Bangladesh University of Engineering and Technology (BUET)

Assignment

Nanoscale Device Modeling and Simulation Techniques

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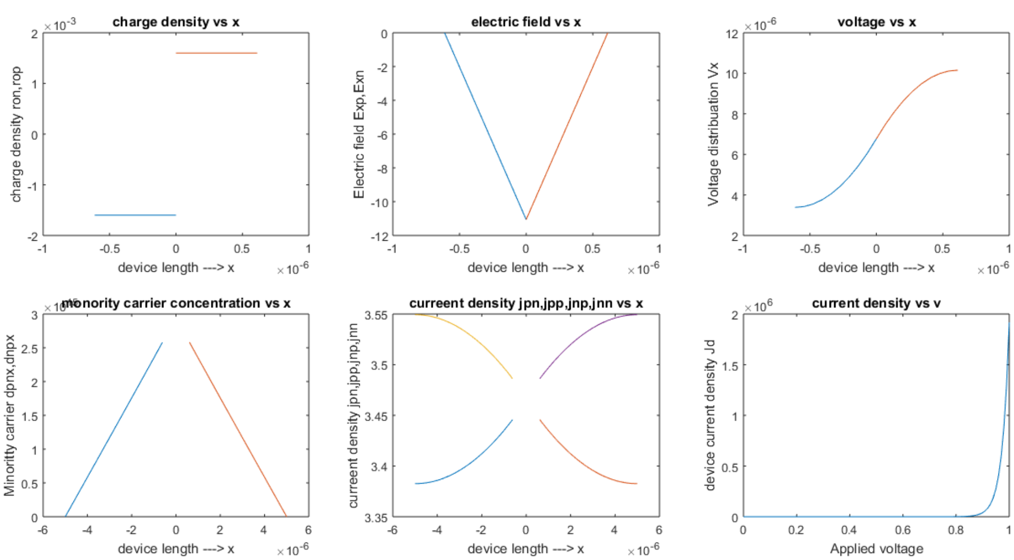
Assignment

- ➢ Solve for a pn junction.
- ➢ Submit the report containing:
- ➢ Solution method and details on your choice of software, implementation etc.
- ➢ J-V curve, n(x), p(x) at different biases, V(x), E(x)Jn(x) and Jp(x)
- ➢ Compare the numerical solution of the above with textbook's analytical equations.

1.Software:MATLAB

2.Working Procedure

- ❖ **Electric field and voltage calculation: Using poison’s formula I calculated electric field and voltage distribution across the junction.Here I used Matlab function for numerical integration.**
- ❖ **Then I solve drift and diffusion equation which is a 2nd order differential equation to get carrier concentration distribution.**
- ❖ **After that I solved a differentiation to get current density from charge distribution which is actually diffusion current for both majority and minority charge carrier.**
- ❖ **Finally make a function for current density vs voltage. I didn’t do it numerically because it would take more than 1. Hour to solve for 40-50 point data for current. Here full Matlab code run for a single bias and give only one current density for a specific voltage that’s take time to process about 2min. so it would be much complex. Due to avoiding this problem I calculated current with analytical equation.**



