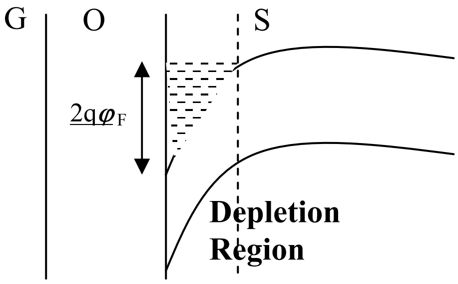
MOS Threshold Voltage

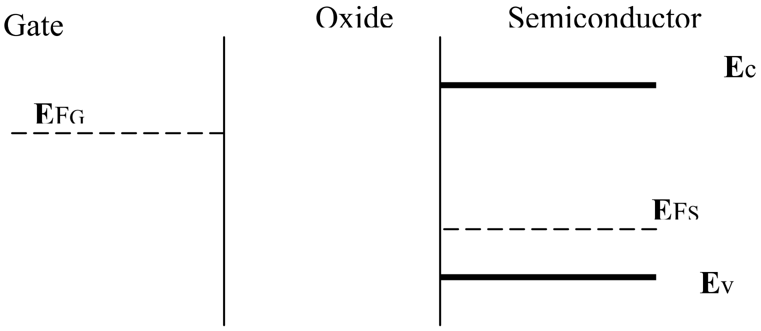
• This is the gate voltage required to strongly invert the surface of the substrate :
N-Type substrate ➔ we need to Bend the Bands Upward by $2q\varphi_F$.
P-Type substrate ➔ we need to Bend the Bands Downward by $2q\varphi_F$.



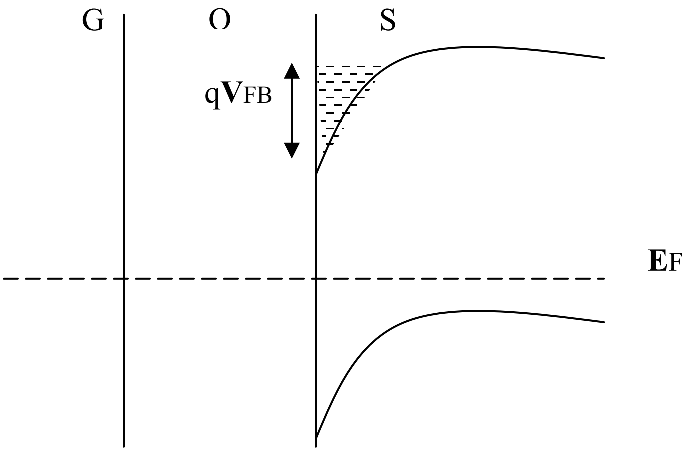
V_{th} = Flat Band voltage (V_{FB}) – $2q\varphi_F$ + Voltage to sustain the Depletion region charge ($-Q_B/C_{ox}$) + Voltage to overcome the Oxide trapped charge ($-Q_{ox}/C_{ox}$)

• Flat Band Voltage V_{FB}: The Voltage required to flatten the energy Bands, at the surface of the substrate $V_{FB} = E_{FG} - E_{FS} = \Phi_G - \Phi_S$

Initially Before Contact:



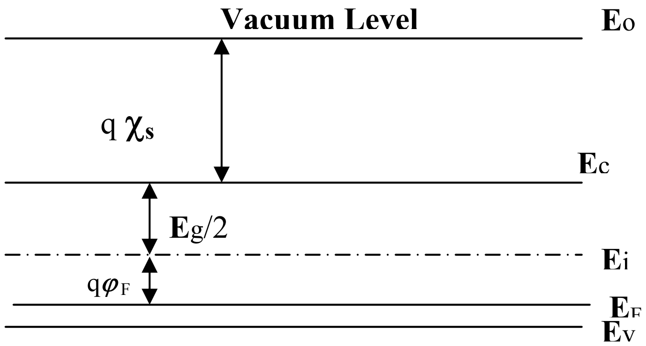
After



Φ_G = Gate Work function
Φ_S = Substrate Work function (Depends on the Doping)
$= \chi_s + E_g/2q - \varphi_F$

χ_s : Electron Affinity ($E_o - E_c$)

The Work function is the Energy required to remove an electron from the Fermi level to outside the Solid.



