EECS 2077
Semiconductor
Devices

4 Diode Currents

Name:______________________________ **Complete** ____

Reminders

(1) ★ will mark areas where we will stop until we agree upon the solution as a group, or until I check your answer. If your group gets done early, then you may move onto problems near the end that we might not complete during class.

(2) When you are done and I have approved, erase all your work on the wall/board. Clean up! No food or drink other than water please.

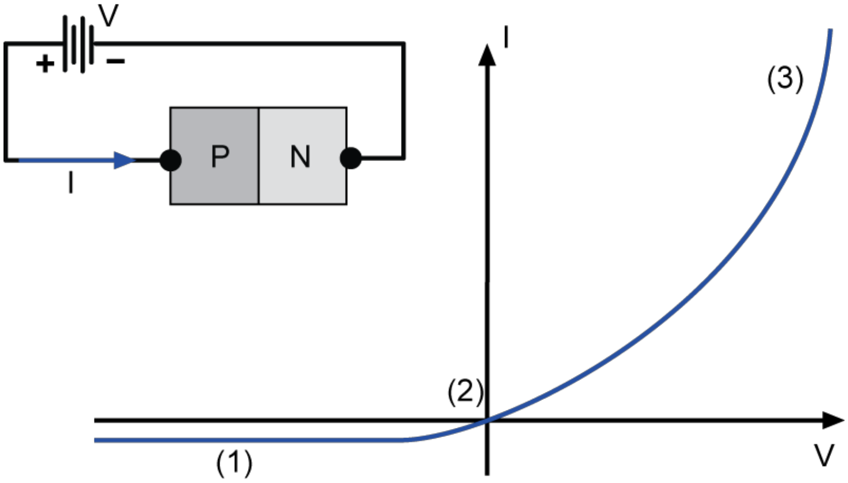
In-Class Problems

(1) The I-V diagram of an ideal PN junction is shown at right. For each of the three points labeled on the curve (1, 2, 3) provide the following:

(a) a simplified version of the diode equation for each point

(b) band-diagram showing with where the current components originate from

(c) a short description of the forces that drive each current component, and which current component dominates (if any)



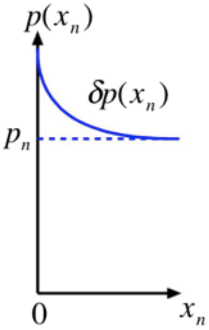
a) (1) $I=-I_o$ (2) $I=0$ (3) $I= I_o e^{qV/kT}$

b) see lecture notes

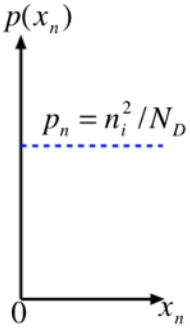
c) (1) dominated by drift of minority carriers that are thermally generated near (diffusion length) the edge of the depletion region, (2) diffusion and drift current are equal, (3) dominated by increased diffusion of majority carriers over a reduced energy barrier, the barrier being reduced by the application of forward voltage across the PN junction. ★

(2) Below is a plot of carrier concentration on either side of a diode, under various bias conditions. You should be able to answer these questions and fully understand them!

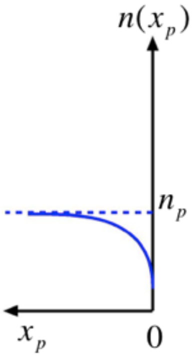
(plot 1)



(plot 2)



(plot 3)



(a) the three plots

X are for minority carriers ONLY

__ are for majority carriers ONLY

__ include both

(b) label each item below as plot 1, plot 2, or plot 3:

1 __ an excess at the depletion edge (X=0) because of forward bias and diffusion

3 __ zero concentration at the depletion edge (X=0) because of reverse bias and drift

2 __ no concentration change because drift and diffusion currents balance at 0V for a diode ★

(3) You increase doping for a diode, the how does the FORWARD current change and WHY. Don't just refer to the equation, explain it based on drift/diffusion, generation, energy barriers, etc. ONE SENTENCE MAX!

DECREASES because the energy barrier for diffusion increases (contact potential, Fermi level offset), and forward bias current in the diode is diffusion of majority carriers. *You may have more majority carriers as you increase doping, but that is like saying if I put a crowd of 1 million people outside of Baldwin hall, I'll find none that can leap 3 stories up onto the building (more people won't help my odds), who cares if you have 'more chances' if the bigger issue is the barrier height!*

(4) You increase doping for a diode, the how does the REVERSE current change and WHY. Don't just refer to the equation, explain it based on drift/diffusion, generation, energy barriers, etc. ONE SENTENCE MAX!

DECREASES because minority carrier concentration decrease with doping (increased recombination, shorter lifetimes), and reverse bias current in the diode is drift of minority carriers. ★

(5) [20 pts] An ideal Si p+n junction at 300K has the following parameters (you may or may not need them all).

p-side:	**n-side:**	**General parameters**
$N_a=10^{17}/cm^3$	**$N_d=10^{15}/cm^3$**	**$A=10^{-4}\ cm^2$**
$D_n=18\ cm^2/sec$	**$D_p=25\ cm^2/sec$**	**$\varepsilon_{Si}=11.8$**
$L_n=10^{-3}\ cm$	**$L_p=10^{-2}\ cm$**	

(a) What is the drift current across the junction at an applied reverse bias of -3V?

$$I_o \simeq eA\left(\frac{D_p}{L_p}p_n\right) = 1.6\times10^{-19}\cdot10^{-4}\cdot\left[\frac{25}{10^{-2}}\cdot(\ )\right] =$$

$$p_n = \frac{n_i^2}{N_d} = \frac{(1.5\times10^{10})^2}{10^{15}} = 2.25\times10^{5}/cc = 9\times10^{-15}A$$

Answer:

(b) What is the diffusion current across the junction at a reverse bias of -3V? ★

Answer: $\boxed{I = 0}$ Think about why this happens. When you reverse bias, see how the energy barrier increases for majority carriers to diffuse to the other side.

