# REPORT

## 4th Homework

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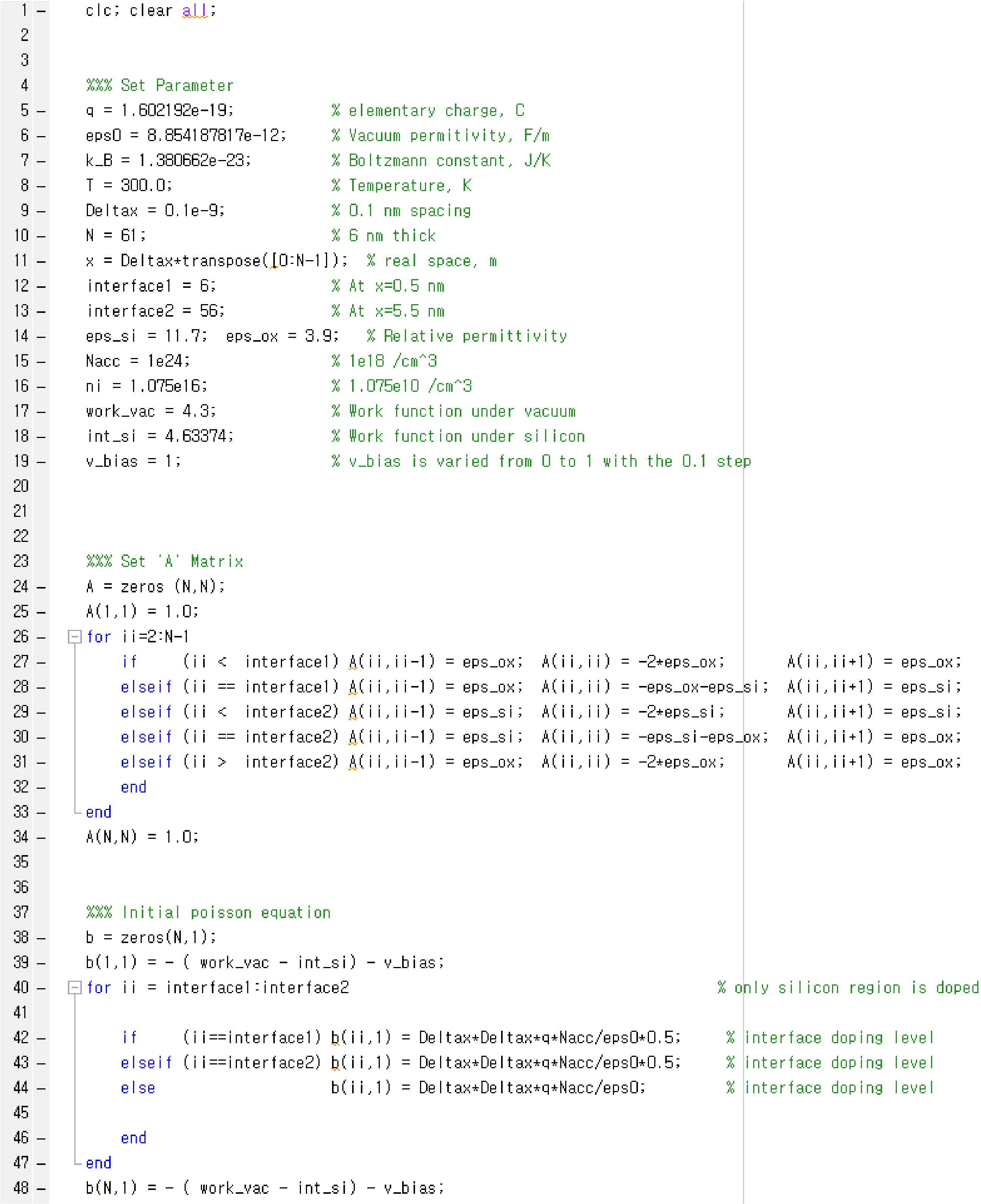
|---|---|
| Subject | Computational Microelectronics |
| Professor | 홍성민 |
| Name | 조성훈 |
| Student Number | 20162071 |
| Due Date | 2018/10/1 - 8AM |

