ECE 3110 Microelectronics - I
Exam 1
Fall 2017
Instructor: Dr. Dhanya Nair

Instructions:
1) Read the question carefully and take into account all factors mentioned, especially the **units**.
2) Show ALL your steps.
3) Box your key equations & steps.
4) Name the **x & y axis** and the **peak values** for all your plots.
5) Provide the **units** with each answer.

Good Luck!

Name: Solution.

Date: ____________

⇒ Solve prob. # 4 & 5.

→ don't know what saturation current is, can't mark it on I-V curve.

→ confused regarding V_o & V_D. $V_o = V_T \ln \frac{N_A N_D}{n_i^2}$, $V_D = V_T \ln \frac{I_D}{I_S}$.

→ no clue about small signal analysis.
  - even though it was HW.

→ equations almost never have a LHS! some random no. floating around.

→ wrong representation of const voltage drop diode. 0.7V or 0.7V

3 prob to choose from: Small signal → 3 diodes in series prob OR something w/ load added.

→ not comfortable w/ transfer chara.

→ correct Zener & Avalanche breakdown range $-7V < V < -5V$ (Zener) not 0.5 to 0.

→ diff b/w drawing

Solving 4:05pm - 5:40pm w/ a bunch of misc stuff

Avalanche - Better explanation: An electron shoots around the depletion region and gains such momentum that it knocks other electrons out of their bonds with a domino effect.

1) Diode & PN junction Concepts: [20pts]

2 or 3

1. Name the 2 types of junction breakdown mechanisms. Briefly explain the difference between them. [3pts]

1. Zener breakdown — Electric field across dep. region breaks a large no. of covalent bonds generating a large no. of carriers.

2. Avalanche breakdown
└ Electric field across dep. region causes the minority carriers in the dep. region to gain a huge drift velocity & as these electrons hit other atoms & create more ehps ⇒ cummulatively a large no. of carriers are generated.

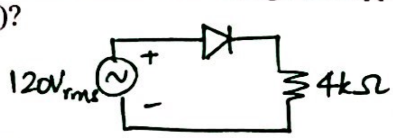
2. At absolute zero temp (0K), an intrinsic semiconductor behaves like [1pt]
   a) a partial conductor
   b) an insulator → all bonds are intact.
   c) a conductor
   d) an insulator sometimes and a conductor sometimes

3. If the diffusion capacitance of a forward biased pn junction carrying 1mA current is 100fF, what will the diffusion capacitance be if the forward bias current increases to 5mA? [1pt]
C_d = 500fF

$C_d = \frac{\tau_T}{V_T} \cdot I$.

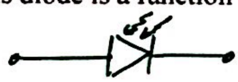
2 or 0

4. Consider a half wave rectifier built using an ideal diode and 4kΩ load resistor. If the rectifier is fed with a sine wave of 120Vrms, what is the maximum voltage that appears across the diode during reverse bias (Peak Inverse Voltage)? [2pt]
PIV = $120 \times \sqrt{2}$
$= \underline{\underline{169.7\,V}}$



5. Identify the diodes described below: [3pts]
[Bonus points if you draw the symbol for each]

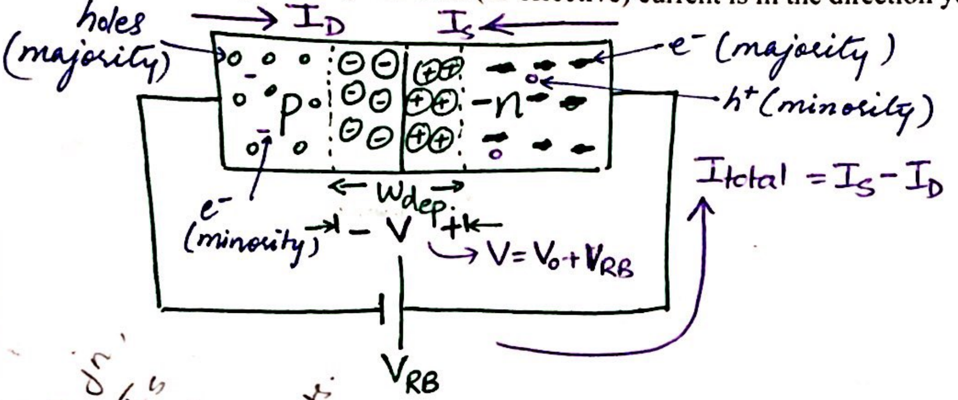
a) The reverse current through this diode is a function of the light falling on it.
Photodiode



