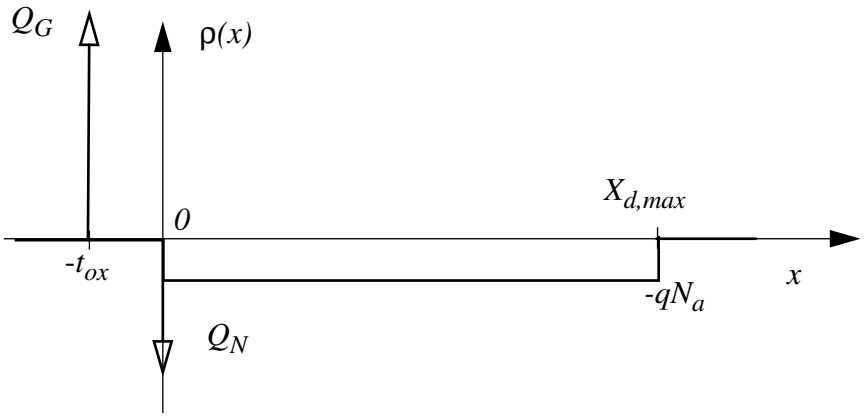
I. The MOS Capacitor in Inversion $V_{GB}>V_{Tn}$

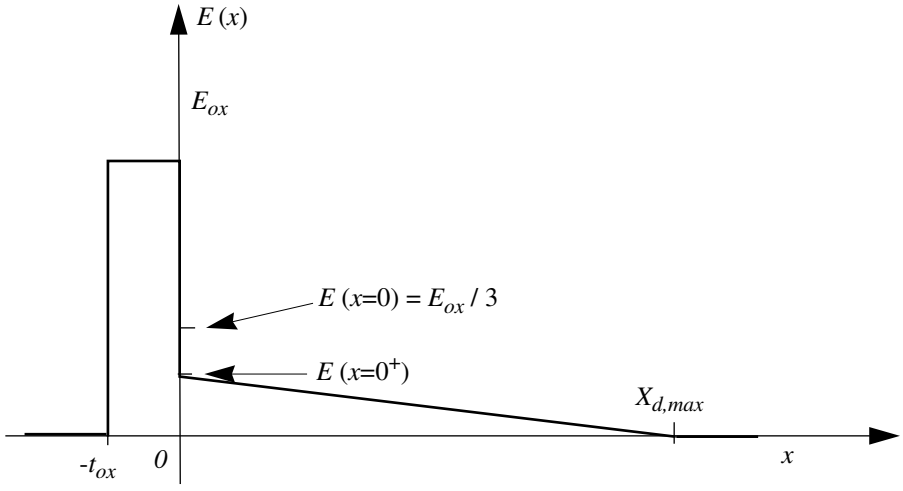
A. Charge Picture

- The gate-bulk voltage is greater than the threshold voltage: an n-type region of electrons (the inversion layer) exists at the surface with charge (per unit area) Q_N



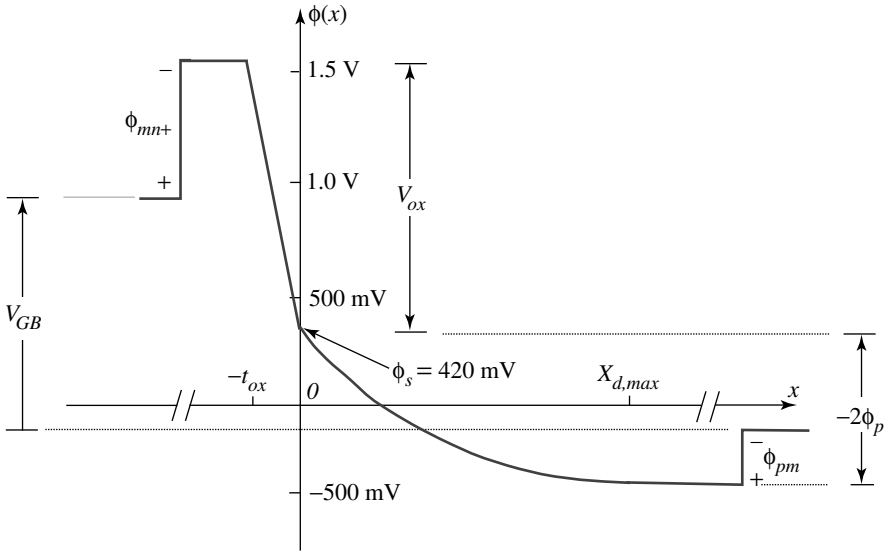
B. Electric Field

- The electric field drops by 3 times due to the change in electric permittivity at $x = 0$. Another drop occurs that is proportional to the inversion charge Q_N



