ECE 3040B Microelectronic Circuits

Grading Criteria

Math error but proper setup ~(-1/3)
Almost correct setup = ~(-2/3)
No Clue = (-100%)

Exam 1

February 9, 2001

Dr. W. Alan Doolittle

Time Required by Professor:
~ 30 minutes

Print your name clearly and largely: Key

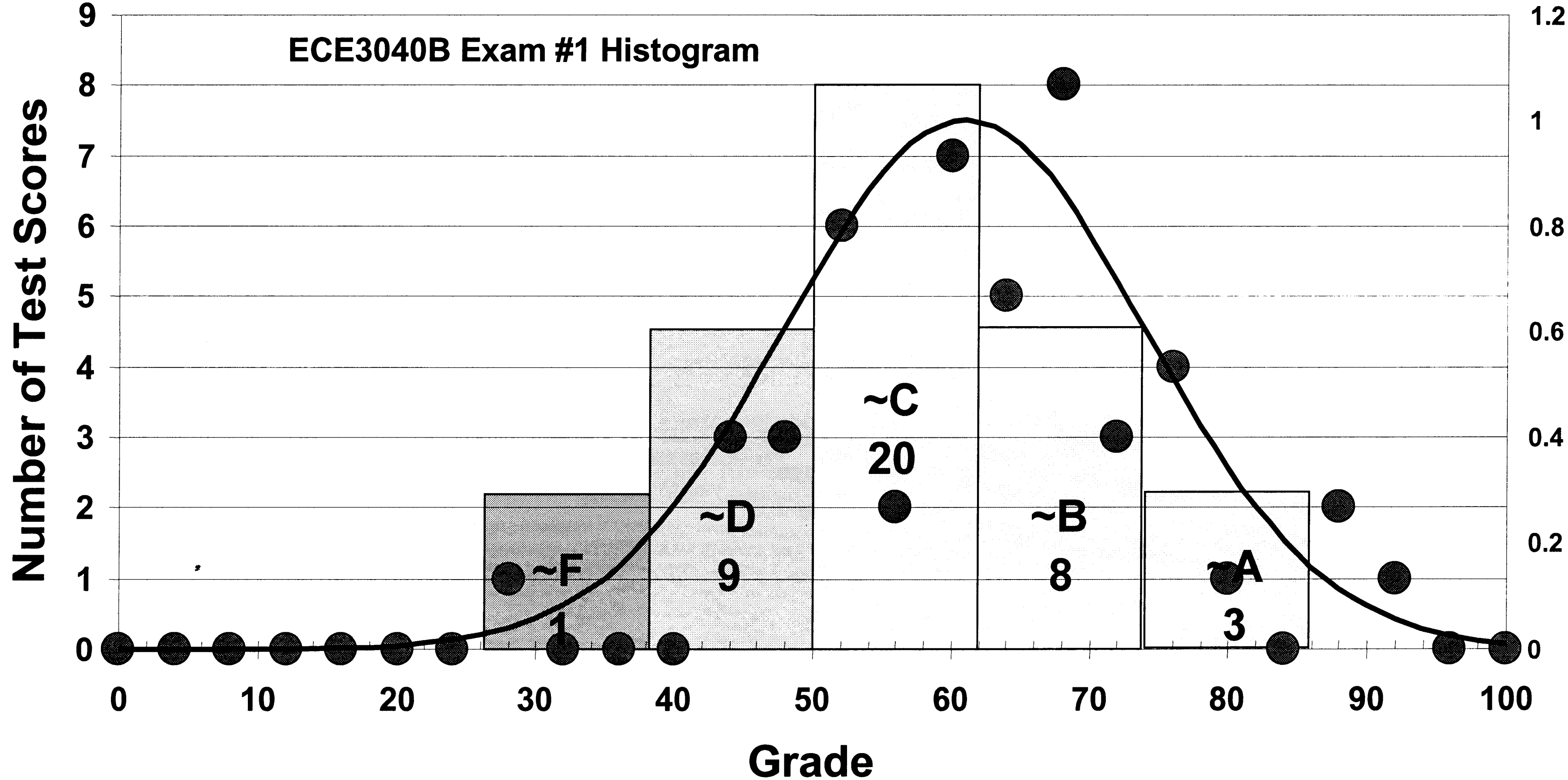
Instructions:
Read all the problems carefully and thoroughly before you begin working. You are allowed to use 2 sheets of notes (1 page front and back) as well as a calculator. There are 100 total points in this exam. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I can not read it, it will be considered to be a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on **ONE** of the two following cases:

I did not observe any ethical violations during this exam:

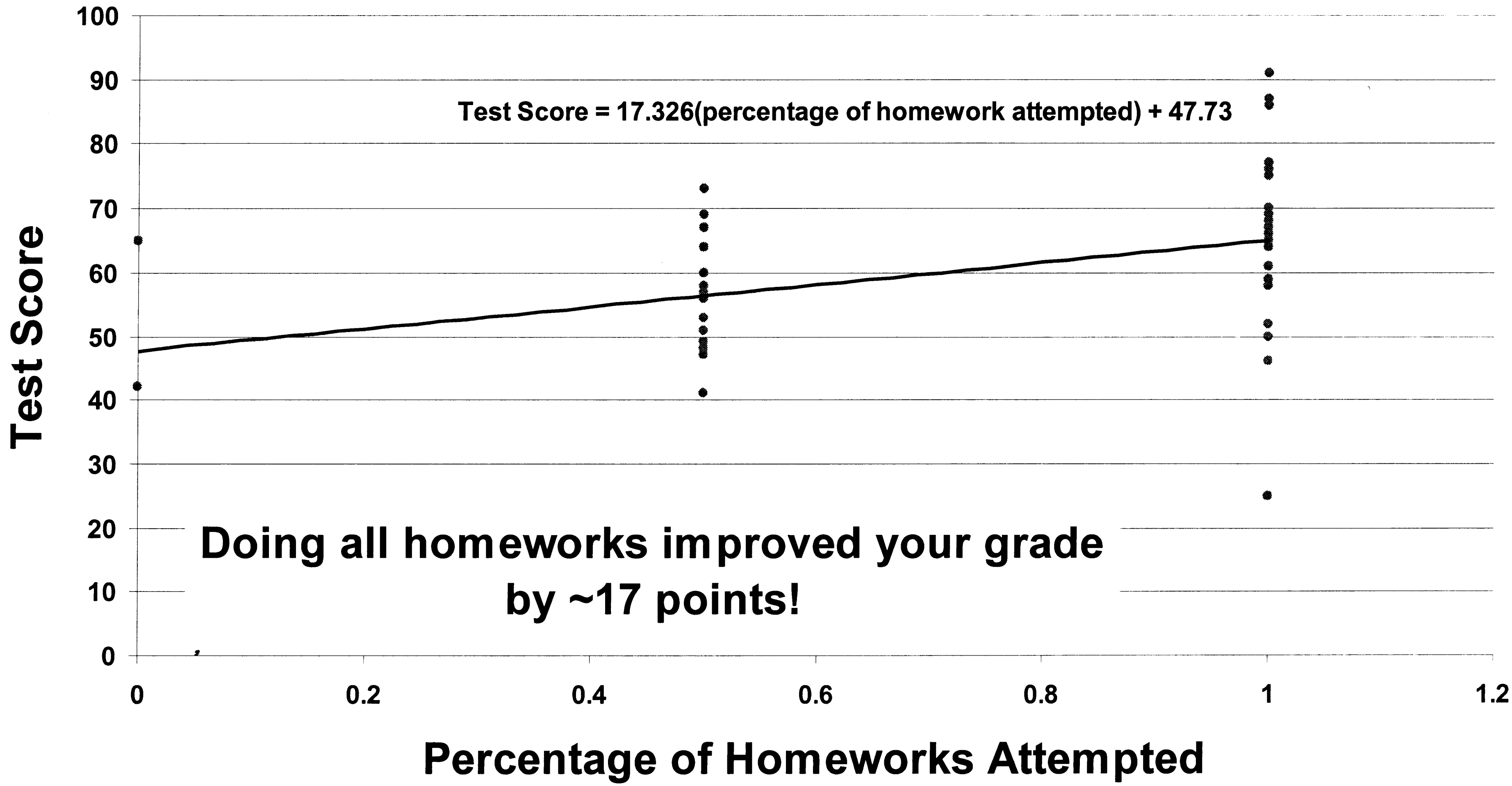
I observed an ethical violation during this exam:

Exam #1 Statistics



Exam #1 Statistics:

Effect of Doing Homework



Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15a	15b	15c	15d	15e	16
% Score per Question	93.5	97.8	95.7	95.7	69.6	97.8	30.4	63	60.9	89.1	65.7	86.7	88.7	60	63.3	78.7	69	65.2	40.8	25
1st 25%	79.3																			
2nd 25%	75.3																			
3rd 25%	63.4																			
4th 25%	25																			

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First 25%, True/False and Multiple choice: Circle the correct answer (only one)

1. (2 points) True or False: An insulator has a smaller energy bandgap than does a semiconductor.

2. (2 points) True or False: A p-type semiconductor has more electrons than holes.

3. (2 points) True or False: An intrinsic semiconductor has a higher number of donors than acceptors.

4. (2 points) True or False: Antimony (symbol Sb from group 5 of the periodic table) would act as a donor in silicon (symbol Si from group 4 of the periodic table).

5. (2 points) True or False: Silicon Carbide, SiC, is an example of an elemental semiconductor. (Both Si and C are from group 4 of the periodic table).

Select the **best** answer for 6-10.

6. (3 points) For a plane intersecting the coordinate axes at x=a, y=2a and z=3a, where a is the lattice constant, the Miller indexes are:
a.) (123)
b.) (321)
c.) (632)
d.) Not enough information to answer this problem.

7. (3 points) When a formerly intrinsic material is converted to an extrinsic material by doping with acceptors,
a.) There are more electrons than holes
b.) The fermi level is above the intrinsic energy
c.) There are fewer electrons than when the material was intrinsic.
d.) None of the above

8. (3 points) The electrons in an intrinsic material come from:
a.) Donors
b.) Acceptors
c.) Photogenerated by breaking the bonds that hold the atoms in the crystal together.
d.) Thermally generated by breaking the bonds that hold the atoms in the crystal together.
e.) The electron factory.
f.) None of the above

9. (3 points) The effective mass...
a.) ... of an electron is always smaller than the mass of an electron in a vacuum.
b.) ... of an electron is always larger than the mass of an electron in a vacuum.
c.) ... is different from the mass of an electron in a vacuum because it is physically smaller.
d.) ... is different from the mass of an electron in a vacuum because it sees different electrostatic potentials.
f.) ... is the same for electrons as it is for holes.

10. (3 points) A semiconductor doped with donors has it's fermi energy, E_f, above it's conduction band energy, E_c. This semiconductor ...
a.) ... is non-degenerate.
b.) ... is a compound semiconductor.
c.) ... is a degenerate semiconductor.
d.) ... obeys the minority carrier diffusion equations.
e.) ... is really messed up!

