Question 3 :

1. Get the doping profile (Given in the question)
2. Calculate ρ (ρ = q(Nd-Na))

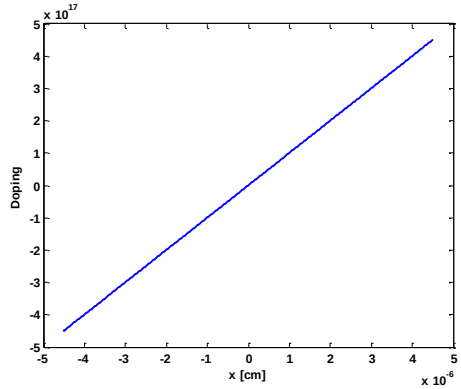


Fig. 1 : Linear doping Profile

3. Calculate field and potential by solving Poisson (Ref. Pierret)

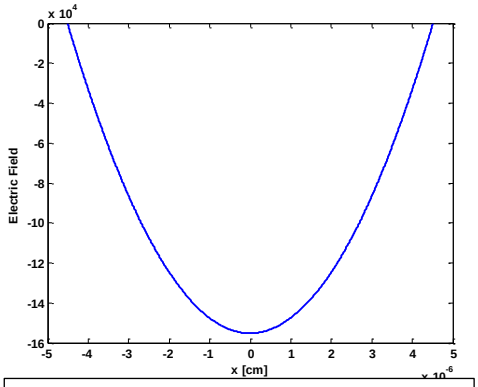


Fig. 2 : Electric Field (assuming depletion approx)

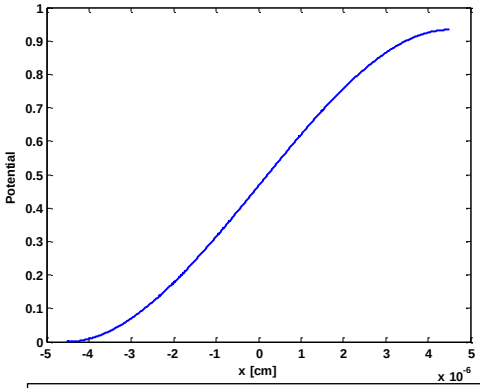


Fig. 3 : Potential (assuming depletion approx)

4. Get intrinsic energy level from potential profile
5. Take the middle point of Ei as the Fermi level
6. Get band diagram by adding and subtracting Eg/2 with the Ei level

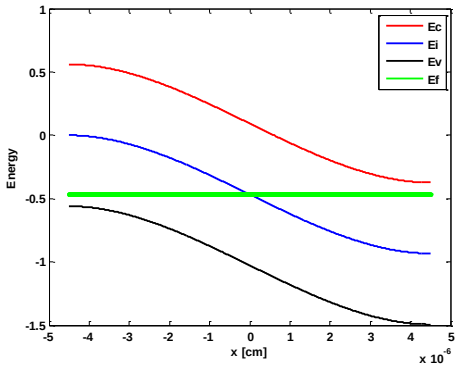


Fig. 4 : Band Diagram

7. Difference between Fermi level and the any of the band (Ec or Ev) will provide the information of the free carrier concentration [use the following equations…. (i) $n = n_i \exp((Ef-Ei)/KT)$ and (ii) $p = n_i \exp((Ei-Ef)/KT)$]
8. Add these free carrier terms into ρ, which is the correction factor