C. Potential in Inversion

- The surface potential is fixed ("pinned") at $\phi_s = -\phi_D$



(c)

D. Inversion Charge - Mobile Electrons

- Bulk charge is constant for $V_{GB} > V_{Tn}$ --> all of the additional charge in the silicon is electrons in the inversion layer once inversion occurs.
- Since the inversion layer is separated from the gate by the gate oxide, the inversion charge density is given by

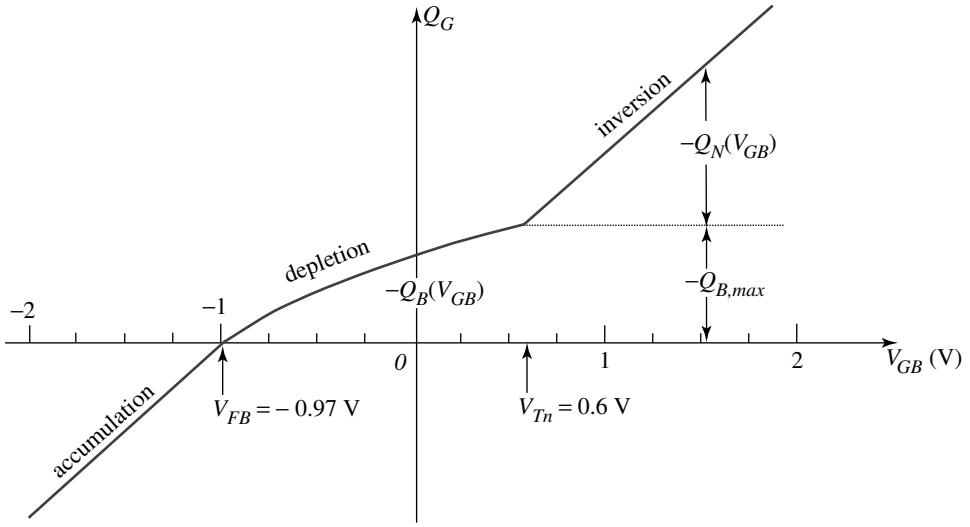
$$Q_N = -C_{ox}(V_{GB} - V_{Tn})$$

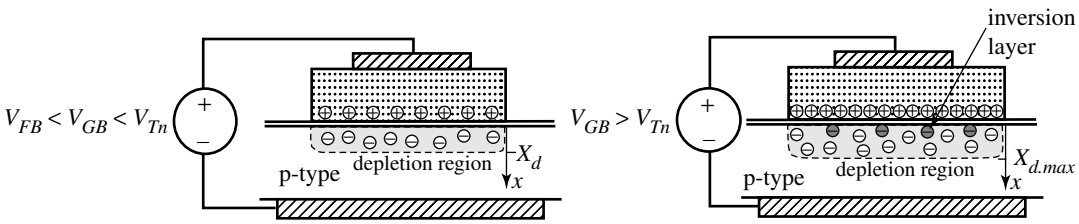
II. Charge Storage in the MOS Structure

A. Three regions of operation:

- *Accumulation:* $q_G = C_{ox}\,(v_{GB} - v_{FB})$ ... parallel plate capacitor
- *Depletion:* $q_G = -\,q_B(v_{GB})$, with the bulk (depletion) charge in the silicon being a nonlinear function of v_{GB}
- *Inversion:* $q_G = -\,q_N - q_{B,max}$, where $q_{B,max} = q_B(v_{GB} = V_{Tn})$ is the depletion charge at the onset of inversion and