Comparison with analytical solution

1.Charge density in Space charge region

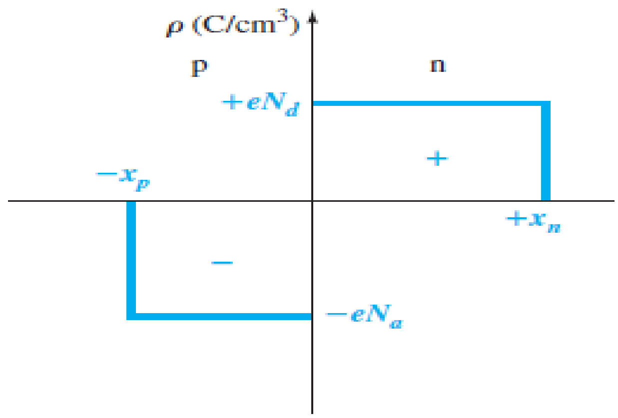
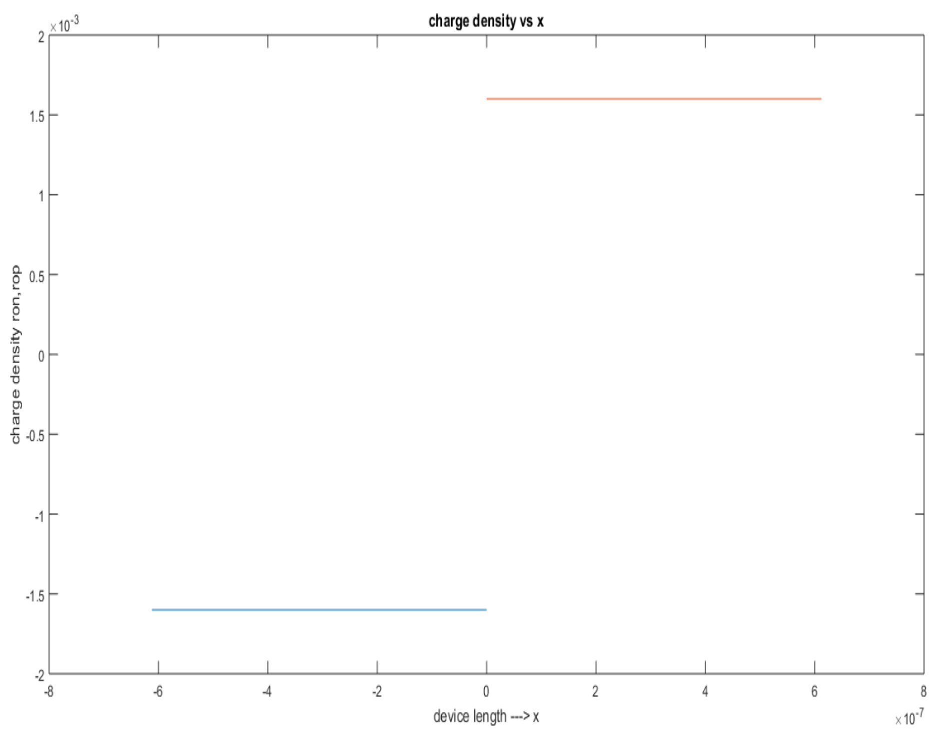


Figure 7.4 | The space charge density in a uniformly doped pn junction assuming the abrupt junction approximation.



2.Electric field distribution

$$\phi(x) = -\int \mathrm{E}(x)dx = \int \frac{eN_a}{\epsilon_s}(x + x_p)dx$$

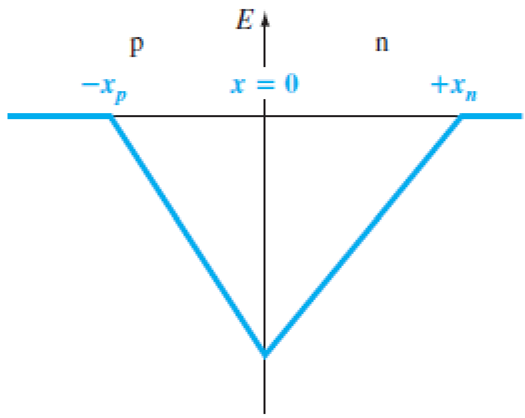
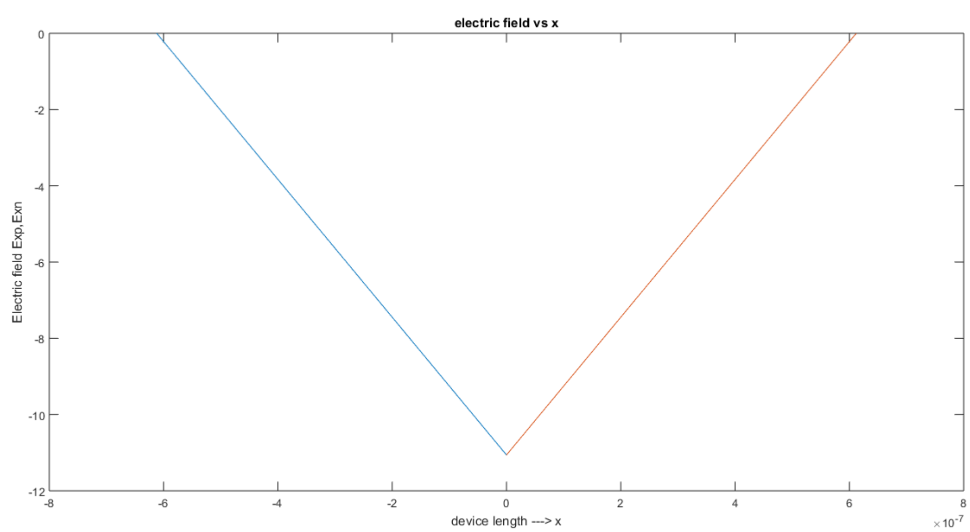


Figure 7.5 | Electric field in the space charge region of a uniformly doped pn junction.



