EE 733: ASSIGNMENT 2

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Total Charge on MOS Capacitor using Delta-Depletion Approximation

THEORY:

The total charge contributed in various region of operation using delta-depletion approximation is given below,

(a) **Accumulation Region** – In this region the applied gate voltage, $V_g \leq 0$ for p-type substrate. Thus, a positive charge is accumulated at the oxide-semiconductor interface which is approximated as $Q = Q_a = -C_{ox}V_g$.

(b) **Depletion Region** $-$ In this region the applied gate voltage, $0 \leq V_g \leq V_{Th}$ for p-type substrate. Thus, a negative charge is accumulated at the oxide-semiconductor interface which is approximated as $Q = Q_d = \frac{q\epsilon_{Si}N_a}{C_{ox}}\left[1 - \sqrt{1 + \frac{2C_{ox}^2 V_g}{q\epsilon_{Si}N_a}}\right]$.

(c) **Inversion Region** $-$ In this region the applied gate voltage, $V_g \geq V_{Th}$ for p-type substrate. Thus, a negative charge is accumulated at the oxide-semiconductor interface which is approximated as $Q = Q_{d_{max}} + Q_i = \sqrt{4q\epsilon_{Si}N_a\psi_F} + C_{ox}(V_g - V_{Th})$

The value of the various parameters are given below,

Threshold voltage, $V_{Th} = \frac{\sqrt{4q\epsilon_{Si}N_a\psi_F}}{C_{ox}} + 2\psi_F$

Oxide Capacitance, $C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$

Oxide thickness, $t_{ox} = 7\ nm$

Acceptor doping concentration, $N_a = 10^{17}\ /cm^3$

$\epsilon_{Si} = 11.8\epsilon_0$

$\epsilon_{ox} = 3.9\epsilon_0$

$\epsilon_0 = 8.85 \times 10^{-14}\ F/cm$

$q = 1.6 \times 10^{-19}\ C$

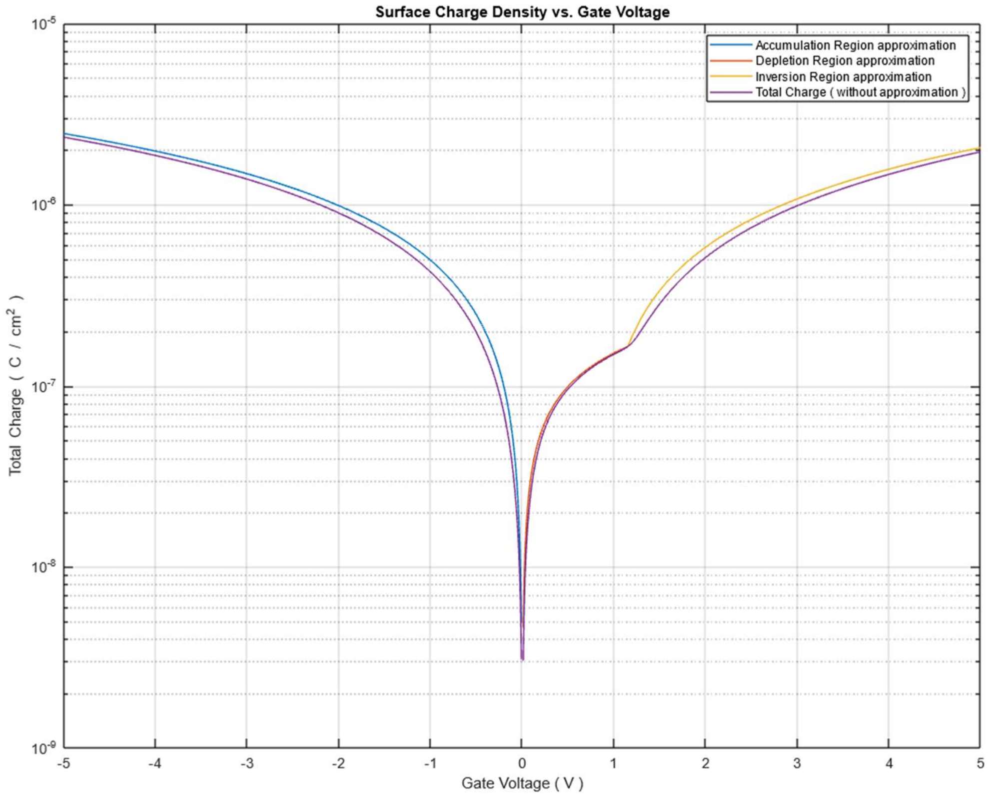
$\psi_F = V_t \ln\left(\frac{N_a}{n_i}\right)$

$V_t = 0.026\ V$

$n_i = 1.5 \times 10^{10}\ /cm^3$

RESULT AND CONCLUSION:

The plot of approximated total charge with respect to applied gate voltage is given below,



The charge profile obtained using delta-depletion approximation is close with the results obtained using analytical method.

