Assignment 5
E3225
Art of Compact Modeling

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May 15, 2021

1 Problem 1

Solve Poisson's Equation using appropriate boundary conditions, including $V_{CB} \geq 0$. Plot $\psi(y)$ vs y and $n_i(y)$ vs y for a constant value of V_G, with $V_{CB} \geq 0$.

Solution: Poisson's Equation for the MOS structure in non-equilibrium:

$$\frac{d^2\psi}{dy^2} = -\frac{qN_A}{\epsilon_s}[e^{-\psi(y)/\phi_t} - 1 - e^{-2\phi_F/\phi_t}(e^{(\psi(y)-V_{CB})/\phi_t} - 1)]\,. \tag{1}$$

Parameters used:

$$\epsilon_{Si} = 3.9\epsilon_0$$
$$\epsilon_{SiO_2} = 11.4\epsilon_0$$
$$\Delta\Phi_{MS} = 0.21\ eV$$
$$\phi_t = 26\ meV$$
$$n_i = 10^{10}\ cm^{-3}$$
$$N_A = 10^{16}\ cm^{-3}$$
$$\phi_f = \phi_t ln\frac{N_A}{n_i}$$
$$t_{Si} = 100\ nm$$
$$t_{ox} = 1\ nm$$

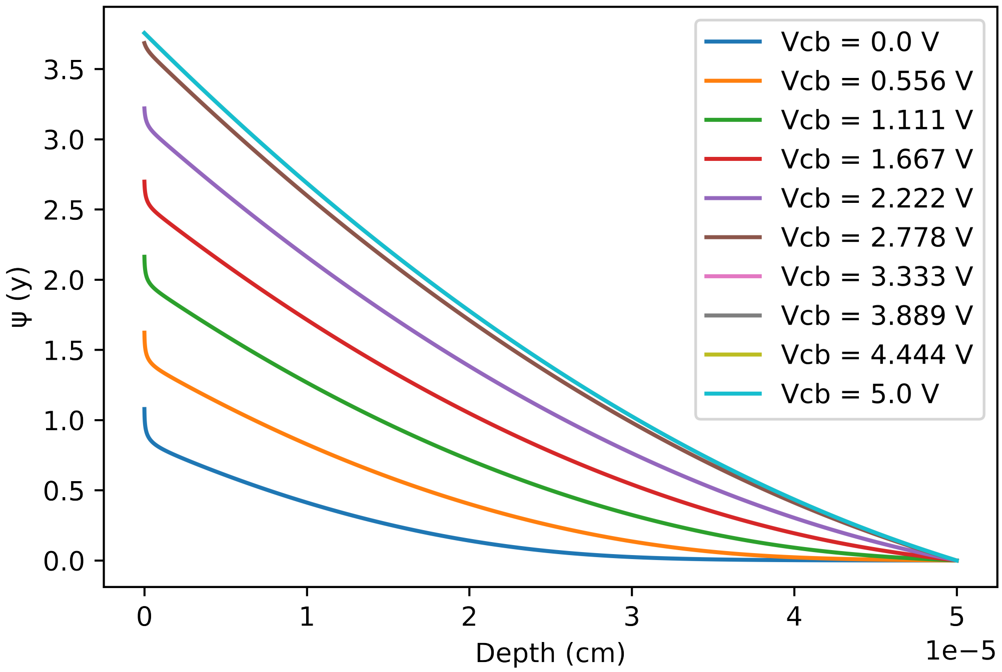
- $$V_{CB} \in (0, 5)\ V$$

  V$_{GB} = 4V$

Boundary Conditions

$\psi(t_{Si}) = 0\ \ (Dritchle's)$

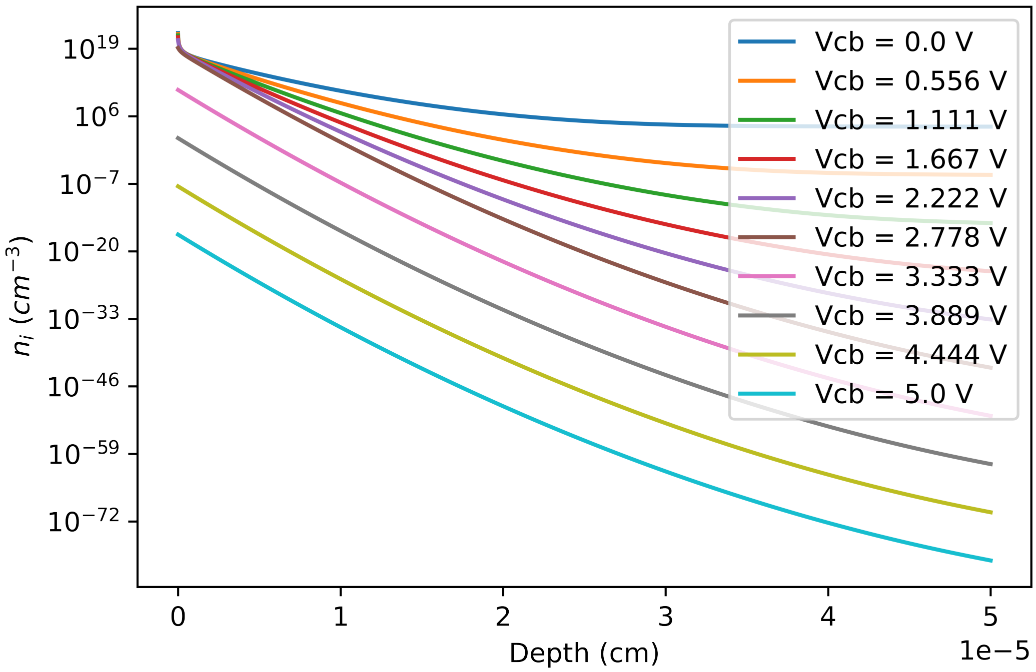