3.Voltage distribution

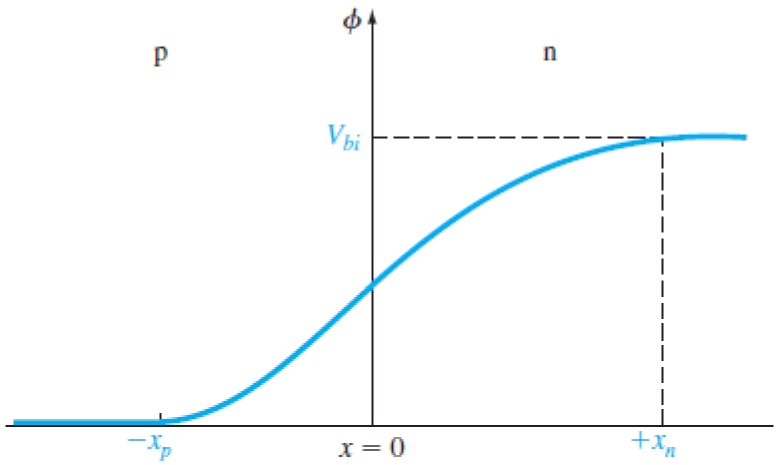
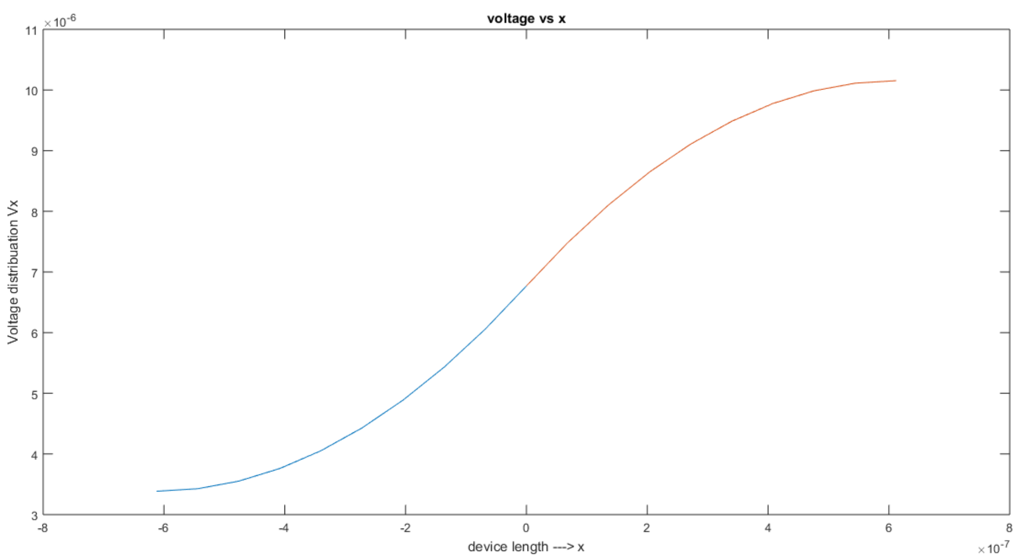


Figure 7.6 | Electric potential through the space charge region of a uniformly doped pn junction.



