# Device simulation Lab :Assignment 5

Praveen Kumar Yadav

EE22M308

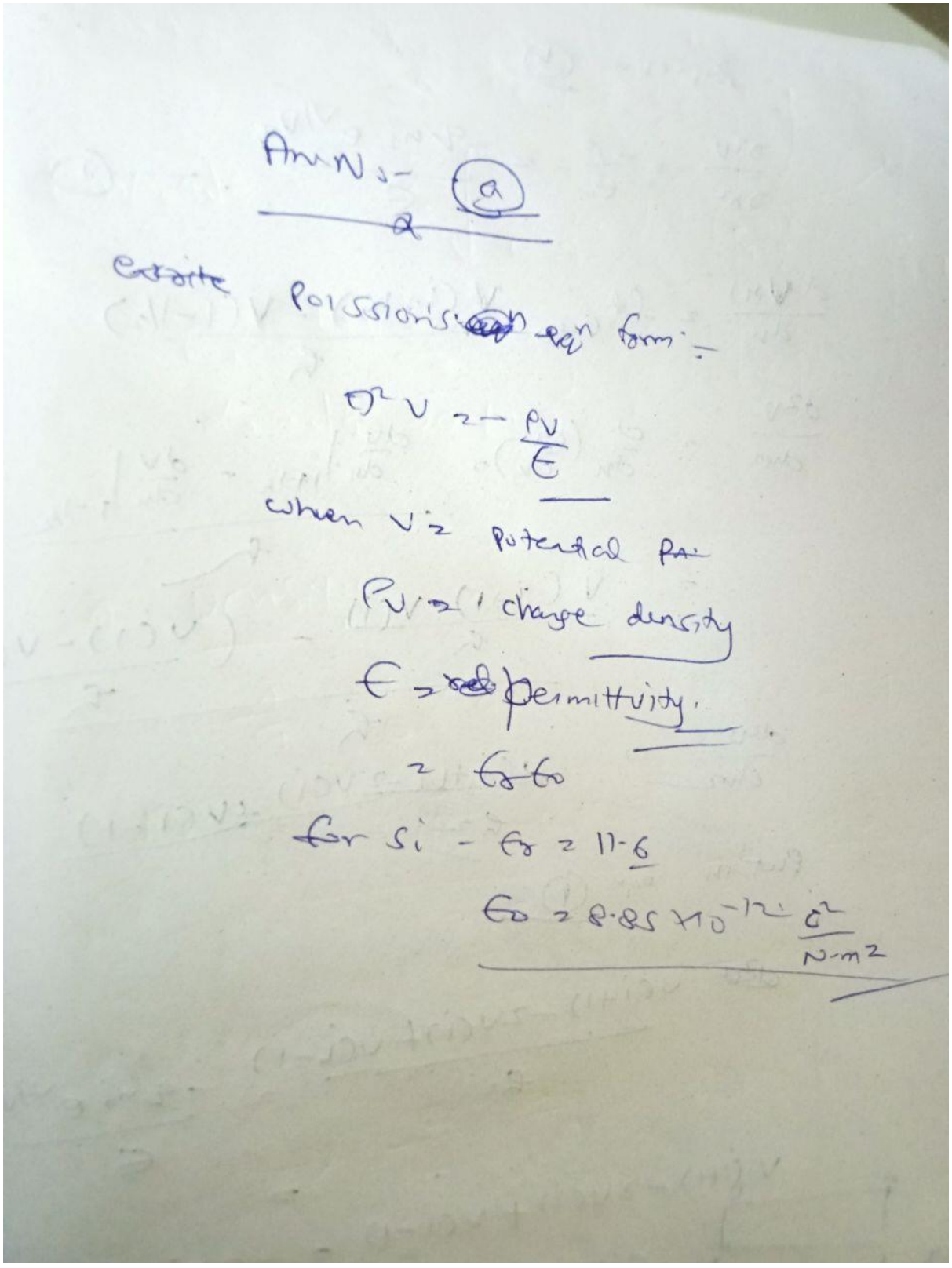
Lab No:5

Software: Matlab 2022a

Numerical solution of Poisson’s equation with Maxwell-Boltzmann distribution of carrier density:

Qa. Assuming electrons as the only type of carriers and an undoped semiconductor, write the appropriate form of poisson’s equation for electrostatics (assume that the current is zero, and Maxwell-Boltzmann statistics for carriers).