1. Write your own code for the double-gate structure

## A. This code is for question 1st, 2nd, 3rd, and 4th



```
clc; clear all;


%%% Set Parameter
q = 1.602192e-19;           % elementary charge, C
eps0 = 8.854187817e-12;     % Vacuum permittivity, F/m
k_B = 1.380662e-23;         % Boltzmann constant, J/K
T = 300.0;                  % Temperature, K
Deltax = 0.1e-9;            % 0.1 nm spacing
N = 61;                     % 6 nm thick
x = Deltax*transpose([0:N-1]);  % real space, m
interface1 = 6;             % At x=0.5 nm
interface2 = 56;            % At x=5.5 nm
eps_si = 11.7;  eps_ox = 3.9;   % Relative permittivity
Nacc = 1e24;                % 1e18 /cm^3
ni = 1.075e16;              % 1.075e10 /cm^3
work_vac = 4.3;             % Work function under vacuum
int_si = 4.63374;           % Work function under silicon
v_bias = 1;                 % v_bias is varied from 0 to 1 with the 0.1 step

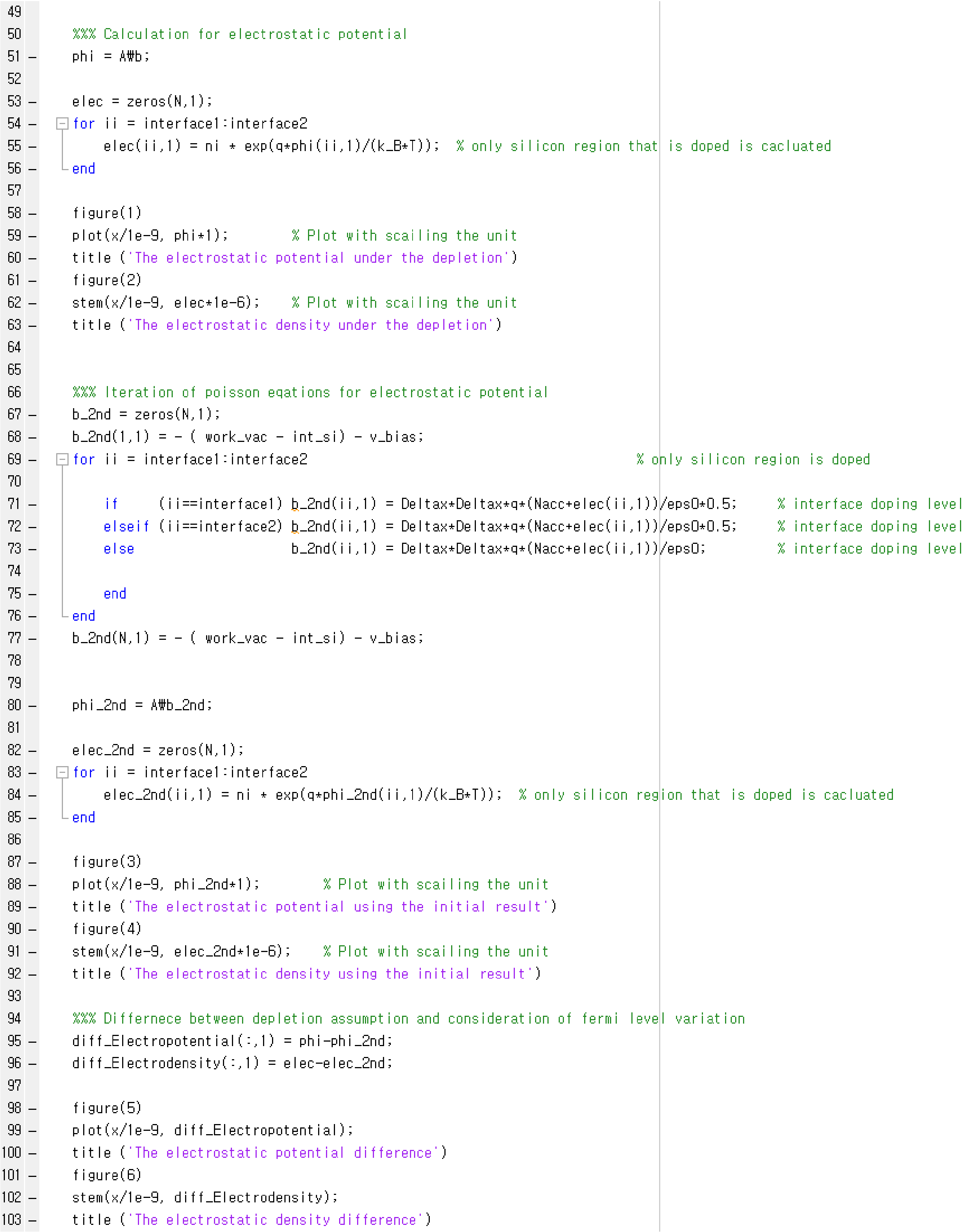


%%% Set 'A' Matrix
A = zeros (N,N);
A(1,1) = 1.0;
for ii=2:N-1
    if     (ii <  interface1) A(ii,ii-1) = eps_ox;  A(ii,ii) = -2*eps_ox;       A(ii,ii+1) = eps_ox;
    elseif (ii == interface1) A(ii,ii-1) = eps_ox;  A(ii,ii) = -eps_ox-eps_si;  A(ii,ii+1) = eps_si;
    elseif (ii <  interface2) A(ii,ii-1) = eps_si;  A(ii,ii) = -2*eps_si;       A(ii,ii+1) = eps_si;
    elseif (ii == interface2) A(ii,ii-1) = eps_si;  A(ii,ii) = -eps_si-eps_ox;  A(ii,ii+1) = eps_ox;
    elseif (ii >  interface2) A(ii,ii-1) = eps_ox;  A(ii,ii) = -2*eps_ox;       A(ii,ii+1) = eps_ox;
    end
end
A(N,N) = 1.0;


%%% Initial poisson equation
b = zeros(N,1);
b(1,1) = - ( work_vac - int_si) - v_bias;
for ii = interface1:interface2                                  % only silicon region is doped

    if     (ii==interface1) b(ii,1) = Deltax*Deltax*q*Nacc/eps0*0.5;     % interface doping level
    elseif (ii==interface2) b(ii,1) = Deltax*Deltax*q*Nacc/eps0*0.5;     % interface doping level
    else                    b(ii,1) = Deltax*Deltax*q*Nacc/eps0;         % interface doping level

    end
end
b(N,1) = - ( work_vac - int_si) - v_bias;
```