B. Gate charge as a function of gate-bulk voltage:



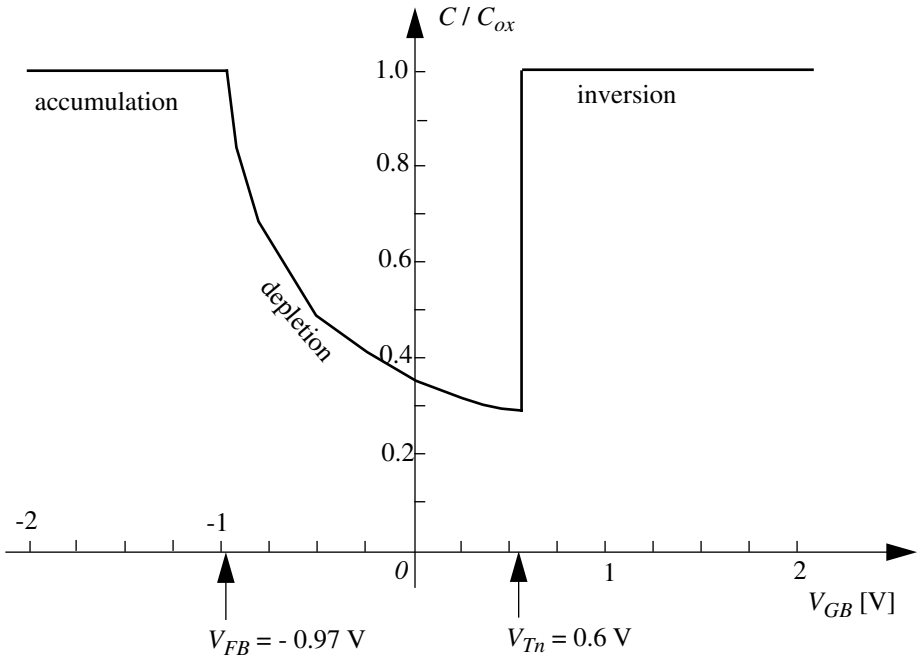


C. MOS Capacitance

- The capacitance of the MOS structure is defined as

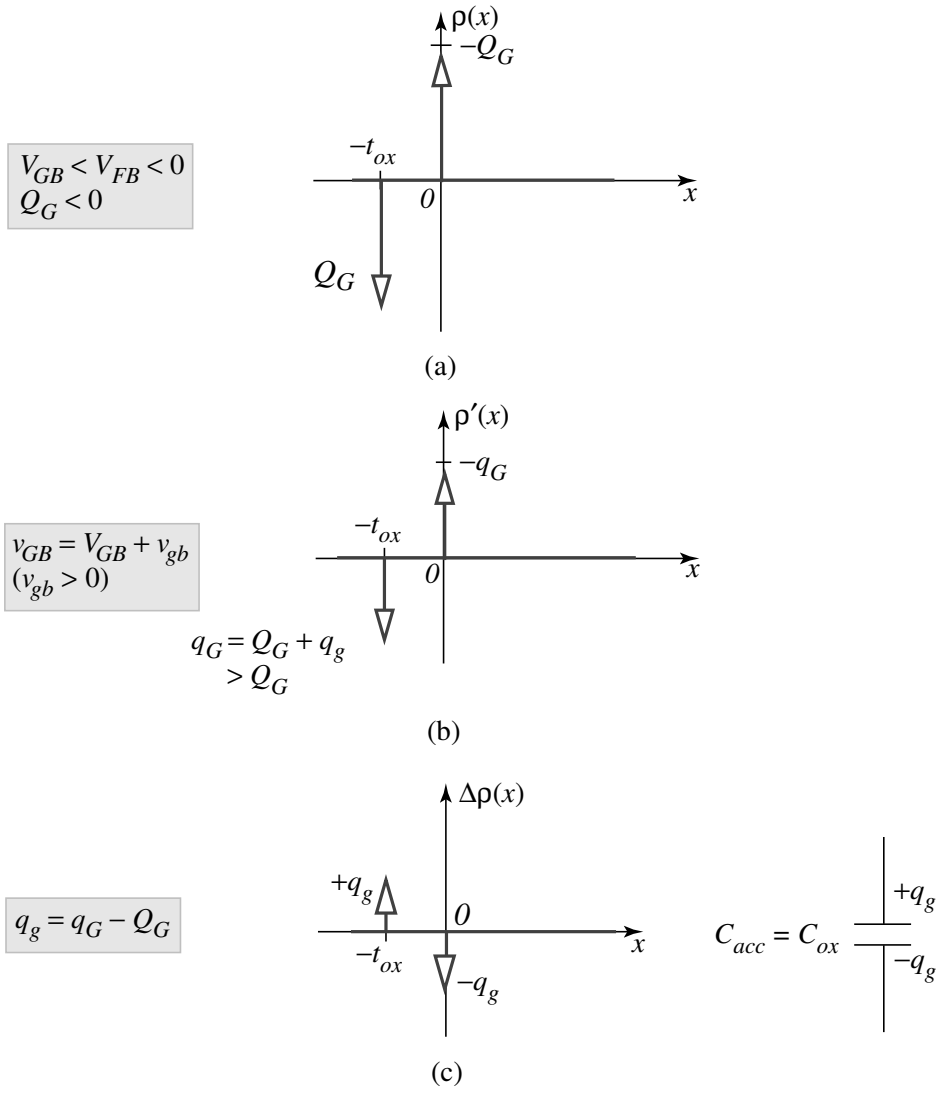
$$C = \left.\frac{dq_G}{dv_{GB}}\right|_{V_{GB}}$$