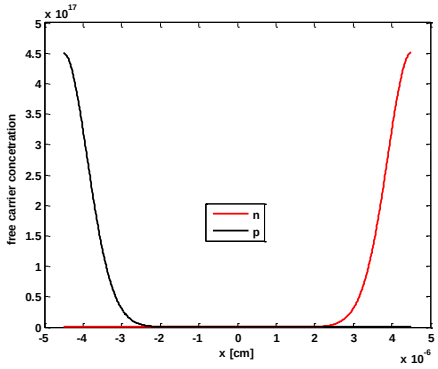


Fig. 5 : Free Carrier Concentration in linear scale

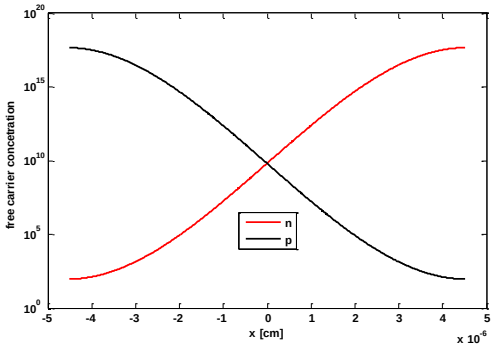
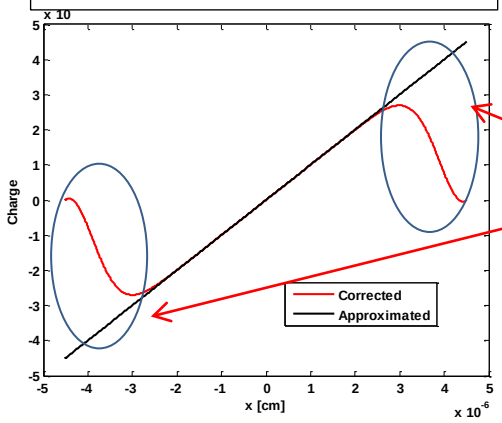


Fig. 6 : Free Carrier Concentration in log scale



At the edges the free carrier start decreasing which we are neglecting while taking depletion approximation into account

Fig. 7 : Rho plotted with correction of free carrier concentration.

9. Get the electric field by integrating ρ w.r.t x
10. Similarly get V
11. Compare the field and the potential with that obtained with depletion approximation

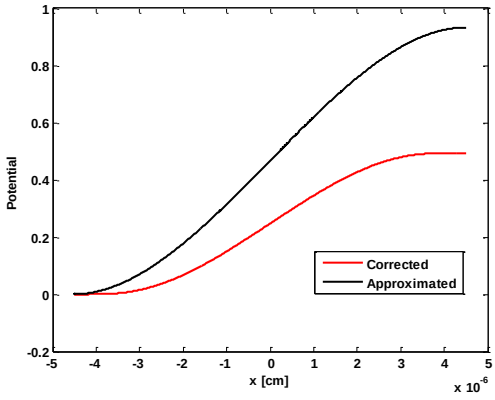
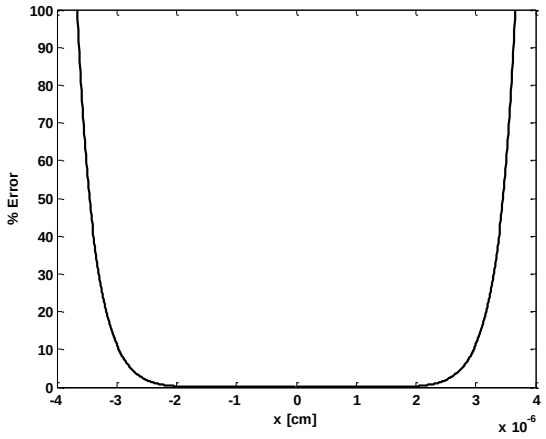


Fig. 8 : Potential Profile with first order correction

Percentage error:



Error comes at the edges since the free carrier concentration decreases there

Fig. 9 : Percentage Error Vs X

Note: Finding depletion width is not straight forward for a linearly graded junction. Below are the steps to find out the depletion width

1. Vbi can be solved by either of the following equations

```
Vbi= 2Vlog(aw/2ni));  … using the equation Vbi = KT/qln[n(x_n)/n(-x_p)]
Vbi = qm(w^3)/(12eps); …. solved using Poisson
```

2. These two equation will intersect at a point which determines the depletion width for a given linear doping profile
3. Taking that number as the depletion width, solve the problem