Second 25%, Short answer

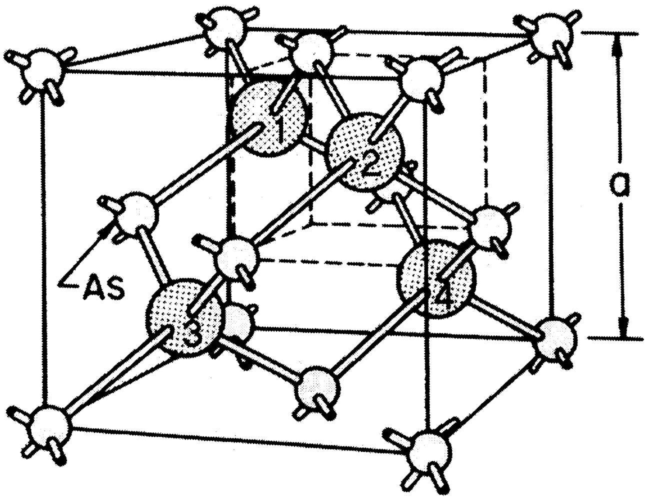
11. (5 points) A semiconductor has 12.5% of the atomic concentration Indium (In) with the rest of the material made up of Aluminum (Al) and Arsenic (As). What is the properly reduced semiconductor formula for this material? (By reduced, I mean put the formula in the format discussed in class, not the standard chemical equation.)

$In_{12.5\%}Al_{37.5\%}As_{50\%}$

$\Downarrow$ reduced

$In_{0.25}Al_{0.75}As$

12. (10 points) The figure below and to the right is the zincblende unit cell of the semiconductor in question (11). If the smaller atoms are arsenic, label the larger atoms numbered 1, 2, 3, and 4 as Al or In such that the structure is consistent with your answer in question 11. Note, your answer may or may not be unique and atoms 1, 2, 3, and 4 are all completely contained inside the unit cell.



ZINCBLENDE

Atom 1: In

Atom 2: Al

Atom 3: Al

Atom 4: Al

or any combination involving 1 In + 3 Al

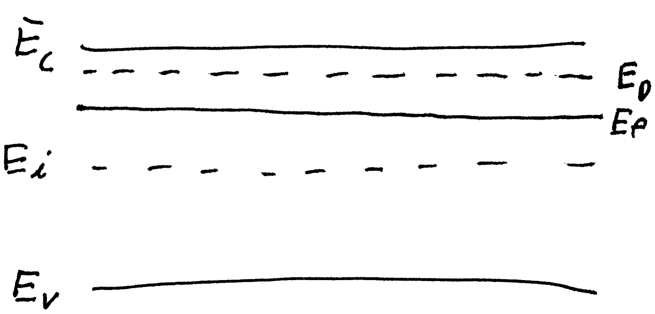
8 atoms/unit cell
½ of atoms must be group 5. These are all on cube faces and are As.
∴ 4 Large interior atoms must be group 3

13. (5 points) In equilibrium, what restriction is placed on the product of the electron concentration, n, and hole concentration, p regardless of doping concentrations?

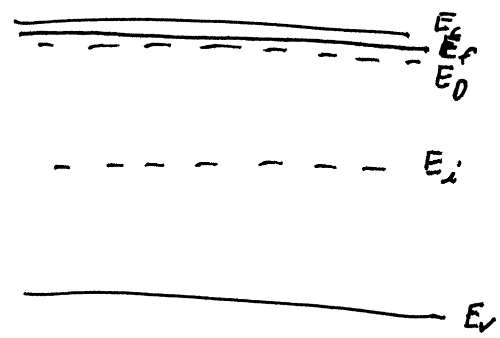
$np = n_i^2$

14. (5 points) If a material is doped with donors, draw the energy band diagram, labeling the conduction band energy E_c, the valence band energy E_v, the intrinsic energy E_i, the fermi energy E_f and the donor energy E_d at ...

(a)... room temperature assuming total ionization



(b) ...0 degrees Kelvin .



Third 25%, Problem Solutions

15. You are given the following information about a semiconductor sample at 27 degrees Celsius:

$N_a = 1.6e15\ cm^{-3}$ $\quad$ $N_d = 2e15\ cm^{-3}$
$m^*_n = 0.01m_o$ $\quad$ $m^*_p = 5m_o$ $\quad$ $E_g = 0.5\ eV$
$N_c = 2.51\times10^{19}\ (m^*_n / m_o)^{3/2}$ $\quad$ $N_v = 2.51\times10^{19}\ (m^*_p / m_o)^{3/2}$
$\mu_n = 2000\ cm^2/Vsecond$ $\quad$ $\mu_p = 500\ cm^2/Vsecond$
Cross sectional area 0.01 cm^2 by 1 cm long