(c) What is the diffusion current across the junction at a forward bias of 0.7? V?

Diffusion will dominate in forward bias, think of that huge concentration of majority carriers ready to spill over if you can just decrease the energy barrier for diffusion. Just use the diode equation in forward bias!

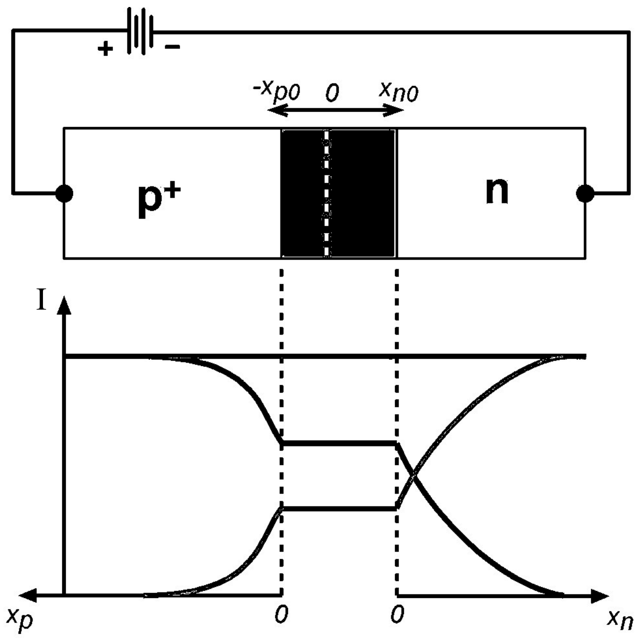
$$\boxed{I = I_o\left(e^{qV/kT}-1\right) = I_o\cdot e^{0.7/0.026} \simeq 4.4\ mA}$$

(d) What is the drift current across the junction at a forward bias of 0.7? V? ★

Answer: is just $I_0=9\times10^{-15}$A. Drift current never goes away! Think about it, the slope is still there! It's just real small…

Extra Problems (if you have time, finish during class when I can help, or on your own time)

(6) Two-part question related to this plot of hole current, electron current, and total current. First, why are the electron and hole currents not constant in the p-type and n-type regions? Second, why are they constant inside the depletion region?



NOT constant, because recombination. Note, this is only near the depletion region, if you go really far into the n and p type materials (now shown above) the currents are all holes or all electrons and are constant in value.

Constant, because of NO recombination in the depletion region.

(7) Why does the ideal diode equation give constant current under reverse bias? 1-2 sentences MAX.

Because the current is proportional to the rate at which carriers are thermally generated near the edge of the depletion region (and this has nothing to do with voltage!). *Only thermally generated carriers near the edge contribute (near, as in diffusio length), carriers further away recombine instead.*

(8) Use MATLAB to visualize effects of doping on diode current (from Pierret Ex. 6.5). Play around with the code a bit. When you enter doping levels at the "ND= " prompt, put the input in square brackets and separated by spaces (1D array of data). A useful range may be several values from 1e+16 to 1e+17 for doping.

```
%Variation of Ideal-Diode I-V  with semiconductor doping.
%Si step junction, T = 300K.
%In response to the "ND=" prompt type [ND1 ND2 ...] to input
%multiple doping values.
%Initialization and Universal Constants
clear
k=8.617e-5;
q=1.6e-19;
%Device, Material, and System Parameters
A=1.0e-4;
ni=1.0e10;
taup=1.0e-6;
ND=input('Input the n-side doping concentration, ND = ');
T=300;
%Hole Mobility Calculation
```

```
NAref=2.35e17;
upmin=54.3;
up0=406.9;
ap=0.88;
up=upmin+up0./(1+(ND./NAref).^ap);
%The mobility calculation here assumes the hole
minority carrier
  %mobility is equal to the hole majority carrier mobility.
%I-V Calculation
VA=linspace(-1,0.2);
DP=k.*T.*up;
LP=sqrt(DP.*taup);
I0=q.*A.*(DP./LP).*(ni^2 ./ND)
I=I0.'*(exp(VA./(k.*T))-1);
%Plotting Result
close
plot(VA,I); grid;
ymin=-2*I0(1);  ymax=5*I0(1);
axis([-1,0.2,ymin,ymax]);
xlabel('VA (volts)');  ylabel('I (amps)');
%Adding axes,key
xx=[-1 0.2];  yx=[0 0];
xy=[0 0]; yy=[ymin,ymax];
hold on
plot(xx,yx,'-w',xy,yy,'-w');
j=length(ND);
for i=1:j;
    yput=(0.70-0.06*i)*ymax;
    yk(i,1)=yput; yk(i,2)=yput;
    text(-0.68,(0.69-
0.06*i)*ymax,['ND=',num2str(ND(i)),'/cm3']);
end
xk=[-0.8 -0.7];
plot(xk,yk);
text(-0.74,0.75*ymax,'Si, 300K');
hold off
```