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%%% Calculation for electrostatic potential
phi = A₩b;

elec = zeros(N,1);
for ii = interface1:interface2
    elec(ii,1) = ni * exp(q*phi(ii,1)/(k_B*T));  % only silicon region that is doped is cacluated
end

figure(1)
plot(x/1e-9, phi*1);        % Plot with scailing the unit
title ('The electrostatic potential under the depletion')
figure(2)
stem(x/1e-9, elec*1e-6);    % Plot with scailing the unit
title ('The electrostatic density under the depletion')


%%% Iteration of poisson eqations for electrostatic potential
b_2nd = zeros(N,1);
b_2nd(1,1) = - ( work_vac - int_si) - v_bias;
for ii = interface1:interface2                                          % only silicon region is doped

    if     (ii==interface1) b_2nd(ii,1) = Deltax*Deltax*q*(Nacc+elec(ii,1))/eps0*0.5;     % interface doping level
    elseif (ii==interface2) b_2nd(ii,1) = Deltax*Deltax*q*(Nacc+elec(ii,1))/eps0*0.5;     % interface doping level
    else                    b_2nd(ii,1) = Deltax*Deltax*q*(Nacc+elec(ii,1))/eps0;         % interface doping level

    end
end
b_2nd(N,1) = - ( work_vac - int_si) - v_bias;


phi_2nd = A₩b_2nd;

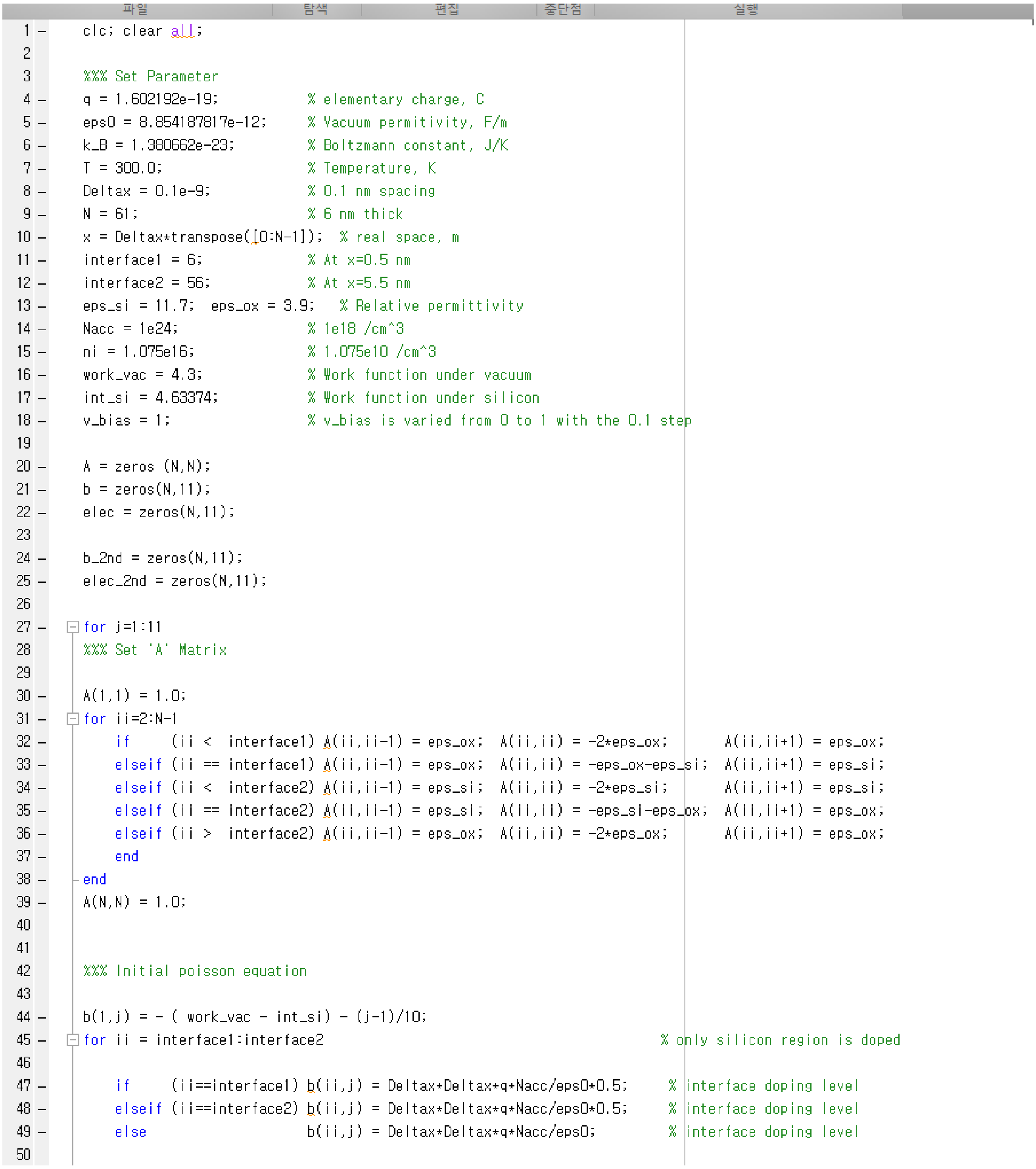
elec_2nd = zeros(N,1);
for ii = interface1:interface2
    elec_2nd(ii,1) = ni * exp(q*phi_2nd(ii,1)/(k_B*T));  % only silicon region that is doped is cacluated
end

figure(3)
plot(x/1e-9, phi_2nd*1);        % Plot with scailing the unit
title ('The electrostatic potential using the initial result')
figure(4)
stem(x/1e-9, elec_2nd*1e-6);    % Plot with scailing the unit
title ('The electrostatic density using the initial result')