Matlab Code:

```
clc;clear all;
close all;
tic;

% Defining the Fundamental and Material Constants %
nm    = 1e-7;              % cm
q     = 1.602E-19;         % C or [J/eV]
kb    = 1.38E-23;          % [J/K]
eps   = 1.05E-12;          % This includes the eps  = 11.7 for Si [F/cm]
T     = 300;               % [K]
% ni    = 1.5E10;          % Intrinsic carrier concentration [1/cm^3]
Vt    = kb*T/q;            % [eV]
Nc    = 2.8*1e19;          % cm-3
Nv    = 1e19;              % cm-3
Eg    = 1.12;              % eV
ni = sqrt((Nc*Nv)*exp(-Eg/(Vt)));
```

```
% Eg  = Vt*log((Nc*Nv)/(ni^2));

%%%%%%%% calculating the depletion width %%%%%%%%%

w0=5e-6;
m =1e23;
% wtrial=[0:0.01:1].*w; %cm
wtrial=[0:0.001:2]*w0; %cm
Vbi_1 = 2*Vt*log(m.*wtrial./(2*ni));
Vbi_2 = q*m*(wtrial.^3)/(12*eps);
% Vbi_1 = Vt*log(m.*wtrial./(ni));
% Vbi_2 = q*m*(wtrial.^3)/(6*eps);

figure(200); plot(wtrial, Vbi_1,'r', wtrial, Vbi_2,'r');
[w, Vbi]=intersections(wtrial, Vbi_1, wtrial, Vbi_2, 1);

% Define dop Profile %


x1 = -w/2;
x2 = w/2;
dx = (w)/1000;
x = [x1:dx:x2];
m = 1e23;
N = m*x;   % [1/cm^3]
rho = q*N;

figure (1); plot(x, N, 'Linewidth',2);
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('Doping');

%%%%%% Using Depletion Approximation %%%%%%%%%
for i = 1:length (x)
%     disp(x(i));
    E(i) = ((q*m)/(2*eps))*((x(i)^2 - (w/2)^2));   %%%% Pierret p-n junction
electrostatics%%%%
    V(i) = ((q*m)/(6*eps))*(2*(w/2)^3 + 3*x(i)*(w/2)^2-x(i)^3);
    Ei(i) = -q*(V(i));
end

figure (2); plot(x,E, 'Linewidth',2);
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('Electric Field');

figure (3); plot(x,V, 'Linewidth',2);
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('Potential');
figure (4); plot(x, Ei, 'Linewidth',2);
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('Ei');
% n_ext = 0; %%% extracted from the edge of  N vs x plot %%%%%%%
```

```
b = round((length(Ei))/2);
Ef = Ei(b);
Ec = Ei+((Eg/2)*q);
Ev = Ei-((Eg/2)*q);
figure (100);plot (x, Ec/q,'r', x, Ei/q,'b', x, Ev/q,'k', x, Ef/q, 'g',
'Linewidth',2);
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('Energy');
legend Ec Ei Ev Ef

%%%%%%% For First Order Correction%%%%%%%%
for j= 1:length(Ec)
zn(j) = Ef-Ei(j);
zp(j)= Ei(j) - Ef;
n(j) = ni*(exp(zn(j)./(kb*T)));
p(j) = ni*(exp(zp(j)./(kb*T)));
rho_1(j) = q*(N(j)-n(j)+p(j));
end

figure (5); plot(x,rho_1/q,'r', x, rho/q,'k', 'Linewidth',2);
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('Charge');
legend Corrected Approximated

E_1 = (1/eps)*cumtrapz (x, rho_1);
V_1 = (-1)*cumtrapz (x, E_1);
Ei_1 = (-1)*V_1;
figure (6); plot(x,E_1,'r', x, E,'k', 'Linewidth',2);
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('Electric Field');
legend Corrected Approximated

figure (7); plot(x,V_1,'r', x, V,'k', 'Linewidth',2);
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('Potential');
legend Corrected Approximated



% figure (8); plot(x, Ei_1,'r', x, Ei/q,'k');
% xlabel('x [cm]');
% ylabel('Ei-Corrected');
% legend Corrected Approximated

figure (9); plot(x, n,'r', x, p,'k', 'Linewidth',2);
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('free carrier concetration');
legend n p

figure (10); plot(x,V_1,'r', x, V,'k', 'Linewidth',2);
```

```
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('Potential');
legend Corrected Approximated

error = (rho - rho_1)./rho_1;
per_error = (error).*100;
figure (11); plot(x,per_error,'k', 'Linewidth',2);
YLIM([0 100]);
XLIM([-4e-6 4e-6])
set(gca,'FontSize',10, 'FontWeight', 'bold');
xlabel('x [cm]');
ylabel('% Error');
```