- Mathematical expression for depletion region (rarely used)
- Graphical interpretation: find slope of charge-voltage plot



D. Physical Interpretation of MOS Capacitance: Accumulation

- By examining where the incremental charge q_g is mirrored in the silicon substrate, we can make sense of the MOS capacitor



$V_{GB} < V_{FB} < 0$
$Q_G < 0$

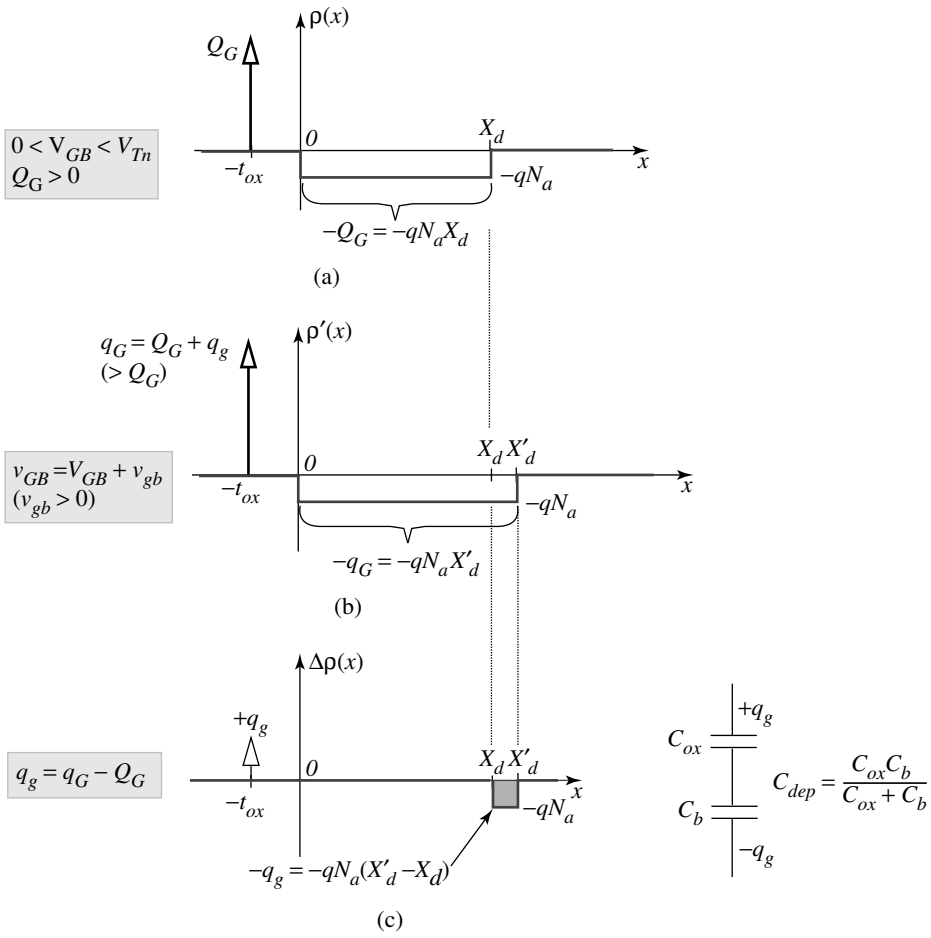
$v_{GB} = V_{GB} + v_{gb}$
$(v_{gb} > 0)$