%%% Differnece between depletion assumption and consideration of fermi level variation
diff_Electropotential(:,1) = phi-phi_2nd;
diff_Electrodensity(:,1) = elec-elec_2nd;

figure(5)
plot(x/1e-9, diff_Electropotential);
title ('The electrostatic potential difference')
figure(6)
stem(x/1e-9, diff_Electrodensity);
title ('The electrostatic density difference')
```

# B. This code is for question 5th



```
clc; clear all;

%%% Set Parameter
q = 1.602192e-19;           % elementary charge, C
eps0 = 8.854187817e-12;     % Vacuum permitivity, F/m
k_B = 1.380662e-23;         % Boltzmann constant, J/K
T = 300.0;                  % Temperature, K
Deltax = 0.1e-9;            % 0.1 nm spacing
N = 61;                     % 6 nm thick
x = Deltax*transpose([0:N-1]);  % real space, m
interface1 = 6;             % At x=0.5 nm
interface2 = 56;            % At x=5.5 nm
eps_si = 11.7;  eps_ox = 3.9;   % Relative permittivity
Nacc = 1e24;                % 1e18 /cm^3
ni = 1.075e16;              % 1.075e10 /cm^3
work_vac = 4.3;             % Work function under vacuum
int_si = 4.63374;           % Work function under silicon
v_bias = 1;                 % v_bias is varied from 0 to 1 with the 0.1 step

A = zeros (N,N);
b = zeros(N,11);
elec = zeros(N,11);

b_2nd = zeros(N,11);
elec_2nd = zeros(N,11);

for j=1:11
%%% Set 'A' Matrix

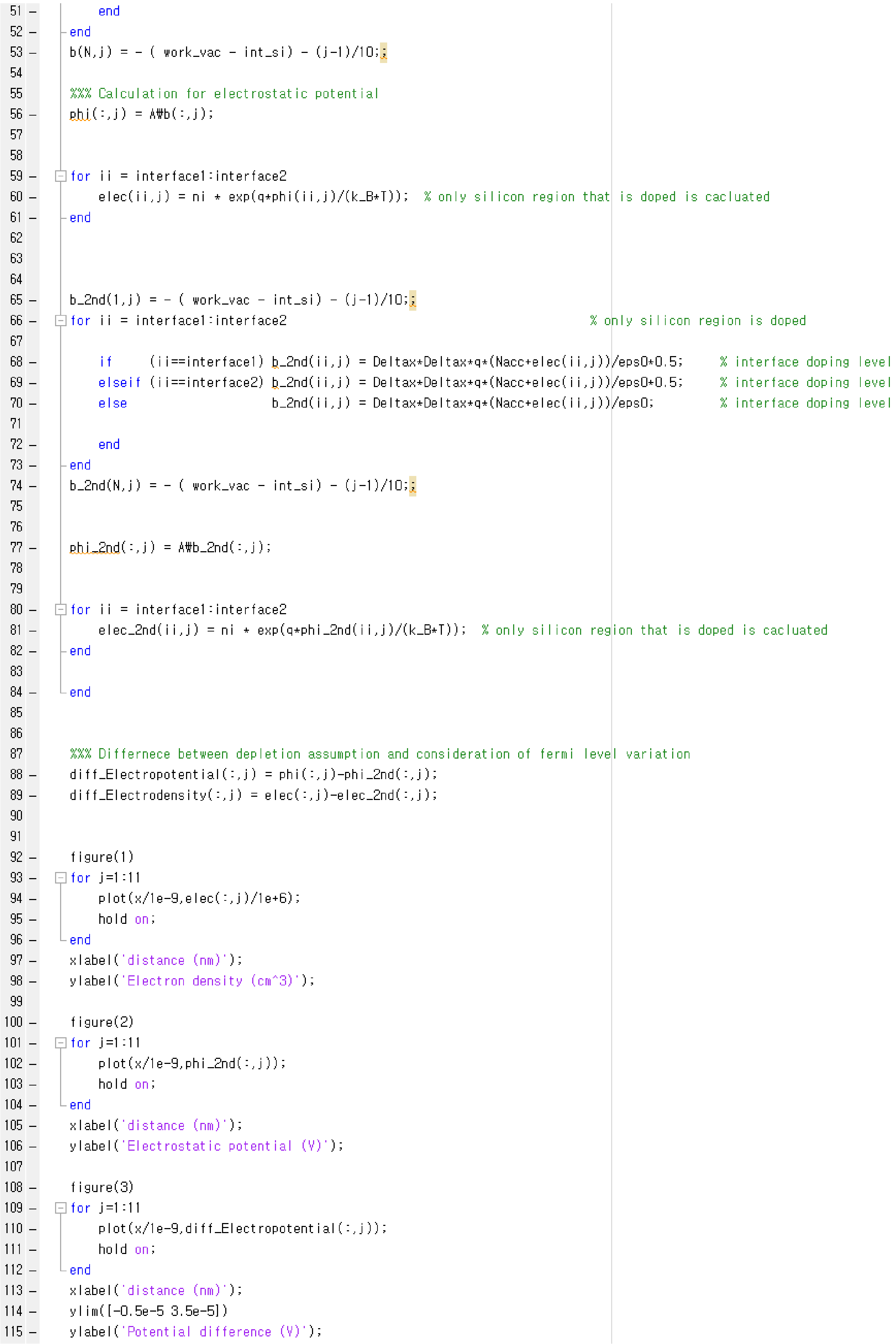
A(1,1) = 1.0;
for ii=2:N-1
    if     (ii <  interface1) A(ii,ii-1) = eps_ox;  A(ii,ii) = -2*eps_ox;       A(ii,ii+1) = eps_ox;
    elseif (ii == interface1) A(ii,ii-1) = eps_ox;  A(ii,ii) = -eps_ox-eps_si;  A(ii,ii+1) = eps_si;
    elseif (ii <  interface2) A(ii,ii-1) = eps_si;  A(ii,ii) = -2*eps_si;       A(ii,ii+1) = eps_si;
    elseif (ii == interface2) A(ii,ii-1) = eps_si;  A(ii,ii) = -eps_si-eps_ox;  A(ii,ii+1) = eps_ox;
    elseif (ii >  interface2) A(ii,ii-1) = eps_ox;  A(ii,ii) = -2*eps_ox;       A(ii,ii+1) = eps_ox;
    end
end
A(N,N) = 1.0;