Ans:




Qb. Discretize the above equation such that finite difference method could be used to

solve the same.

ANS:

$\nabla^2 V = -\frac{\rho}{\epsilon}$ — (1)

$\frac{\partial^2 V}{\partial x^2} = \frac{\rho}{\epsilon} = -\frac{q n_i e^{V/V_T}}{\epsilon}$

$\frac{dV_{(i)}}{dx} = \lim_{h \to 0} \frac{V_{(i+1/2)} - V_{(i-1/2)}}{h}$

$\frac{d^2V}{dx^2} = \frac{d}{dx}\left(\frac{dV}{dx}\right) = \frac{\frac{dV}{dx}\Big|_{i+1/2} - \frac{dV}{dx}\Big|_{i-1/2}}{h}$

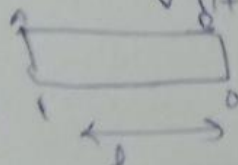
$= \frac{\frac{V(i+1)-V(i)}{h} - \left(\frac{V(i)-V(i-1)}{h}\right)}{h}$

$\frac{d^2V}{dx^2} = \frac{V(i+1) - 2V(i) + V(i-1)}{h^2}$

Put in eqn (1)

$\frac{V(i+1) - 2V(i) + V(i-1)}{h^2} = -\frac{q n_i e^{V/V_T}}{\epsilon}$

$V(i+1) - 2V(i) + V(i-1) = -\frac{h^2 q n_i e^{V/V_T}}{\epsilon}$




for any length $l$ of any sc. take two end points A & B

for N points $V_A = 1$, $V_B = 0$

$V(1) - V_A = 0$

$i = 2 \quad V(3) + V(1) - 2V(2) - \frac{q n_i h^2 e^{V(2)/V_T}}{\epsilon} = 0$

$i = 3 \quad V(4) + V(2) - 2V(3) - \frac{q n_i h^2 e^{V(3)/V_T}}{\epsilon} = 0$

$V_N - V_B = 0$

Qc. List out the general form for Jacobian for the above set of equations.

ANS:

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Let for any N fn taken N points,

$$f_1(V_1, V_2, \ldots V_N) = 0$$

$$f_2(V_1, V_2, \ldots V_n) = 0$$

$$\vdots$$

$$f_n(V_1, V_2 \ldots V_n) = 0$$

$$J = \begin{bmatrix} \frac{\partial f_1}{\partial V_1} & \frac{\partial f_2}{\partial V_2} & \cdots & \frac{\partial f_1}{\partial V_n} \\ \frac{\partial f_2}{\partial V_1} & \frac{\partial f_2}{\partial V_2} & \cdots & \frac{\partial f_1}{\partial V_n} \\ \vdots & & & \\ \frac{\partial f_N}{\partial V_1} & \frac{\partial f_N}{\partial V_2} & \cdots & \frac{\partial f_N}{\partial V_N} \end{bmatrix}$$

for Previous ~~eqn~~ question's eqn

$$J = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 \\ 1 & -2\frac{\hbar^2 2m_1 e^{V(2)/V_t}}{\epsilon V_t} & & \cdots & 0 \\ 0 & 1 & -2\frac{\hbar^2 2m_1 e^{V(3)/V_t}}{\epsilon V_t} & \cdots & 0 \\ \vdots & & & & \\ 0 & 0 & 0 & \cdots & 1 \end{bmatrix}$$

Q d. Consider a semiconductor (say, Silicon) of thickness 200 m. Assume that one end (A) is

held at at 100mV while the other (B) is held at zero potential. Using a-c given above, solve for

this system using Newton's method. Use a linearly varying potential profile as the initial guess.

Plot the potential and carrier density profiles.