$-\frac{d\psi}{dy}|_{y=0} = \frac{C_{ox}}{\epsilon_{Si}}[V_{gs} - \psi(0)]\ \ (Mixed)$



Increased V_{CB} leads to decrease in the inversion charge density, to maintain the same carrier density higher surface potential is required for larger values of V_{CB}. Also for $V_{CB} \geq 2.8V$ it moves out of strong inversion regime.

Inversion charge at non-equilibrium condition can be evaluated using:

$$n_i(y) = n_0 e^{\frac{\psi(y) - V_{CB}}{\phi_t}} . \tag{2}$$



It can be seen that for $V_{CB} \geq 2.8V$ n_i at surface reduces drastically by about 6 orders of magnitude.

2 Problem 2

Plot ψ_s (Surface Potential) as a function of V_G, for $VCB \geq 0$.

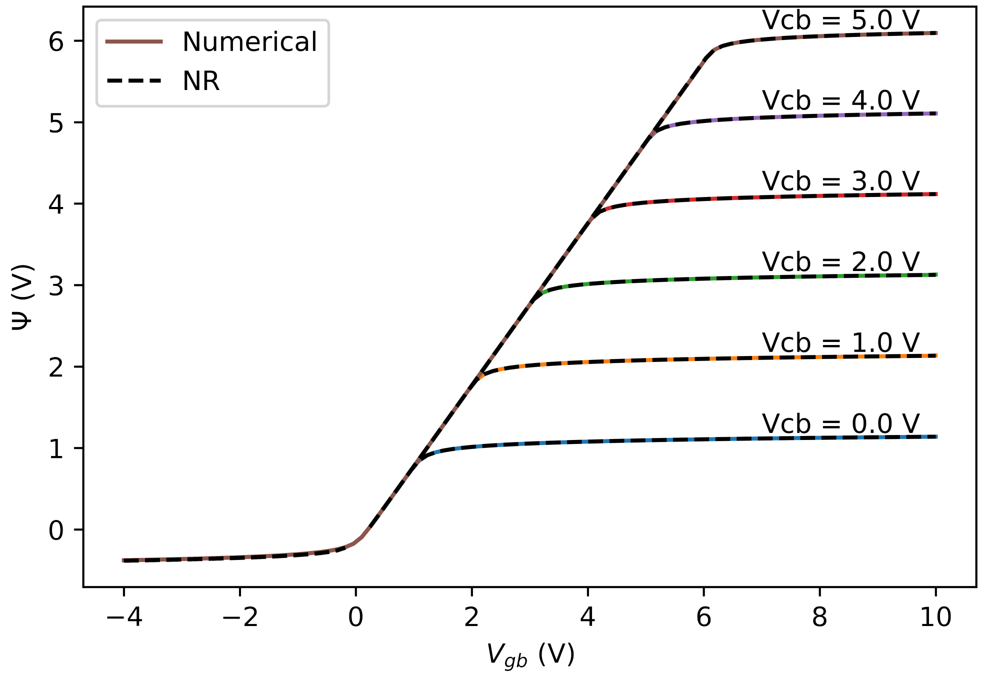
Solution: Solved with same boundary conditions, here gate voltage was varied from -4 V (accumulation) to 10 V (strong inversion) (broader range is for better clarity).

$$V_{CB} \in (0, 5)\, V$$

Rest all other parameters were the same.