%%% Initial poisson equation

b(1,j) = - ( work_vac - int_si) - (j-1)/10;
for ii = interface1:interface2                                          % only silicon region is doped

    if     (ii==interface1) b(ii,j) = Deltax*Deltax*q*Nacc/eps0*0.5;     % interface doping level
    elseif (ii==interface2) b(ii,j) = Deltax*Deltax*q*Nacc/eps0*0.5;     % interface doping level
    else                    b(ii,j) = Deltax*Deltax*q*Nacc/eps0;         % interface doping level

```



```
    end
end
b(N,j) = - ( work_vac - int_si) - (j-1)/10;;

%%% Calculation for electrostatic potential
phi(:,j) = A₩b(:,j);


for ii = interface1:interface2
    elec(ii,j) = ni * exp(q*phi(ii,j)/(k_B*T));  % only silicon region that is doped is cacluated
end



b_2nd(1,j) = - ( work_vac - int_si) - (j-1)/10;;
for ii = interface1:interface2                                     % only silicon region is doped

    if     (ii==interface1) b_2nd(ii,j) = Deltax*Deltax*q*(Nacc+elec(ii,j))/eps0*0.5;     % interface doping level
    elseif (ii==interface2) b_2nd(ii,j) = Deltax*Deltax*q*(Nacc+elec(ii,j))/eps0*0.5;     % interface doping level
    else                    b_2nd(ii,j) = Deltax*Deltax*q*(Nacc+elec(ii,j))/eps0;         % interface doping level

    end
end
b_2nd(N,j) = - ( work_vac - int_si) - (j-1)/10;;


phi_2nd(:,j) = A₩b_2nd(:,j);


for ii = interface1:interface2
    elec_2nd(ii,j) = ni * exp(q*phi_2nd(ii,j)/(k_B*T));  % only silicon region that is doped is cacluated
end

