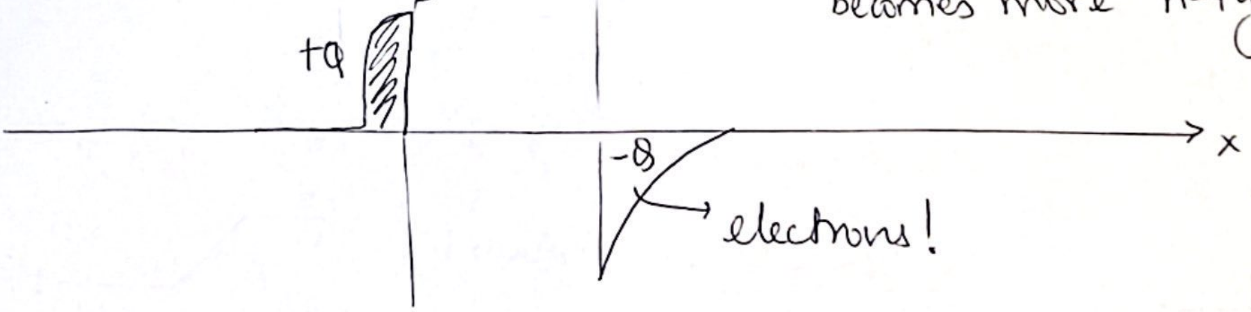
$U = \frac{V}{q}$

$$\Rightarrow \quad E_{f,M} - E_{f,S} = -q V_G$$

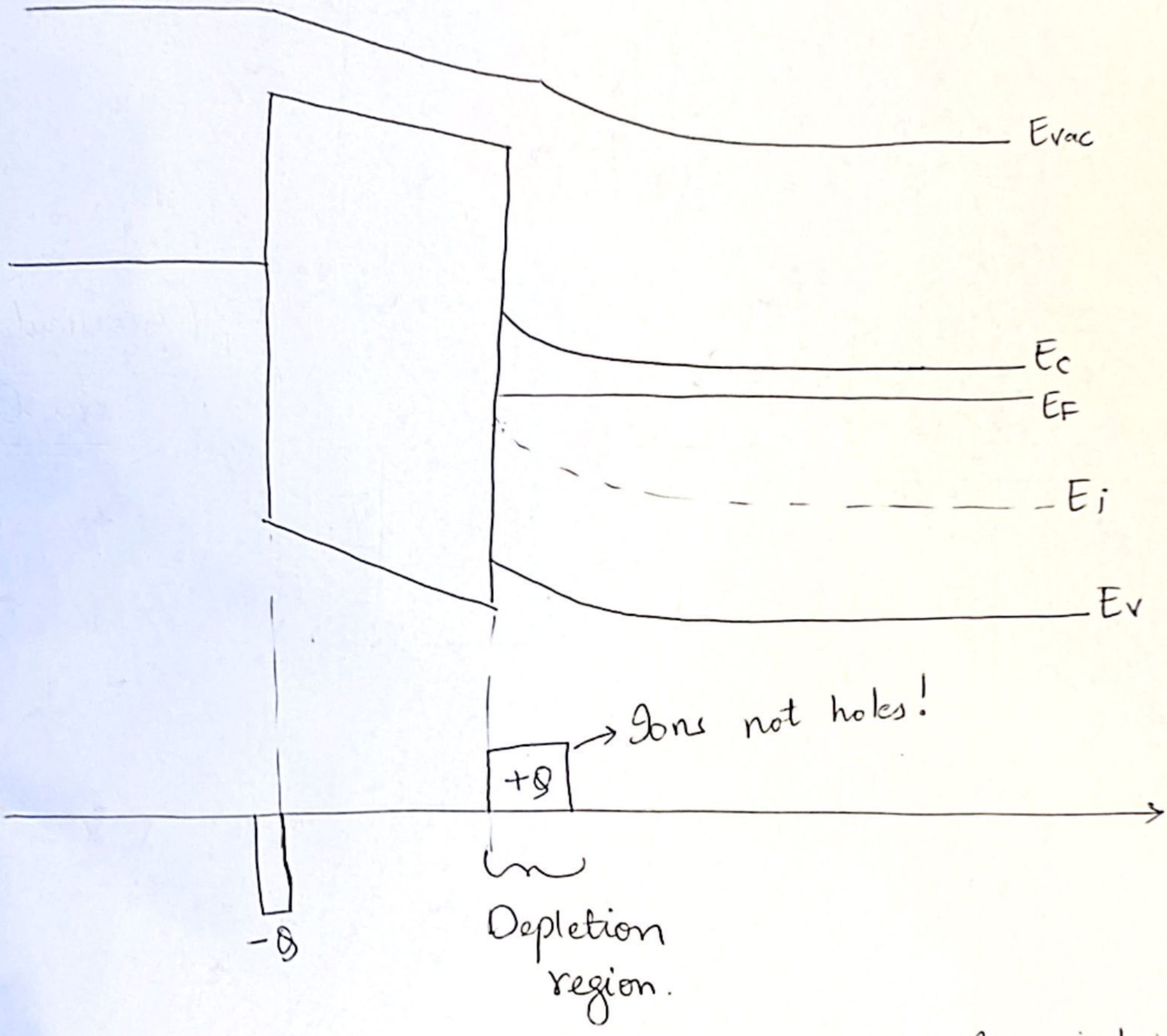



$$n = n_i \, e^{\frac{E_f - E_i}{kT}}$$

⇒ near surface material becomes more n-type!



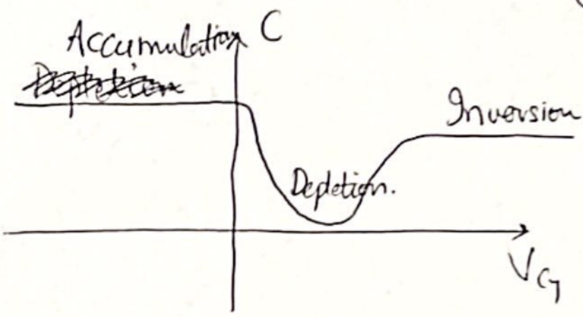
## $V_G < 0$ & small (Depletion mode)