4.Carrier distribution

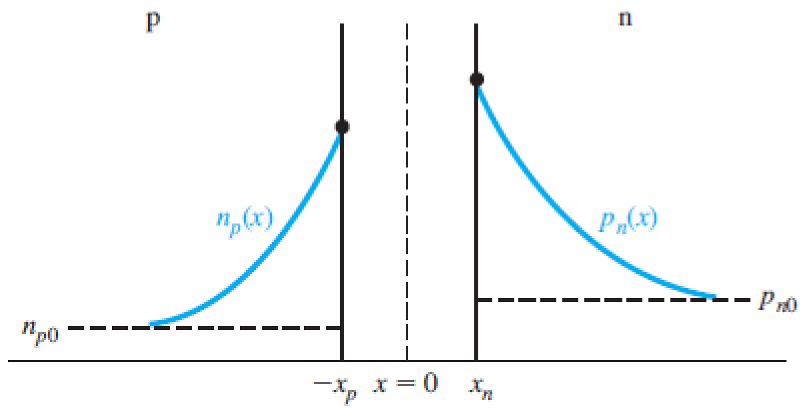
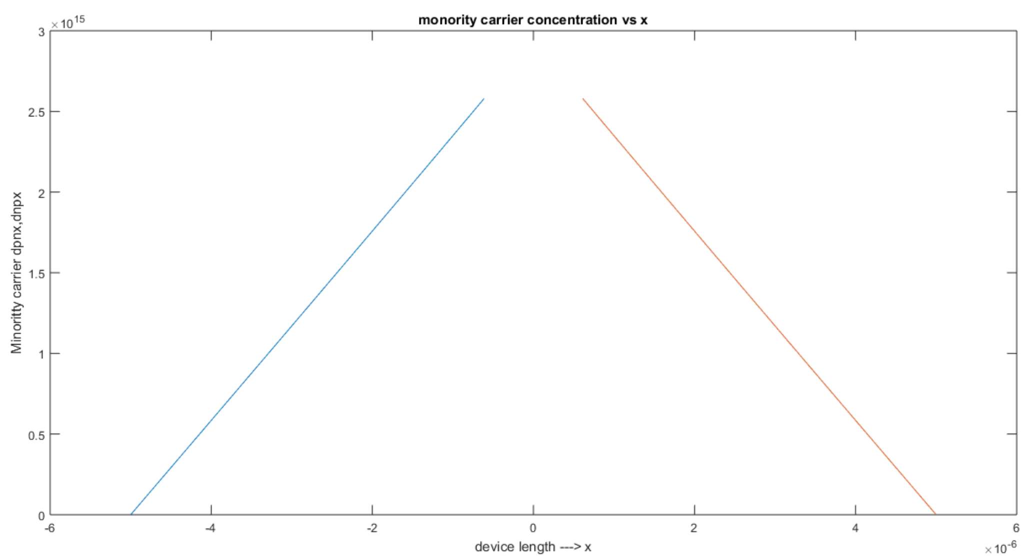


Figure 8.5 | Steady-state minority carrier concentrations in a pn junction under forward bias.