b) This diode works on the principle that its junction capactiance changes as a function of the reverse bias voltage.
Varactor diode

c) This diode is used in switch mode power supply due to its low forward voltage drop and fast switching response.
Shottky Barrier diode

6. Draw a PN junction under **reverse bias**. Note the direction of the *drift and diffusion currents*, the *depletion width*, the *voltage* across the barrier, the *total current* through the system. Please show the majority carriers, minority carriers and uncovered bound charges too.
Explain why the total (or effective) current is in the direction you have shown. [5pts]

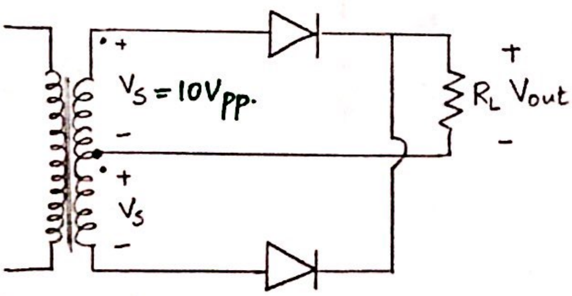


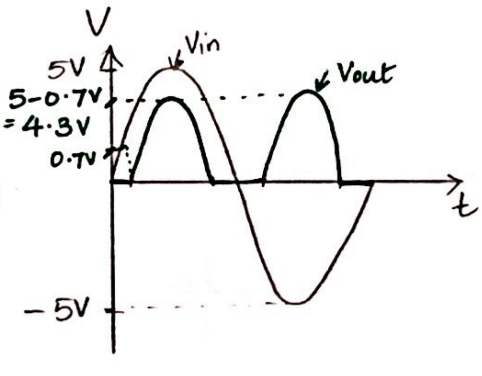
During reverse bias, the dep. region widens & hence diffusion current reduces. For $V_{RB} > 1V$, $I_D = 0$.
⇒ $I_{total} = I_S$ alone.
⇒ current flows in the same dir. as drift I.

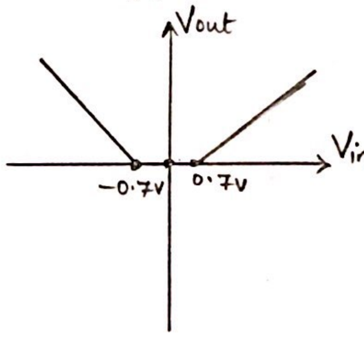
pn jn, I_D, I_S = 3pts. OR full 5pts.

7. Rectifiers:
Given the rectifiers shown below are fed with an input signal Vs = 10Vpp, 1kHz, plot the *output waveforms* and the *tranfer characteristics* for each. Assume a constant voltage drop model for the diodes with $V_D = 0.7V$ [5pts]