$q_G = Q_G + q_g$
$> Q_G$

$q_g = q_G - Q_G$

E. Physical Interpretation of MOS Capacitance: Depletion

- For the case of depletion, where $V_{FB} < V_{GB} < V_{Tn}$, the small-signal gate charge is mirrored at the bottom of the depletion region

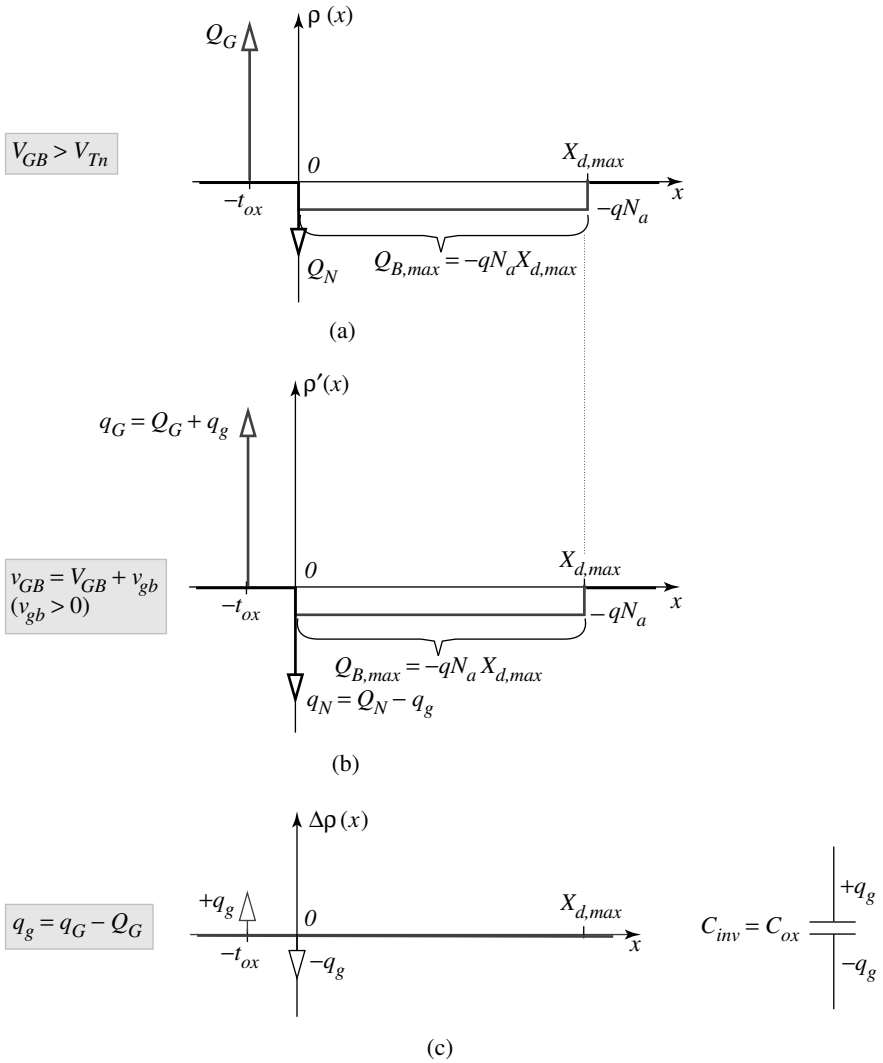


- Capacitance is given by the oxide capacitance in series with the bulk capacitance:

$$C = \frac{C_{ox}C_b}{C_{ox} + C_b} \text{ where } C_b = \frac{\varepsilon_s}{X_d(V_{GB})} .$$

F. Physical Interpretation of MOS Capacitance: Inversion

- For $V_{GB} > V_{Tn}$, the small-signal gate charge is mirrored in the electron inversion layer ... since the bulk depletion layer is constant



$$Q_N = -C_{ox}(V_{GB} - V_{Tn})$$