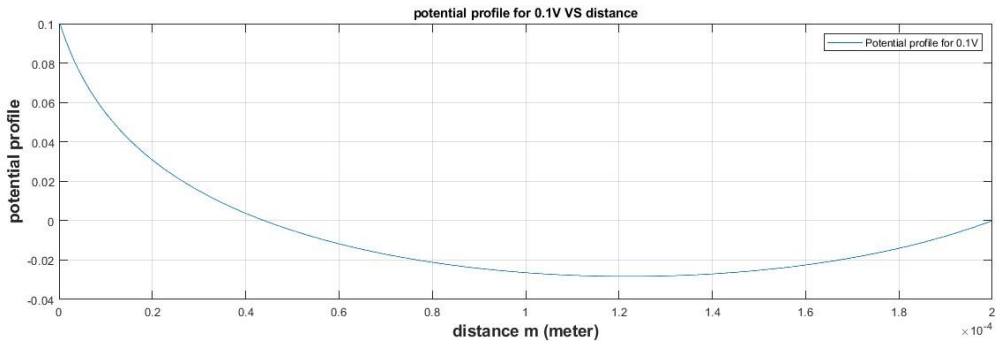
ANS:

Code:

Potential:

```
clear all;
clc;
q=1.6*(10)^(-19);
epsilon=103.368*(10)^(-12);
a=200*10^(-6);
ni=1.5*(10)^(16);
e = 0.0001;
h=a/1000;
Vt=0.0258;
k=(q*ni*(h)^2)/epsilon;
N=1000;
Va=0.1;
Vb=0;
V=linspace(Va,Vb,1000);
V1=V';
for i=1:1000


F(1,1)=0;
F(1000,1)=0;
for i=2:999
    F(i,1)=V1(i+1)+V1(i-1)-2*V1(i)-(k*exp(V1(i)/Vt));

end


M(1,1)=1;
for i=2:1000
    M(i,i)=-2-((k/Vt)*exp(V1(i)/Vt));
end
for i=2:999
    M(i,i+1)=1;
end
for i=1:998
    M(i+1,i)=1;
```

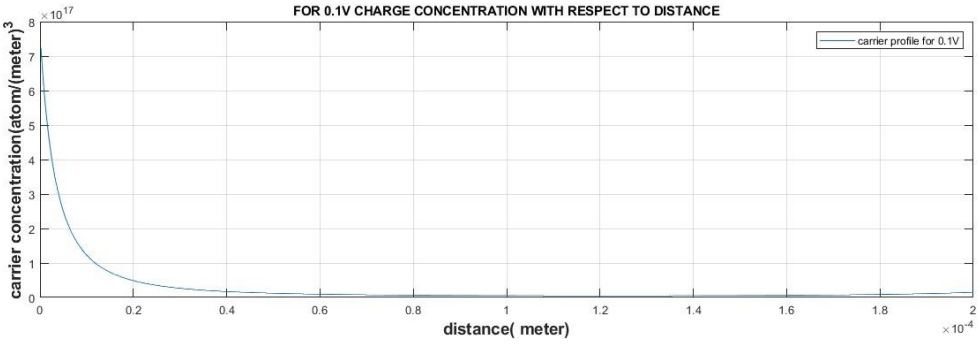
```
end
M(N,N)=1;
p1=inv(M);
p2=p1*F;
V2=V1-p2;
% if abs(V2-V1)<Vt
%         break;
% end
V1=V2;
end
i=1:1000;
x=i*(a/1000);
plot(x,V2);

xlabel('distance ( meter)');
ylabel('potential profile(volt)');
title(' FOR 0.1V POTENTIAL PROFILE WITH RESPECT TO DISTANCE');
grid on;
```




Carrier density:

```
clear all;
clc;
q=1.6*(10)^(-19);
epsilon=103.368*(10)^(-12);
a=200*10^(-6);
ni=1.5*(10)^(16);
e = 0.0001;
h=a/1000;
Vt=0.0258;
k=(q*ni*(h)^2)/epsilon;
N=1000;
Va=0.1;
Vb=0;
V=linspace(Va,Vb,1000);
V1=V';
for i=1:1000


F(1,1)=0;
F(1000,1)=0;
for i=2:999
```