5.Current density

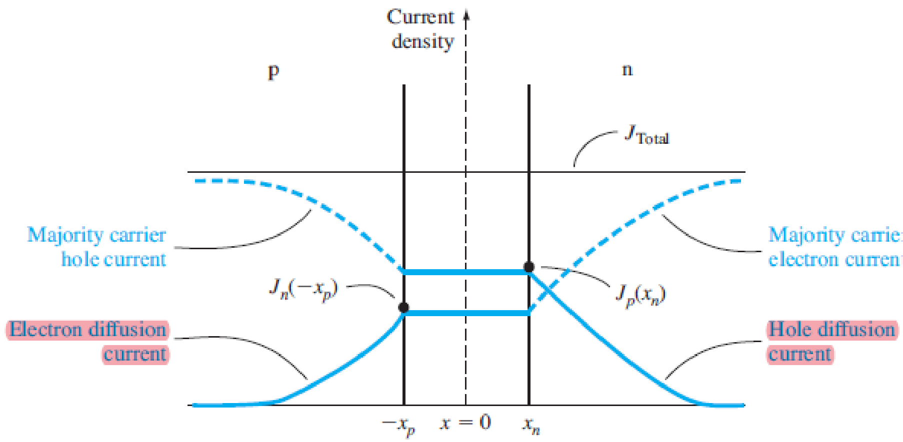


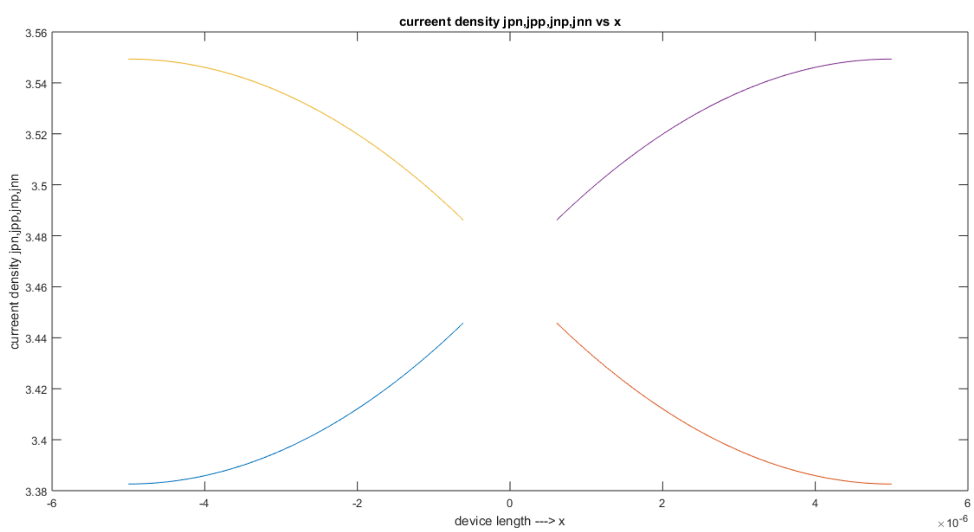
Figure 8.10 | Ideal electron and hole current components through a pn junction under forward bias.

the minority carrier diffusion current densities as a function of distance through the p and n regions. These results are

$$J_p(x) = \frac{eD_p p_{n0}}{L_p}\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right]\exp\left(\frac{x_n - x}{L_p}\right) \quad (x \geq x_n) \qquad (8.28)$$

and

$$J_n(x) = \frac{eD_n n_{p0}}{L_n}\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right]\exp\left(\frac{x_p + x}{L_n}\right) \quad (x \leq -x_p) \qquad (8.29)$$



6.Current vs voltage

CHAPTER 8 The pn Junction Diode

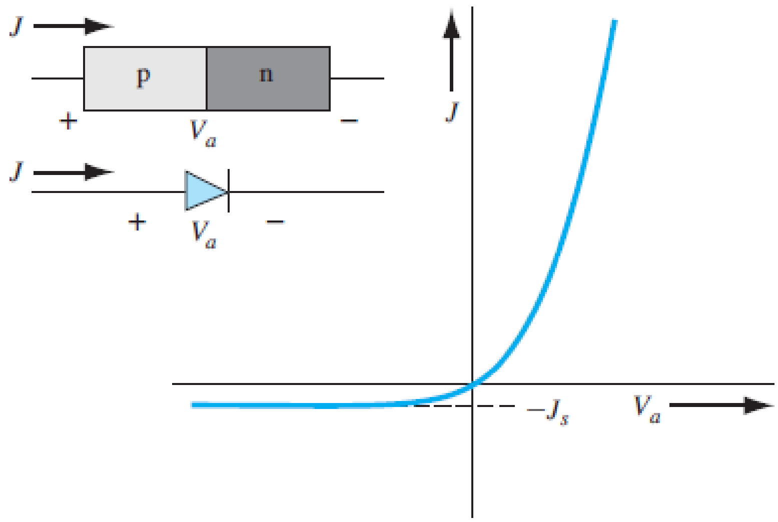
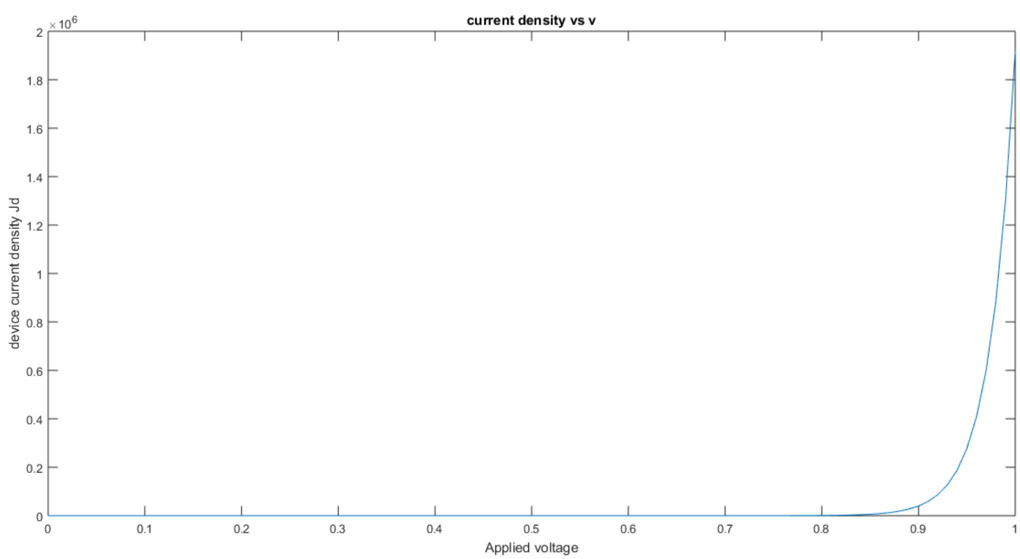


Figure 8.8 | Ideal *I*–*V* characteristic of a pn junction diode.