Implicit analytical expression was solved using Newton Raphson solver, expression solved is:

$$V_{GB} = V_{FB} + \psi_s + sgn(\psi_s)\gamma\sqrt{\psi_s + \phi_t e^{-\frac{\psi_s}{\phi_t}} - \phi_t + \phi_t e^{\frac{\psi_s - 2\phi_f - V_{CB}}{\phi_t}} - e^{-\frac{2\phi_f}{\phi_t}}(\psi_s + \phi_t e^{\frac{-V_{CB}}{\phi_t}})}\,. \quad (3)$$

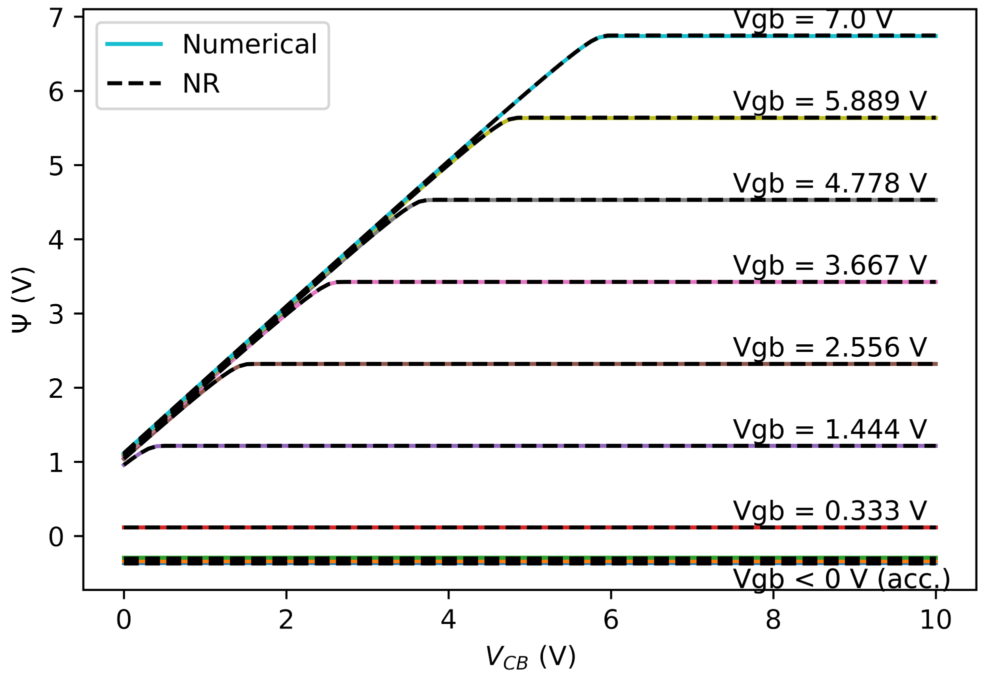


Both the solution matches well in the entire domain of simulation but around 0. In accumulation region V_{CB} has no effect since E_{fp} is relatively flat (majority carrier). Here ψ_s increased by almost V_{CB} owing to the term $\psi_s - 2\phi_f - V_{CB}$ in the Poisson's equation.

3 Problem 3

Plot ψ_s as a function of V_{CB}, for different values of V_G.

Solution: Solved in a similar manner as Problem 2 (just loop variables are interchanged):



Here both solutions matches almost in all regions. In accumulation region ψ is almost independent of V_{CB} as E_{fp} is relatively flat. Curves in depletion region are also flat. Once V_{gb} crosses the threshold voltage inversion region starts to emerge. Span of inversion region increases with V_{gb} because for higher V_{gb} high channel potential (V_{CB}) is required to pinch off the channel.