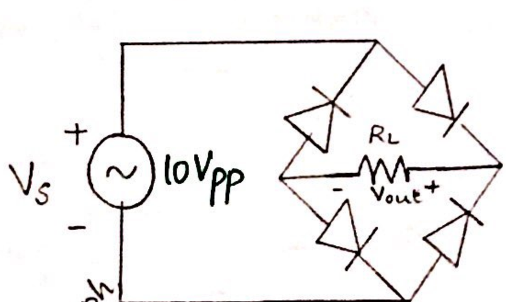
a) Full wave rectifier

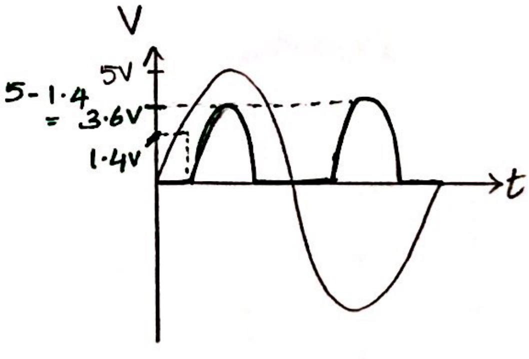


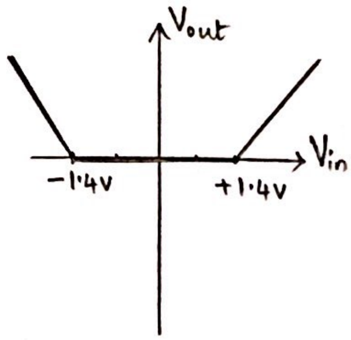




b) Bridge rectifier



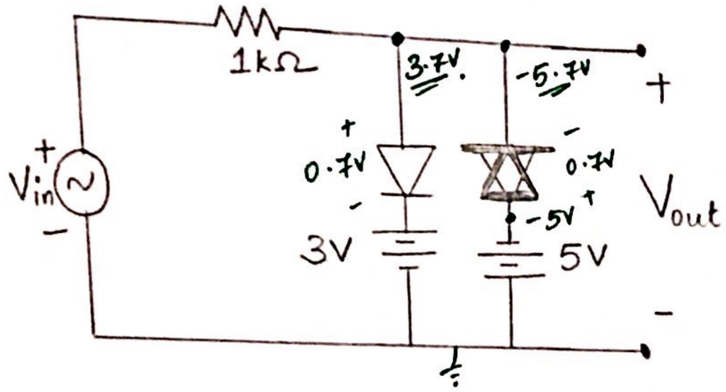


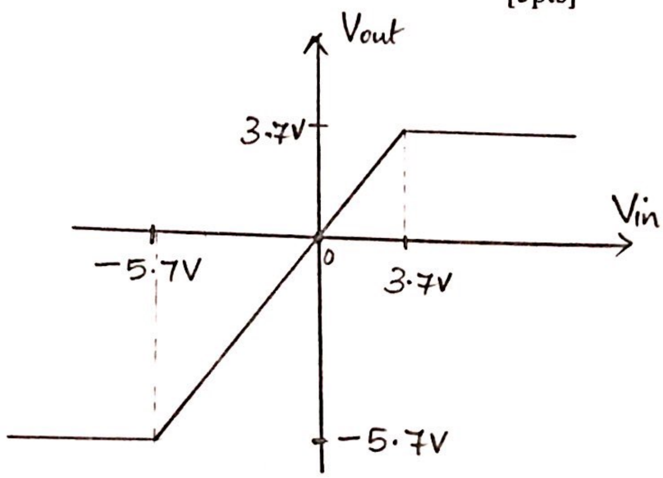


1 pt per graph
+1 pt. for correct cutoff values.

2) Clipper & Clamper circuits: Bonus: **[10pts]**

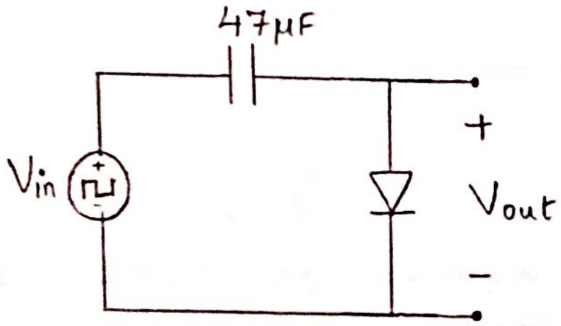
a) Sketch the *transfer characteristic* for the circuit shown below. Assume a constant voltage drop model for diodes with $V_D = 0.7V$. [5pts]