end

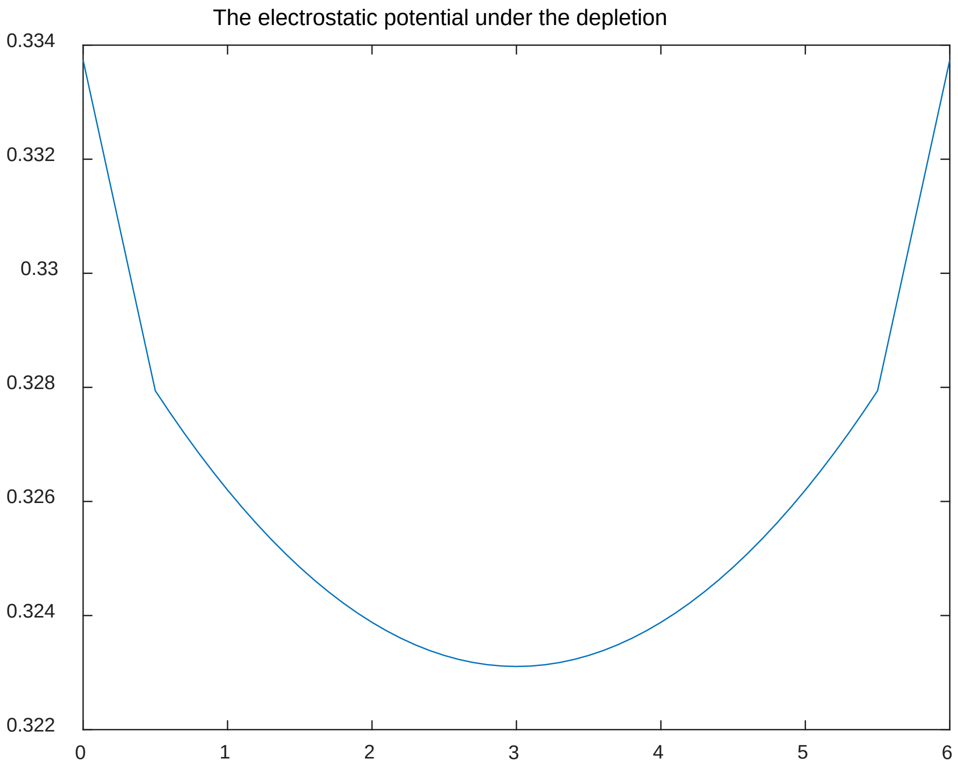

%%% Differnece between depletion assumption and consideration of fermi level variation
diff_Electropotential(:,j) = phi(:,j)-phi_2nd(:,j);
diff_Electrodensity(:,j) = elec(:,j)-elec_2nd(:,j);


figure(1)
for j=1:11
    plot(x/1e-9,elec(:,j)/1e+6);
    hold on;
end
xlabel('distance (nm)');
ylabel('Electron density (cm^3)');

figure(2)
for j=1:11
    plot(x/1e-9,phi_2nd(:,j));
    hold on;
end
xlabel('distance (nm)');
ylabel('Electrostatic potential (V)');