CODE:

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%%%% ASSIGNMENT 2 : MOSCAP Charge vs. Gate Voltage Profile %%%%%

epsilon_Si = 11.8; % Dielectric constant of Silicon
epsilon_ox = 3.9; % Dielectric constant of Silicon
epsilon_0 = 8.85 * 10^(-14); % Permittivity of free space in F/cm
n_i = 1.5 * 10^10; % Intrinsic carrier concentration per cm^3
N_a = 1 * 10^17; % Acceptor doping concentration per cm^3
q = 1.6 * 10^(-19); % Charge of an electron
V_t = 0.026; % Thermal voltage in volts
t_ox = (2+5) * 10^(-7); % Oxide thickness in cm
h = 0.01; % Voltage step size

%%%% Total Charge ( C / cm^2 ) with delta-depletion approximation %%%%

C_ox = (epsilon_ox*epsilon_0)/t_ox; % Oxide capacitance per unit area in F/cm^2
V_g = -5:h:5; % Gate voltage
psi_f = V_t * log(N_a/n_i); % Fermi potential in V
V_Th = sqrt(4*q*N_a*epsilon_Si*epsilon_0*psi_f)/C_ox + 2 * psi_f; % Threshold
voltage in V
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Q_a = -1*(C_ox * V_g(1,1:round((5/h)+1))); % Charge in accumulation region in
C/cm^2
Q_d = abs((q*epsilon_Si*epsilon_0*N_a) * (1-
sqrt(1+(2*C_ox^2*V_g(1,round((5/h)+2):round(((5+V_Th)/h)+1)))/(q*epsilon_Si*epsilo
n_0*N_a)))/C_ox); % Charge in depletion region in C/cm^2
Q_i = C_ox * (V_g(1,round(((5+V_Th)/h)+1):length(V_g))-V_Th) +
sqrt(4*q*N_a*epsilon_Si*epsilon_0*psi_f); % Charge in inversion region in C/cm^2
Q_i(1,1) = Q_d(1,length(Q_d)); % for continuous curve

%%%% Newton-Raphson for determining Surface Potential, psi_s %%%%

psi_s = zeros(1,length(V_g));
for k = 1:length(V_g)
V = V_g(1,k);
if V >= 0
x = 0.01;
else
x = -0.01;
end
for i = 1:1000
g = 2*q*epsilon_Si*epsilon_0*V_t*(N_a*(exp(-x/V_t)-1)+(n_i^2/N_a)*(exp(x/V_t)-
1)+(N_a*x)/V_t);
e = 2*q*epsilon_Si*epsilon_0*(-N_a*exp(-x/V_t)+(n_i^2/N_a)*exp(x/V_t)+N_a);
m = C_ox*(V-x);
f = g-m^2;
f_1 = e - 2*C_ox^2*(x-V);
x = x - (f/f_1);
end
psi_s(1,k) = x;
end

%%%% Total Charge ( C / cm^2 ) without delta-depletion approximation %%%%

Q_s = sqrt(2*q*epsilon_Si*epsilon_0*V_t*(N_a*(exp(-psi_s/V_t)-
1)+(n_i^2/N_a)*(exp(psi_s/V_t)-1)+(N_a*psi_s)/V_t));
Q_s(1,round((5/h)+1)) = 0; % No charge for zero gate voltage

%%%% Plot of Total Charge %%%%
figure;
semilogy(V_g(1,1:round((5/h)+1)),Q_a,'Displayname','Accumulation Region
approximation');
hold on;
semilogy(V_g(1,round((5/h)+2):round(((5+V_Th)/h)+1)),Q_d,'Displayname','Depletion
Region approximation');
semilogy(V_g(1,round(((5+V_Th)/h)+1):length(V_g)),Q_i,'Displayname','Inversion
Region approximation');
semilogy(V_g,Q_s,'Displayname','Total Charge ( without approximation )');
xlabel('Gate Voltage ( V )');
ylabel('Total Charge ( C / cm^2 )');
title('Surface Charge Density vs. Gate Voltage');
legend;
grid on;
hold off;
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