Vacuum Level: Energy level that electrons outside Semiconductor

➔ +ve V_{FB} means that Bands are Bent Upward at zero Bias (since We need a +ve voltage to push them down to make them flat).

➔ -ve V_{FB} means that Bands are Bent Downward at zero Bias (since We need a -ve voltage to pull them up to make them flat).

$\varphi_F = V_T \ln(N_D/n_i)$ For N-Type substrate.

$\varphi_F = - V_T \ln(N_a/n_i)$ For P-Type substrate.

• Q_B, the Depletion charge $= + \sqrt{(2q\, N_{Sub}\, \varepsilon_{sub}\, |2\varphi_F|)}$ For N-Type substrate

$= - \sqrt{(2q\, N_{Sub}\, \varepsilon_{sub}\, |2\varphi_F|)}$ For P-Type substrate

N_{Sub} = net substrate Doping.

ε_{sub} = Dielectric constant of substrate.

e.g) For Si $\varepsilon_{si} = \varepsilon_o\, \varepsilon_{sir}$: $\varepsilon_o = 8.85\text{x}10^{-14}$; $\varepsilon_{sir} = 12$

• Q_{ox} = this is a charge trapped in the Oxide during manufacturing.

Example 1: A MOS device is made with an AL Gate (Φ_{AL} = 4.15 ev) and P-Type substrate ($N_a = 10^{16}$ cm^{-3}). The Oxide capacitance =2 fF/μm^2.
f = 1exp-15. Assume Qox = 0.
Calculate V_{th} χ_{si} = 4.1 ev E_{gsi} = 1.1 ev = 1.1 * q J

Sol

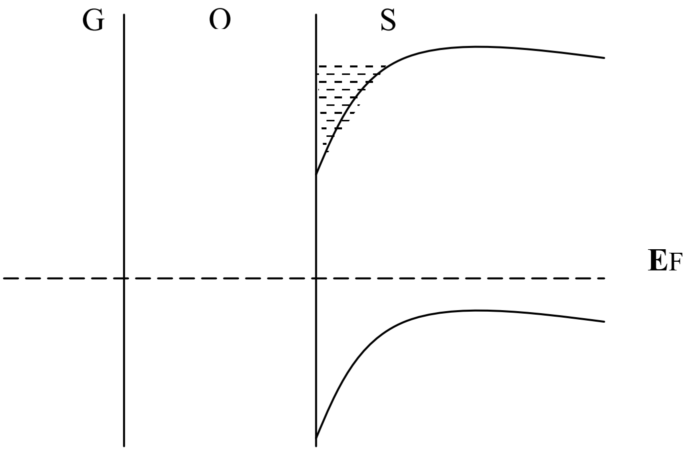
$V_{th} = V_{FB} - 2\varphi_F - Q_B/C_{ox} - Q_{ox}/C_{ox}$

$V_{FB} = \Phi_G - \Phi_S = 4.15 - [X_s + E_g/2q - \varphi_F] = 4.15 - [4.1 + 0.55 - \varphi_F]$

$\varphi_F = -0.025 \ln(1exp16/1exp10) = -0.345$ V

$V_{FB} = 4.15 - 4.1 - 0.55 - 0.345 = -0.89$ V

at zero Bias



$Q_B = -\sqrt{(2 * 1.6*10^{-19} * 10^{16} * 8.85*10^{-14} * 12 * 0.69)} = -4.8*10^{-8}$ C/cm²
Cox = 2 fF/μm^2 = $2 * 1*10^{-15} * 1 * 10^{8} = 2 * 10^{-7}$ F/cm²

$V_{th} = -0.89 + 0.69 + [4.8*10^{-8} / 2 * 10^{-7}] = 0.04$V

at $V_G = V_{th}$