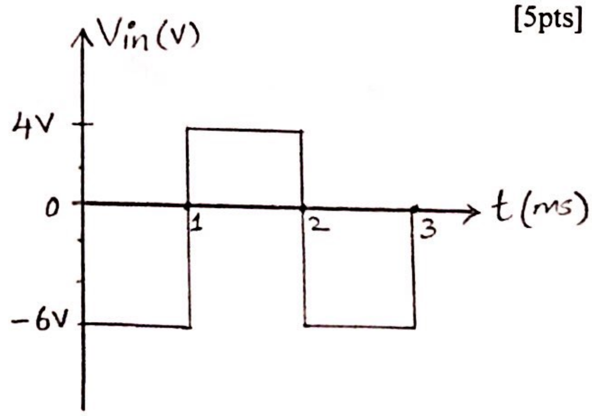


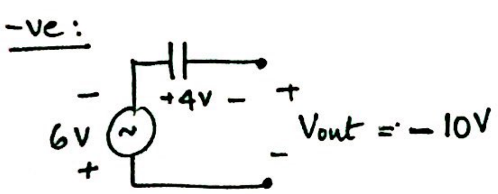


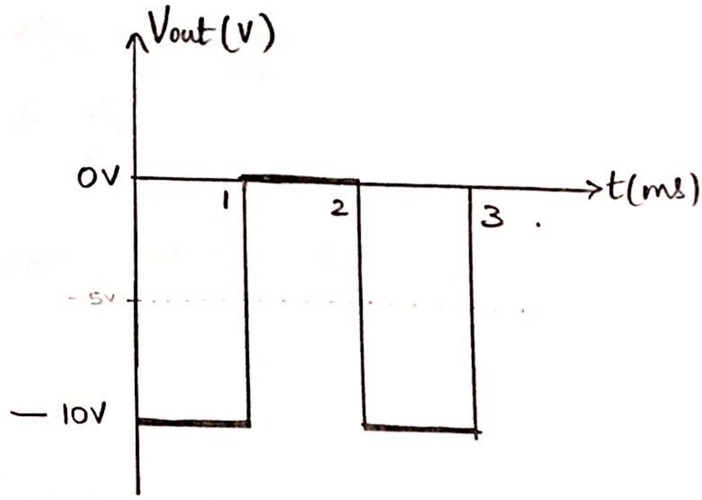
→ 2 pts for correct values.
→ 1 pt for graph

b) Sketch the *output waveform* for the following circuit, given the input waveform, Vin. Assume an ideal diode. [5pts]









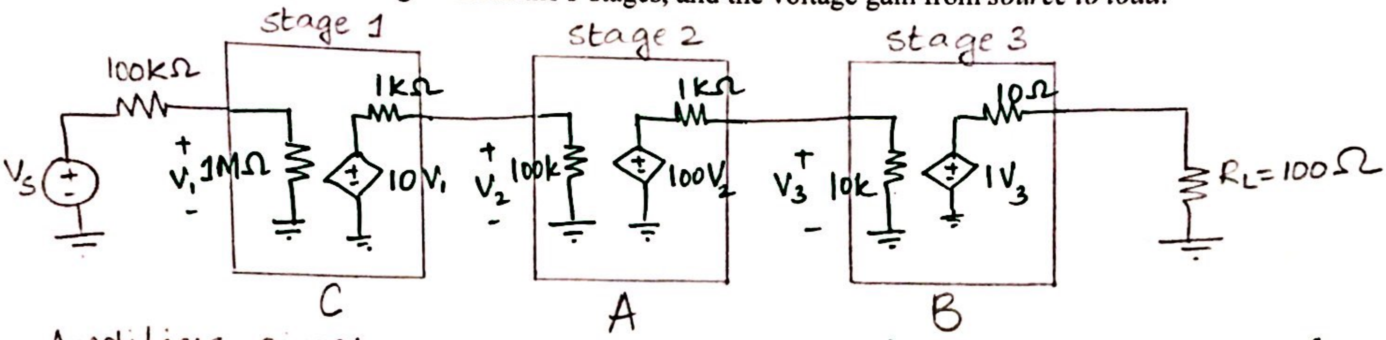
→ 2 pts for attempt
→ total 4 for correct values but shifted

HW prob # Exp. 1.3.

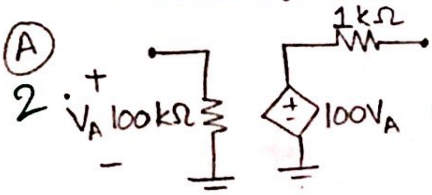
3) Cascaded Amplifier: 20pts [10pts]

Given the following 3 amplifiers, identify which one to use as the input stage, the output stage and the middle stage for a cascaded amplifier circuit.

