Crib sheet 3: (MOS devices, Schottky junctions, CMOS)

Electrostatic potentials for MOS capacitors

$$\phi(x) = \frac{1}{q}\left[E_i(\text{bulk}) - E_i(x)\right] \qquad \phi_S = \frac{1}{q}\left[E_i(\text{bulk}) - E_i(\text{surface})\right]$$

Potential at position x Potential at semiconductor / oxide interface

$$\phi_F = \frac{1}{q}\left[E_i(\text{bulk}) - E_F\right]$$

Bulk potential in semiconductor (ϕ_F depends on doping concentration)

Gate-Voltage relationship

$$V_G = \phi_S \pm \frac{\varepsilon_{Si}}{\varepsilon_{ox}} x_{ox} \sqrt{\frac{2qN_{A/D}|\phi_S|}{\varepsilon_{Si}}} \qquad \text{+/– and } N_A/N_D \text{ for NMOS/PMOS}$$

Threshold voltage $V_G = V_T'$ if $\phi_S = 2\phi_F$ (V_T' doping dependent, see ϕ_F above)

Depletion layer width: $$W = \sqrt{\frac{2\varepsilon_{Si}|\phi_S|}{q N_{A/D}}} \qquad (W = W_T \text{ if } \phi_S = 2\phi_F)$$

MOS-Capacitances: $$C_{ox} = \frac{\varepsilon_{ox}}{x_{ox}}; \quad C_S = \frac{\varepsilon_{Si}}{W}; \quad C_G = \frac{C_S C_{ox}}{C_S + C_{ox}}$$

***I-V* relationships for NMOS devices:** Z = gate width, L = gate length, A = gate area = $Z \times L$

$$I_{DSat} = \frac{Z\mu C_{ox}}{2L}(V_G - V_T)^2 \text{ for } V_D > V_{DSat} \text{ and } V_G \geq V_T \text{ with } V_{DSat} = V_G - V_T$$

$$I_D = \frac{Z\mu C_{ox}}{L}\left[(V_G - V_T)V_D - \frac{V_D^2}{2}\right] \text{ for } 0 \leq V_D \leq V_{DSat} \text{ and } V_G \geq V_T$$

Small-signal parameters and cut-off frequency:

Below pinch-off: ($V_D \leq V_{DSat}$) $g_d = \frac{Z\mu C_{ox}}{L}(V_G - V_T - V_D)$ $g_m = \frac{Z\mu C_{ox}}{L} V_D$

Under saturation: ($V_D > V_{DSat}$) $g_d = 0$ $g_m = \frac{Z\mu C_{ox}}{L}(V_G - V_T)$

Cut-off frequency: $f_t = \frac{g_m}{2\pi C_G} \approx \frac{g_m}{2\pi C_{ox} A}$

Relationships for real MOS devices:

Flatband voltage $V_{FB} = \frac{1}{q}\Phi_{MS} + (-\frac{Q_i}{C_{ox}})$ with $\Phi_{MS} = \Phi_M - \Phi_S$

Real threshold voltage: $V_T = V_{FB} + V_T'$ (V_T' = threshold voltage of ideal device)

Relationships for MS (Schottky) junctions (n-type semiconductor):

Schottky barrier height: $\Phi_B = \Phi_M - \chi$ (independent of applied voltage)

Schottky-diode built-in potential: $qV_{bi} = \Phi_B - (E_c - E_F) = \Phi_B - \left[\frac{E_G}{2} - (E_F - E_i)\right]$

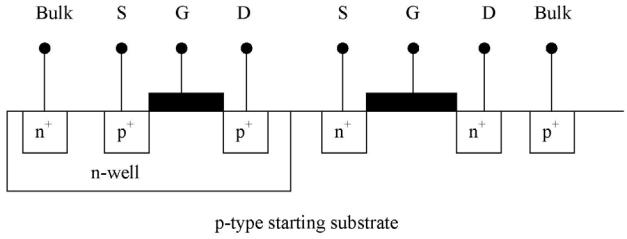
Ion implantation

Ion implantation profile: $N(x) = \frac{iondose}{\sqrt{2\pi}\Delta R_p}\exp\left[-\frac{1}{2}\left(\frac{x - R_p}{\Delta R_p}\right)^2\right]$ [$iondose$] = # of ions/cm^2

V_T-shift by ion-implantation: $|\Delta V_T| = \left|\frac{q\ iondose}{C_{ox}}\right|$

Boron ions in Si ➔ acceptors: $\Delta V_T > 0$ (positive shift)
Phosphorous ions in Si ➔ donors: $\Delta V_T < 0$ (negative shift)

CMOS schematic for p-type starting substrate
(For n-type starting substrate, change conductivity types appropriately)



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