MATLAB CODE

```
clear all
close all
clc

%%
e=1.6*10e-19;
mun = 0.14;
mup = 0.04;
Na = 10^15;
Nd = 10^15;
Dn = 0.003618;
Dp = 0.001034;
Vt = 0.025855;
T = 300;
Xn = 6.1204e-7;
Xp = 6.1204e-7;
npo = 2.25e5;
pno = 2.25e5;
Ln = (Dn*5e-7)^0.5;
Lp = (Dp*5e-7)^0.5;
ni = 1.5e10;
pl = 5e-6;
nl = 5e-6;
nxp = 2.58e15;
pxn = 2.58e15;
ep0=8.854*10e-12;

%%
syms x
rop(x)=-e*Na+0*x;
a=linspace(0,-Xn,10);
subplot(2,3,1)
plot(a,rop(a))
hold on
b=linspace(0,Xp,10);
ron(x)=e*Nd+0*x;
plot(b,ron(b))
title('charge density vs x')
xlabel('device length ---> x')
ylabel('charge density ron,rop')

exp=int(rop)/ep0;
exp=exp-e*Na*Xp/ep0;
subplot(232)
plot(a,exp(a))
hold on
exn=int(ron)/ep0;
exn=exn-e*Na*Xn/ep0;
plot(b,exn(b))
title('electric field vs x')
xlabel('device length ---> x')
ylabel('Electric field Exp,Exn')
vxp=-int(exp);
vxp=vxp+(e*Na*Xp^2)/ep0;
subplot(233)
plot(a,vxp(a))
hold on
vxn=-int(exn);
vxn=vxn+(e*Na*Xp^2)/ep0;
plot(b,vxn(b))
title('voltage vs x')
xlabel('device length ---> x')
ylabel('Voltage distribuation Vx')
```

```
%%
syms dpnx(x)
ode = diff(dpnx,x,2) -dpnx/(Lp^2) == 0;
cond1 = dpnx(-Xp) == nxp;
cond2 = dpnx(-pl) == npo;
conds = [cond1 cond2];
ySol(x) = dsolve(ode,conds);
ySol = simplify(ySol);
x1= linspace(-pl,-Xp,100);
z1=ySol(x1);
subplot(234)
plot(x1,z1)
hold on

syms dnpx(x)
ode2 = diff(dnpx,x,2) -dnpx/(Lp^2) == 0;
cond1 = dnpx(Xp) == nxp;
cond2 = dnpx(pl) == npo;

conds = [cond1 cond2];
ySol2(x) = dsolve(ode2,conds);
ySol2 = simplify(ySol2);

x2= linspace(Xn,pl,100);
z2=ySol2(x2);
plot(x2,z2)
title('monority carrier concentration vs x')
xlabel('device length ---> x')
ylabel('Minoritty carrier dpnx,dnpx')

%%
jpn=e*Dn*diff(ySol);
subplot(235)
plot(x1,jpn(x1))
hold on
jnp=-e*Dn*diff(ySol2);
plot(x2,jnp(x2))
hold on

j=vpa(jpn(Xp)+jnp(Xn));
jnn=j-vpa(jpn(x1));
plot(x1,jnn)
hold on
jpp=j-vpa(jnp(x2));
plot(x2,jpp)
title('curreent density jpn,jpp,jnp,jnn vs x')
xlabel('device length ---> x')
ylabel('curreent density jpn,jpp,jnp,jnn')


%%
syms vab
jd(vab)=(e*Dp*pno/Lp)+(e*Dn*npo/Ln)*((2.7182.^(vab/Vt))-1);
vd=0:.01:1;
subplot(236)
plot(vd,jd(vd))
title('current density vs v')
xlabel('Applied voltage')
ylabel('device current density Jd')
```