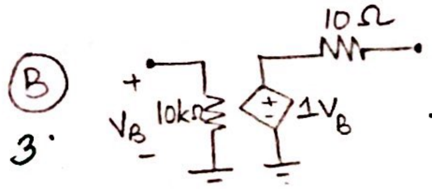
Connect your cascaded amplifier to a source with a 100kΩ internal resistance, and a load resistance of 100Ω and find the total gain from the 3 stages, and the voltage gain from *source to load.*



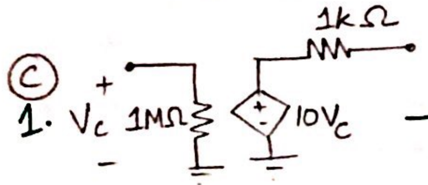
Amplifiers given:



→ middle (high gain).



→ o/p stage (low Ro.)



→ input stage (high Ri)

$$Av_1 = \frac{V_2}{V_1} = \frac{100k}{101k} \times \frac{10\cancel{V_1}}{\cancel{V_1}} = 9.9\,V/V$$

$$Av_2 = \frac{V_3}{V_2} = \frac{10k}{11k} \times \frac{100\cancel{V_2}}{\cancel{V_2}} = 90.9\,V/V$$

$$Av_3 = \frac{V_L}{V_3} = \frac{100}{110} \times \frac{1\cancel{V_3}}{\cancel{V_3}} = 0.909\,V/V$$

total V gain $= Av = Av_1 \cdot Av_2 \cdot Av_3 = \frac{V_L}{V_1} = \underline{818\,V/V}$

V gain from source to load $= \frac{V_L}{V_s} = Av \cdot \frac{V_1}{V_s}$

$$= 818 \cdot \left[\frac{\frac{1M\Omega}{1.1M\Omega} \times \cancel{V_s}}{\cancel{V_s}} \right]$$

$$= \underline{743.6\,V/V}$$

– 10pts for selecting correct amp.
– 5pts for finding any gain.

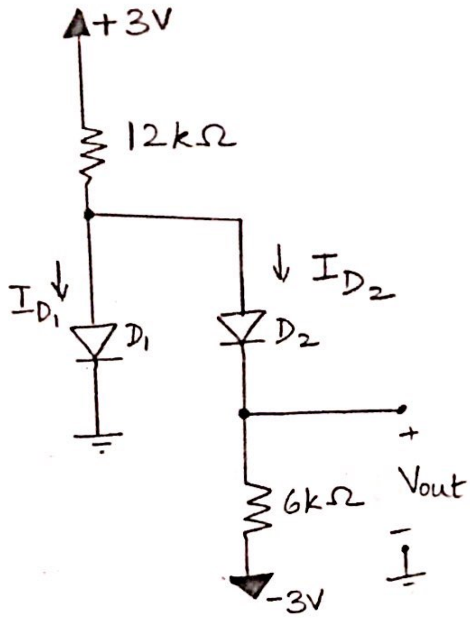
Variant of HW #4.38.
– Prob. # 4.9.

– attempt = 10 pts
– D_1 off, D_2 on = 5 pts
– solution = 5 pts.

4) Constant voltage drop model:

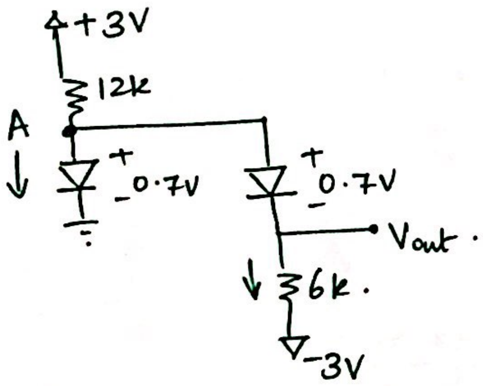
~~[10pts]~~ 20pts 6.

Solve for the diode currents and output voltage in the circuit below. Assume a constant voltage drop model for the diodes with $V_D = 0.7V$.