figure(3)
for j=1:11
    plot(x/1e-9,diff_Electropotential(:,j));
    hold on;
end
xlabel('distance (nm)');
ylim([-0.5e-5 3.5e-5])
ylabel('Potential difference (V)');
```

## 2. The electrostatic potential is obtained under the depletion approximation. (The initial potential)



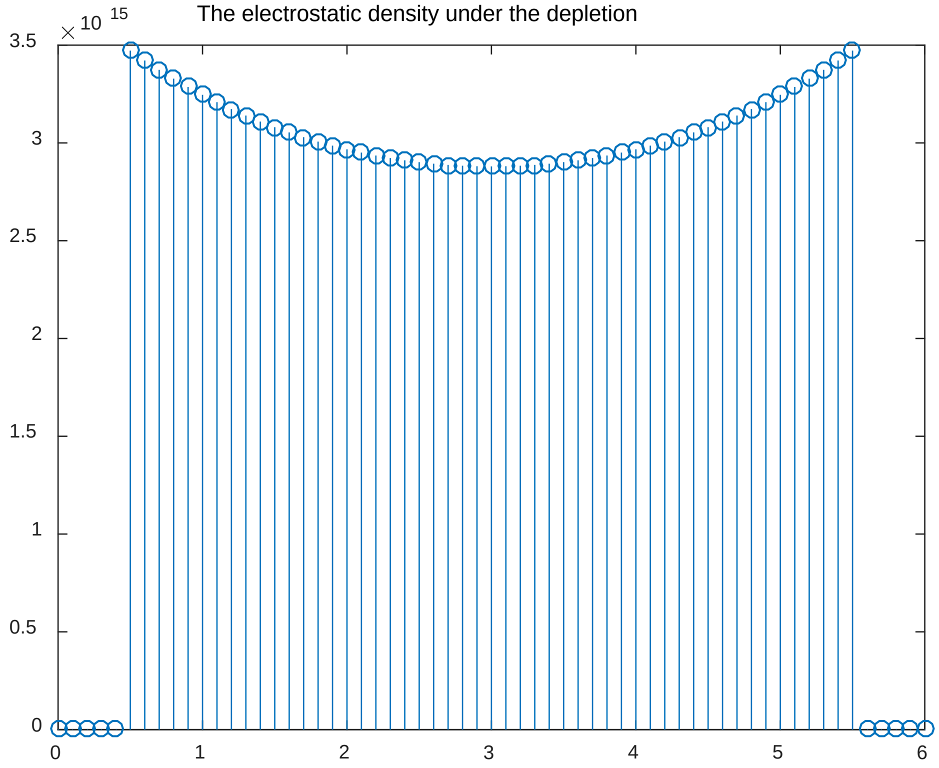
### A. The electrostatic potential is divided by three region

i. The first region is ‘x_SiO$_2$ = [0, 5nm]’. At this point because of the free-charge space, the slop is linear.

ii. The second region is ‘x_Si = [5, 55nm]’. At this point because of the existence of the dopant, the slop is parabolic.

iii. The first region is ‘x_SiO$_2$ = [55, 60nm]’. At this point because of the free-charge space, the slop is linear.

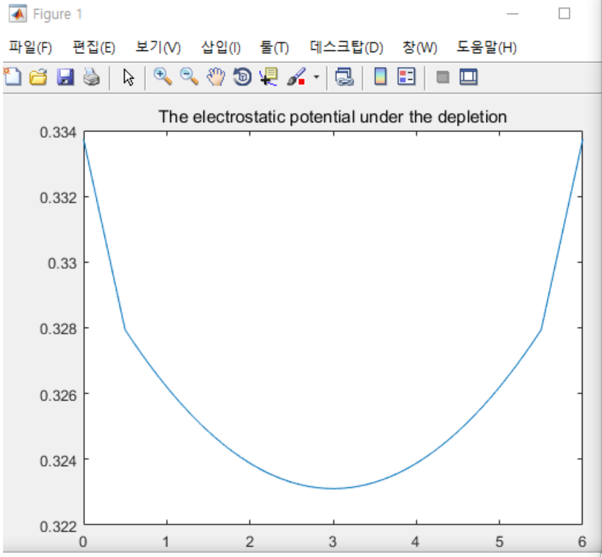
3. The electron density is calculated by assuming $n_i$*exp(q*phi/$k_B$/T)



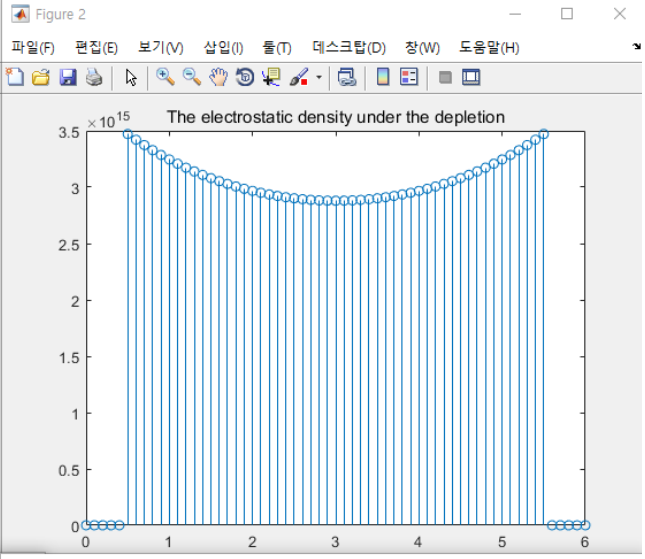
A. Using the interface doping charge equation, we can find the electrostatic density

B. Because of the free charge space of the $SiO_2$, the ranges of '[0, 5 nm]', '[55 nm, 60 nm]' have zero electron density.

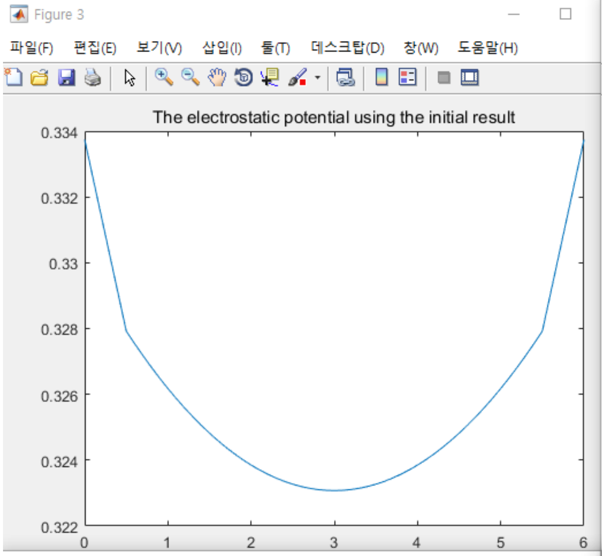
4. Then, using the electron density, re-calculate the potential. (The updated potential)



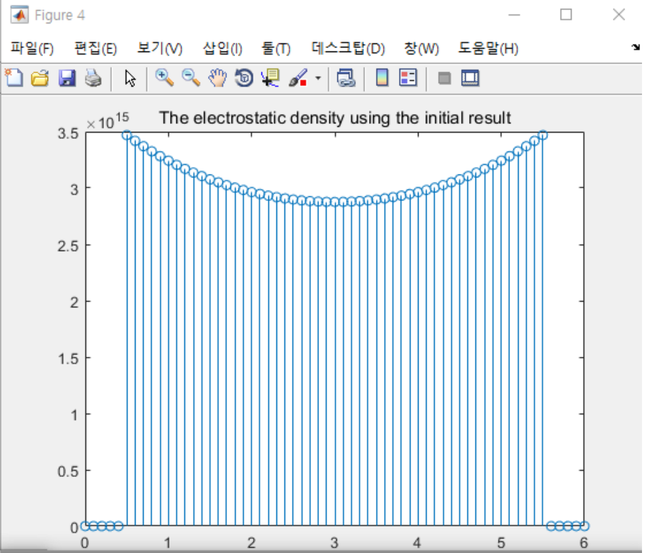