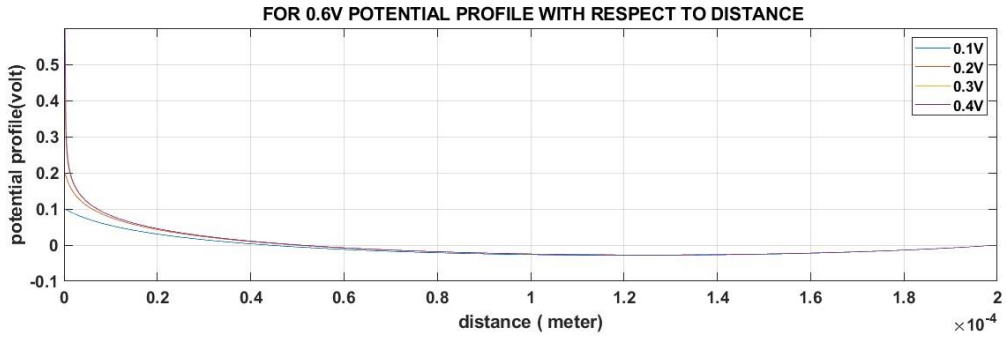
```
    F(i,1)=V1(i+1)+V1(i-1)-2*V1(i)-(k*exp(V1(i)/Vt));

end


M(1,1)=1;
for i=2:1000
    M(i,i)=-2-((k/Vt)*exp(V1(i)/Vt));
end
for i=2:999
    M(i,i+1)=1;
end
for i=1:998
    M(i+1,i)=1;
end
M(N,N)=1;
p1=inv(M);
p2=p1*F;
V2=V1-p2;
% if abs(V2-V1)<Vt
%         break;
% end
V1=V2;
end
for i=1:1000
    n=ni*exp(V2/Vt);
end
i=1:1000;
x=i*(a/1000);
plot(x,n);
xlabel('distance( meter)');
ylabel('carrier concentration(atom/(meter)^3');
title('FOR 0.1V CHARGE CONCENTRATION WITH RESPECT TO DISTANCE');
grid on;
```



Qe. Repeat (d) for applied biases like 200mV, 400mV, and 600mV. Analyse your solutions.
ANS:
CODE:
Compare:
Potential:

```
clear all;
clc;
q=1.6*(10)^(-19);
epsilon=103.368*(10)^(-12);
a=200*10^(-6);
ni=1.5*(10)^(16);
e = 0.0001;
h=a/1000;
Vt=0.0258;
k=(q*ni*(h)^2)/epsilon;
N=1000;
for i=1:4
m=([0.1,0.2,0.4,0.6]);
Va =m(i) ;
Vb=0;
V=linspace(Va,Vb,1000);
V1=V';
for i=1:1000


F(1,1)=0;
F(1000,1)=0;
for i=2:999
    F(i,1)=V1(i+1)+V1(i-1)-2*V1(i)-(k*exp(V1(i)/Vt));

end


M(1,1)=1;
for i=2:1000
    M(i,i)=-2-((k/Vt)*exp(V1(i)/Vt));
end
for i=2:999
    M(i,i+1)=1;
end
for i=1:998
    M(i+1,i)=1;
end
M(N,N)=1;
p1=inv(M);
p2=p1*F;
```