a.(8 points) Find the intrinsic, electron and hole concentration (assume total ionization)

$$n_i = \sqrt{N_c N_v}\, e^{-E_g/2kT} \Rightarrow n_i = \sqrt{\left[2.51\times10^{19}(0.01)^{3/2}\right]\left[2.51\times10^{19}(5)^{3/2}\right]}\; e^{-0.5/(0.0259 \cdot 2)}$$

$$= 2.65e18\, e^{-9.65}$$

$$\boxed{n_i = 1.7e14\ cm^{-3}} \approx (N_D - N_A)$$

$$\boxed{n = \left(\frac{N_D - N_A}{2}\right) + \sqrt{\left(\frac{N_D - N_A}{2}\right)^2 + n_i^2}}$$

$$n = \frac{(2.0e15 - 1.6e15)}{2} + \sqrt{\left(\frac{2e15 - 1.6e15}{2}\right)^2 + (1.7e14)^2}$$

$$= 2e14 + \sqrt{(2e14)^2 + (1.7e14)^2}$$

$$\boxed{n = 4.6e14\ cm^{-3}}$$

$$p = \frac{n_i^2}{n} = \frac{(1.7e14)^2}{4.6e14} \approx \cancel{6.}$$

$$\boxed{p = 6.25e13\ cm^{-3}}$$

b.(5 points) Find the intrinsic energy.

$$E_i = \frac{E_g}{2} + \frac{3}{4} kT \ln\left(\frac{m_p^*}{m_n^*}\right)$$

$$= 0.25 + 0.75(0.0259)\ln\left(\frac{5}{0.01}\right)$$

$$\boxed{E_i = 0.37\ eV} \neq E_g/2$$

c.(4 points) Find the fermi energy position relative to the intrinsic energy.

$$(E_f - E_i) = kT \ln\left(\frac{n}{n_i}\right) \neq kT \ln\left(\frac{N_D}{n_i}\right)$$

because $N_D \sim n_i$

$$= 0.0259 \ln\left(\frac{4.6e14}{1.7e14}\right)$$

$$\boxed{E_f - E_i = 0.0258\ eV}$$

d.(4 points) The resistance of a piece of material..

$$\rho = \frac{1}{q(2000(4.6e14) + 500(6.3e13))} = \frac{1}{q(\mu_n n + \mu_p p)}$$

$$= 6.57\ \Omega\text{-cm}$$

$$R = \frac{\rho L}{A} = \frac{6.57(1)}{0.01} \Rightarrow \boxed{R = 657\ \Omega}$$

e.(4 points) The hole drift velocity of the sample when 1000 volts are applied along the sample's length.

$$\vec{E} = V/cm = \frac{1000\ V}{1\ cm}$$

$$v_d = \mu_p \vec{E}$$

$$= 500(1000)$$

$$\boxed{v_d = 5 \times 10^5\ cm/sec}$$

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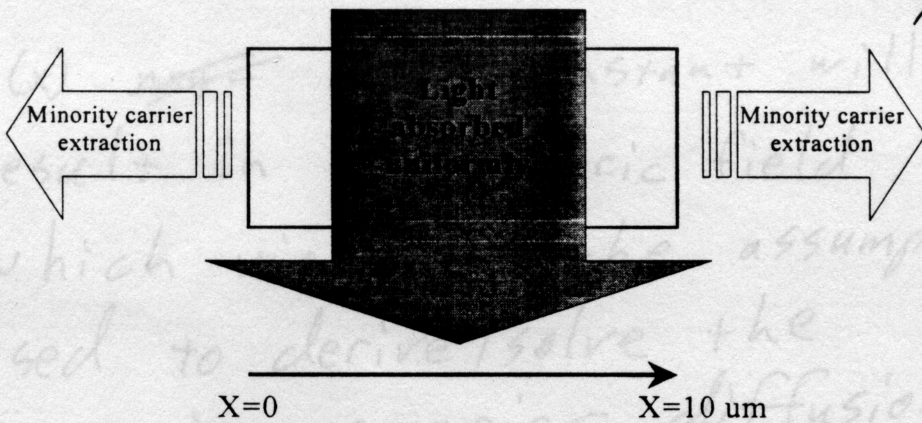
Fourth 25%, Problem Solutions