I_{D1} =	0A
I_{D2} =	294µA.
V_{out} =	– 1.23V.

① Assumption : $D_1, D_2 = FB$



$V_A = 0.7V$.

$V_A - V_{out} = 0.7V$

$\Rightarrow V_{out} = 0V$.

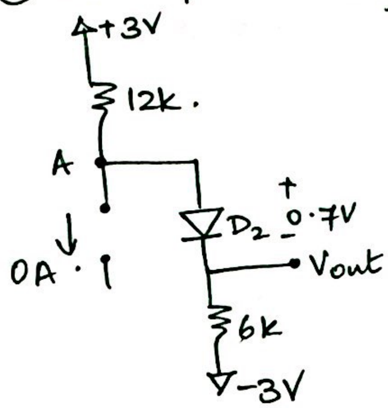
$\Rightarrow I_{D_2} = \frac{0-(-3)}{6k} = 500\mu A$.

$I_{12k} = \frac{3-0.7}{12k} = 191.6\mu A$.

$I_{D_1} = I_{12k} - I_{D_2}$.

$\Rightarrow I_{D_1}$ is –ve!! $\Rightarrow$ wrong assumption.

② Assumption : $D_1 = RB$, $D_2 = FB$.



$\Rightarrow I_{D_2} = I_{12k}$.

$= \frac{3-0.7-(-3)}{(12+6)k}$.

$= 294\mu A$.

$\Rightarrow V_{out} = I_{D_2} \cdot 6k - 3V$

$= -1.23V$.

$\Rightarrow V_A = 0.7 - 1.23$

$= -533mV$

$\Rightarrow D_1$ would be reverse biased.

& D_2 would be forward biased.

$\Rightarrow$ Validated assumption

& ~~$I_{D_1} = I_{12k} + I_{D_2}$~~

~~I_{12k}~~

HW prob # 4.56.

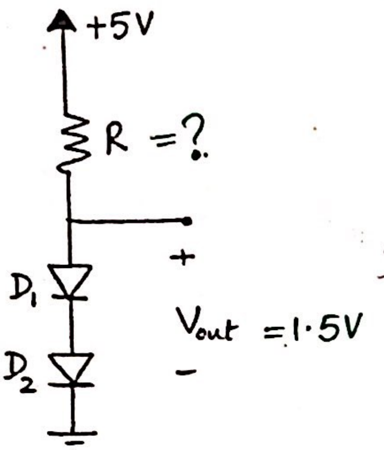
5) **Small signal model:** **[20pts]**

(10pts) a) Design the diode voltage regulator shown below such that it supplies 1.5V at no load, and fed from a +5V supply.

(5pts) b) Find the change in output voltage or line regulation for a ±0.5V change in the power supply voltage.

(5pts) c) Find the change in output voltage or load regulation for a 1mA load connected to it.

The diodes have a 0.7V drop at 1mA current. Use thermal voltage, $V_T = 25.9mV$ at room temperature.



Line regulation = ΔVout/ΔVin = 14.6 mV/V

Load regulation = $\Delta V_{out}/\Delta I_L$ = −7.52 V/A.

$V_{D_1} + V_{D_2} = 1.5V$

3 ✓ $\Rightarrow V_{D_1} = V_{D_2} = \frac{1.5}{2} = 0.75V$.

given: $V_D' = 0.7V$, $I_D' = 1mA$

3 ✓ $R = \frac{5 - V_{out}}{I_D} = \frac{5 - 1.5}{I_D} = \frac{3.5}{I_D}$.

3 ✓ $\frac{I_D''}{I_D'} = e^{\frac{V_D'' - V_D'}{V_T}}$

$\Rightarrow I_D'' = (1mA)\, e^{\left(\frac{0.75 - 0.7}{0.0259}\right)}$

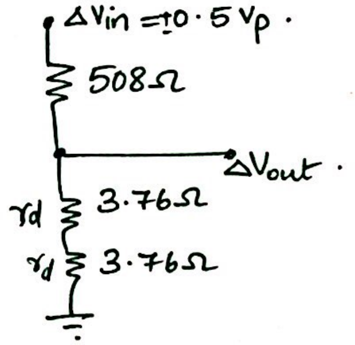
$= 6.89mA$.