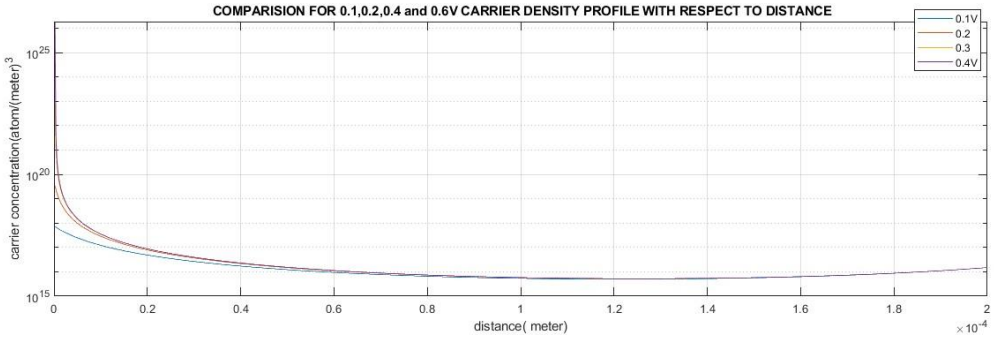
```
V2=V1-p2;
% if abs(V2-V1)<Vt
%         break;
% end
V1=V2;
end
i=1:1000;
x=i*(a/1000);
plot(x,V2);

xlabel('distance ( meter)');
ylabel('potential profile(volt)');
title(' FOR 0.6V POTENTIAL PROFILE WITH RESPECT TO DISTANCE');
grid on;
hold on
end
```




Carrier density:

```
clear all;
clc;
q=1.6*(10)^(-19);
epsilon=103.368*(10)^(-12);
a=200*10^(-6);
ni=1.5*(10)^(16);
e = 0.0001;
h=a/1000;
Vt=0.0258;
k=(q*ni*(h)^2)/epsilon;
N=1000;
for i=1:4
m=([0.1,0.2,0.4,0.6]);
Va =m(i) ;
Vb=0;
V=linspace(Va,Vb,1000);
V1=V';
for i=1:1000


F(1,1)=0;
F(1000,1)=0;
for i=2:999
    F(i,1)=V1(i+1)+V1(i-1)-2*V1(i)-(k*exp(V1(i)/Vt));
```

```
end


M(1,1)=1;
for i=2:1000
    M(i,i)=-2-((k/Vt)*exp(V1(i)/Vt));
end
for i=2:999
    M(i,i+1)=1;
end
for i=1:998
    M(i+1,i)=1;
end
M(N,N)=1;
p1=inv(M);
p2=p1*F;
V2=V1-p2;
% if abs(V2-V1)<Vt
%         break;
% end
V1=V2;
end
for i=1:1000
    n=ni*exp(V2/Vt);
end
i=1:1000;
x=i*(a/1000);
plot(x,n);
xlabel('distance( meter)');
ylabel('carrier concentration(atom/(meter)^3');
title(' COMPARISION FOR 0.1,0.2,0.4 and 0.6V CARRIER DENSITY PROFILE WITH RESPECT
TO DISTANCE');
grid on;
hold on
end
```




Qf. Assume that SiO2 of thickness 20nm is deposited at the end A and the potential is applied
across the SiO2 and the Semiconductor. Modify your code in (d) and find the carrier density
profiles inside the semiconductor for an applied bias of 1V. Comment on your results.

ANS:

CODE

```
clear all;
clc;
q=1.6*(10)^(-19);
```

```
epsilon=103.368*(10)^(-12);
a=((200*10^(-6))-(20*10^(-9)));
ni=1.5*(10)^(16);
e = 0.0001;
h=a/1000;
Vt=0.0258;
k=(q*ni*(h)^2)/epsilon;
N=1000;
Va=1;
Vb=0;
V=logspace(Va,Vb,1000);
V1=V';
for i=1:1000


F(1,1)=0;
F(1000,1)=0;
for i=2:999
    F(i,1)=V1(i+1)+V1(i-1)-2*V1(i)-(k*exp(V1(i)/Vt));

end


M(1,1)=1;
for i=2:1000
    M(i,i)=-2-((k/Vt)*exp(V1(i)/Vt));
end
for i=2:999
    M(i,i+1)=1;
end
for i=1:998
    M(i+1,i)=1;
end
M(N,N)=1;
p1=inv(M);
p2=p1*F;
V2=V1-p2;
% if abs(V2-V1)<Vt
%         break;
% end
V1=V2;
end
for i=1:1000
    n=ni*exp(V2/Vt);
end
i=1:1000;
x=i*(a/1000);
plot(x,n);
xlabel('distance( meter)');
ylabel('carrier concentration(atom/(meter)^3');
```

```
title('FOR 1V CHARGE CONCENTRATION WITH RESPECT TO DISTANCE');
grid on;
```