The electrostatic potential under the depletion



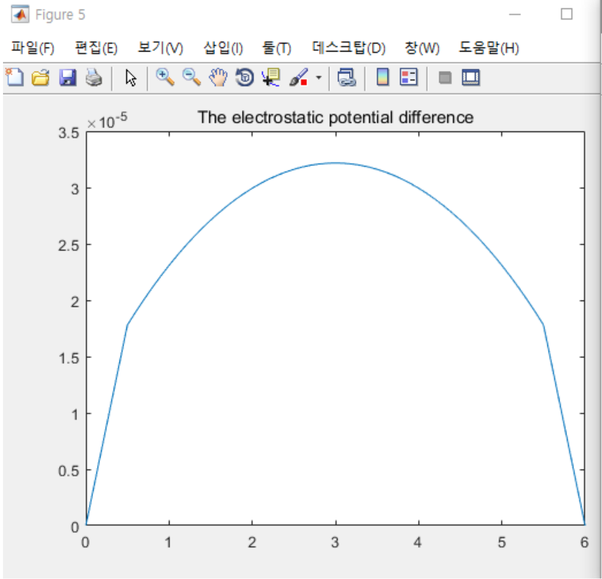
The electrostatic density under the depletion



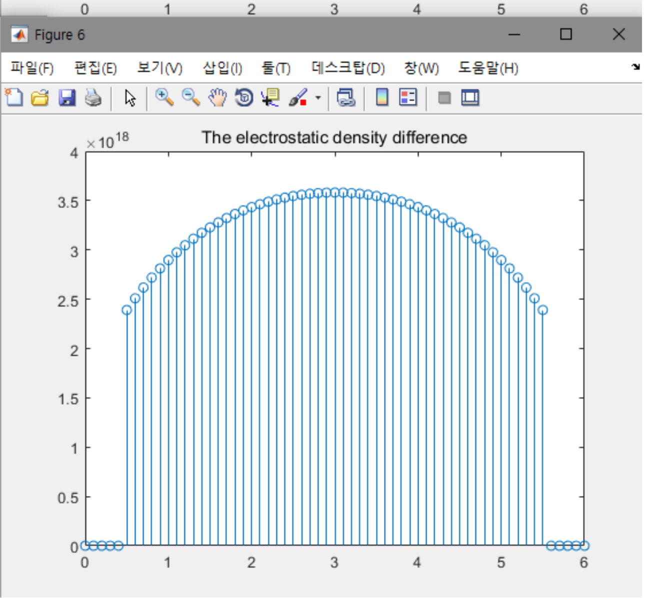
The electrostatic potential using the initial result



The electrostatic density using the initial result



The electrostatic potential difference



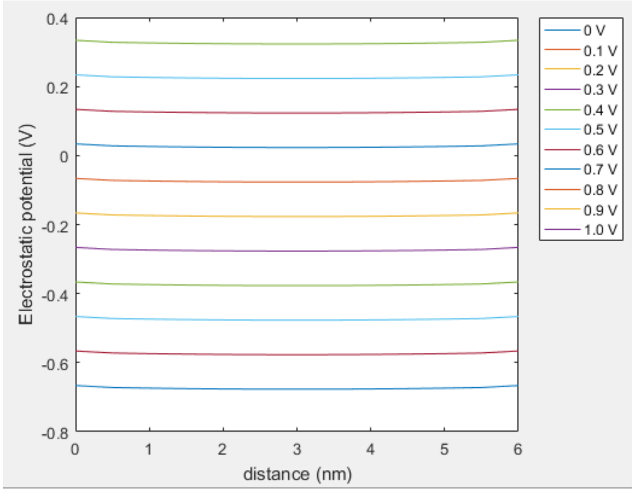
The electrostatic density difference

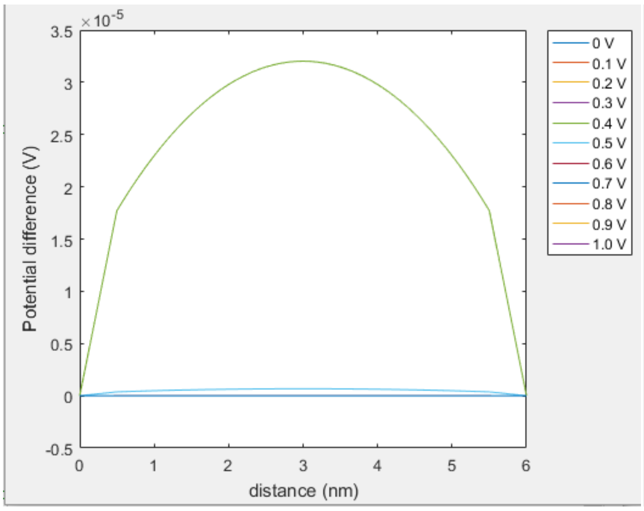
A. The difference electrostatic potential and electron density exist

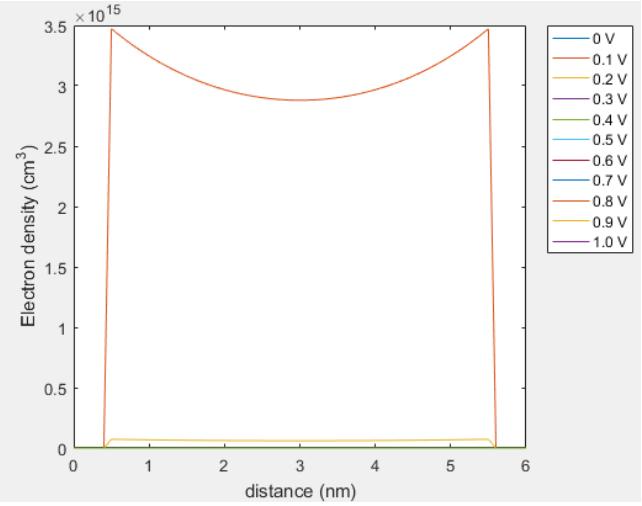
B. This difference is introduced by electron density that it was assumed by depletion in the Si region (range from 5 nm to 55nm)

C. This charge which make potential difference can be accurately calculated by this iteration process

## 5. Check their difference for several gate voltages from 0 V to 1V. (The voltage step is 0.1 V. 11points in total)







A. When the gate voltage is varied from 0V to 1V, the difference is drastically reduced

i. The electron density is function of energy of conduction band

ii. This relation is inverse proportional and exponentially decrease with $E_C$

iii. When the larger gate bias is applied, the energy of conduction band is greater than no bias condition

iv. So, the electron density in the Si region is drastically reduced