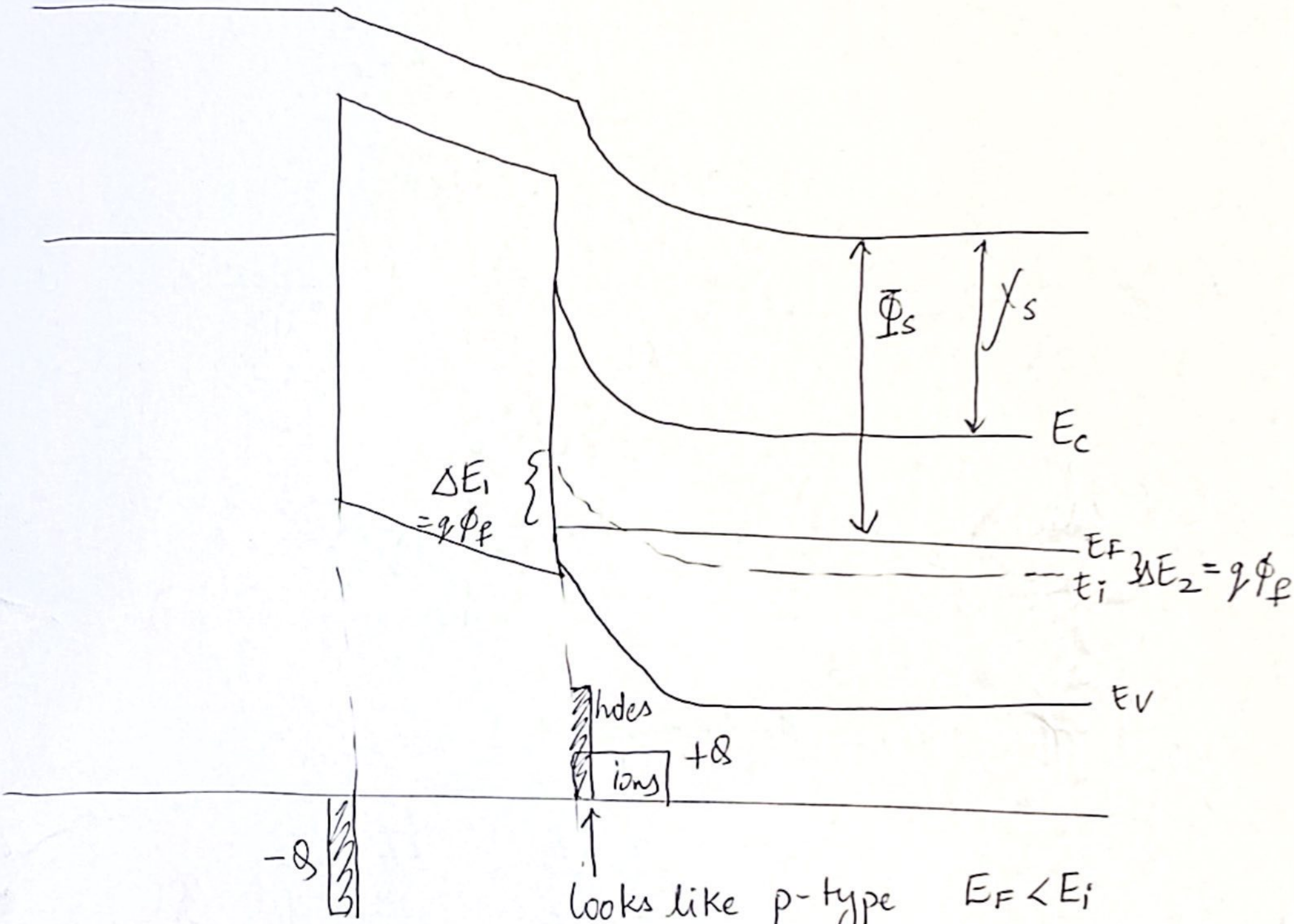

> At the interface the Sc looks almost like intrinsic since $E_F \simeq E_i$.

> Note: Fermi level is not well defined since the bandgap is large


→ But it does slope continuously.




## $V_G \ll 0$ (Inversion mode)




When $\Delta E_1 = \Delta E_2 \Rightarrow$ Strong Inversion!

$\Rightarrow P_{surface} = n_{bulk}$ (recall $p = n_i e^{\frac{E_i - E_F}{KT}}$ ; $n = n_i e^{\frac{E_F - E_i}{KT}}$)

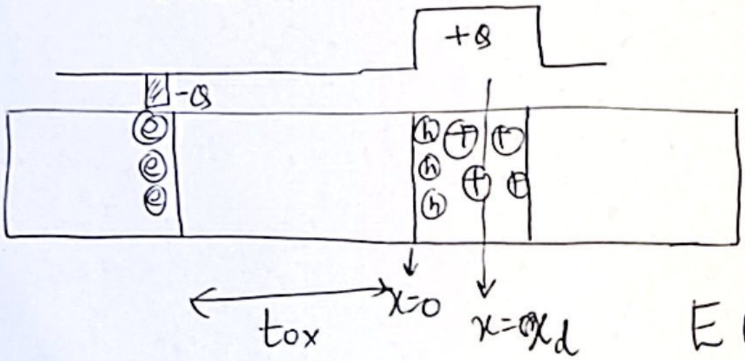
> Where do these holes come from? e-h pair generation.

$\Rightarrow$ Slow process so it makes a slow varactor.

# When does strong inversion occur? What is $V_G$?

$$V_G = \phi_s + \Delta\phi_{ox}$$ (Here $\phi_s$ is potential drop, not $\Phi_s$)

↑ drop across semi — ← drop across oxide.




Gauss Law

$$E(x) = \frac{qN_D}{\epsilon_s}(x - x_d)$$

$$\phi(x) = -\int_{x_d}^{x} E(x)\,dx = \frac{qN_D}{2\epsilon_s}(x - x_d)^2$$

$$\Rightarrow \phi_s = \phi(x=0) = \frac{qN_D}{2\epsilon_s}x_d^2$$

$$\Delta\phi_{ox} = -t_{ox}E_{ox} = -t_{ox}E_s\frac{\epsilon_s}{\epsilon_{ox}} = \frac{t_{ox}}{\epsilon_{ox}}qN_D x_d$$

$$\Rightarrow qN_D x_d = \sqrt{2\epsilon_s qN_D\phi_s} \quad \& \quad C_{ox} \triangleq \frac{\epsilon_{ox}}{t_{ox}}$$

$$\Rightarrow \Delta\phi_{ox} = \frac{qN_d x_d}{C_{ox}} = \frac{\sqrt{2\epsilon_s qN_D\phi_s}}{C_{ox}} \qquad \text{Let } \gamma = \frac{\sqrt{2\epsilon_s qN_D}}{C_{ox}}$$