1pt $\Rightarrow R = \frac{3.5}{6.89m} = 507.9 = 508\Omega$

Small signal model.

3 ✓ $r_d = \frac{V_T}{I_D} = \frac{0.0259}{6.89m} = 3.76\Omega$

$\Rightarrow$



$\Delta V_{out} = \Delta V_{in}\left(\frac{3.76 \times 2}{3.76 \times 2 + 508}\right)$

$= \pm 7.3\,mV_p$.

3 ✓ line reg $= \frac{\Delta V_{out}}{\Delta V_{in}} = \pm 14.6 mV/V$

3 ✓ load reg $= (\Delta I)(2 \times r_d)$

$= (-1m)(7.52)$

$= -7.52mV$

HW prob# 3.20.

7) PN junction

For a particular PN junction, the acceptor concentration is $10^{17}/cm^3$, and the donor concentration is $10^{16}/cm^3$. Given that $n_i = 1.5 \times 10^{10}/cm^3$, the diffusion lengths Lp = 5μm, Ln = 10μm, and the diffusion constants Dp = 10 cm^2/s, Dn = 18 cm^2/s. **[20pts]**

(5pts) a) What should be the cross sectional area of this PN junction diode so that there is 0.3mA current flowing through it when it is biased with 0.75V?

(10pts) b) Find the saturation current, and the barrier voltage for this diode.

(5pts) c) Sketch the I-V curve for this PN junction diode. Please note the saturation current, barrier voltage, and show an approx. breakdown region on the curve.

$N_A = 10^{17}/cm^3$.

$N_D = 10^{16}/cm^3$.

$I_D = 0.3mA$.

$V_D = 0.75V$.

3 ✓ $$I = Aqn_i^2\left(\frac{D_p}{L_pN_D} + \frac{D_n}{L_nN_A}\right)\left(e^{V/V_T} \cancel{-1}\right).$$ ignore.

$$0.3\times10^{-3} = A(1.6\times10^{-19}C)(1.5\times10^{10})^2\left(\frac{10}{(5\times10^{-4})(10^{16})} + \frac{18}{(10\times10^{-4})(10^{17})}\right)e^{\left(\frac{0.75}{0.0259}\right)}$$

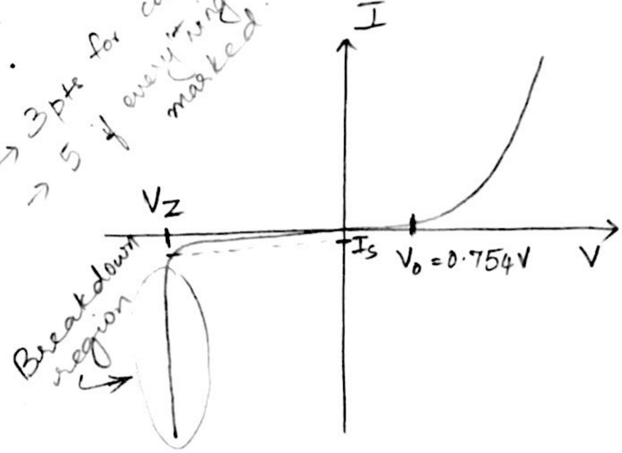
$\Rightarrow 0.3\times10^{-3} = A(78.48 \cancel{\times10^{-12}})(3.76\times10^{\cancel{+12}})$.

$\Rightarrow A = 1.017\times10^{-6}\ cm^2$

$= 102\times10^{-8}\ cm^2$

2 $= \underline{102\ \mu m^2}$

→ 3pts for curve
→ 5 if everything is marked.



5 ✓ $I_s = A(78.48\times10^{-12})$

$= \underline{79.8\times10^{-18}\ A}$ or $\underline{80\times10^{-18}\ A}$

5 ✓ $V_o = V_T \ln\left(\frac{N_AN_D}{n_i^2}\right) = 0.0259 \ln\left(\frac{10^{17}\times10^{16}}{(1.5\times10^{10})^2}\right) = \underline{754mV}$.