16. (25 points) A single "pixel" from semiconductor camera (a CCD camera) has a 10 μm long region of silicon that is at 27 degrees C, is in non-equilibrium and is uniformly doped. The material is p-type, is doped with 10^{16} cm^{-3} acceptors, and has a minority carrier lifetime that is long enounugh to neglect recombination when compared with the deminsions of the material. $\Rightarrow \cancel{\frac{\Delta n_p}{\tau}} \rightarrow 0$

The electron mobility is 500 cm^2/VSecond and the intrinsic concentration is 1e10 cm^{-3}. The material is continuously illuminated with light for a very long time. $\cancel{\frac{\partial \Delta n_p}{\partial t}} \rightarrow 0$ The light is uniformly absorbed throughout the volume of the semiconductor. The light generates 10^{17} cm^{-3} per second extra ***holes***. Minority carriers are extracted from the sample at x=0 and x=10 μm maintaining the minority carrier concentration at a constant value equal to the equilibrium minority carrier concentration at both edges of the material. Write an numerical expression (no unknowns) for the minority carrier concentration as a function of position. (The distance variable, "x" should be the only alphabetic variable in your answer. I.E. no unsolved constants.)



$$\cancel{\frac{\partial \Delta n_p}{\partial t}}^{\,0} = D_n \frac{\partial^2 \Delta n_p}{\partial x^2} - \cancel{\frac{\Delta n_p}{\tau_n}}^{\,0} + G_L$$

$$\boxed{\begin{aligned} D_n &= \mu_n \left(\frac{kT}{q}\right) \\ &= 500\ \text{cm}^2/\text{Vsec}\ (0.0259\text{V}) \\ &= 12.95\ \text{cm}^2/\text{sec} \end{aligned}}$$

$$\frac{d^2 \Delta n_p}{dx^2} = \frac{-G_L}{D_n} = -\left(\frac{1e17}{12.95}\right) = -7.72e15$$

$$\frac{d \Delta n_p}{dx} = \frac{-G_L}{D_n} x + A$$

$$\therefore \quad \Delta n_p(x) = -\frac{G_L}{2D_n} x^2 + Ax + B$$

$$\text{B.C.:} \quad \Delta n_p(x=0) = \Delta n_p(x=10\,\mu m) = n_o = \frac{n_i^2}{p_o} = \frac{(1e10)^2}{1e16} = \cancel{1e4\ \text{cm}^{-3}} = 0$$

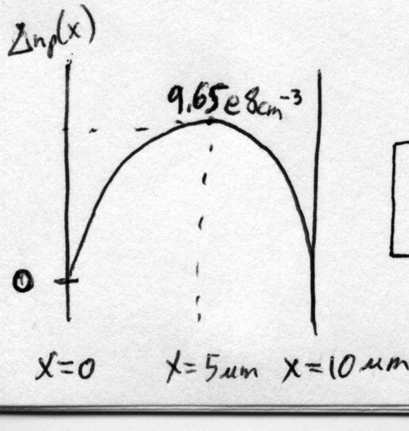
$$\Rightarrow \Delta n_p(x=0) = \cancel{1e4} = B = 0$$

$$\Rightarrow \Delta n_p(x=10\,\mu m) = -\frac{G_L}{2D_n}(1e\text{-}3)^2 + A(1e\text{-}3) = 0$$

$$A = +\frac{G_L}{2D_n}(1e\text{-}3) = +3.86 \times 10^{12}$$

Final Answer Resis ....

$$\boxed{\therefore \quad \Delta n_p(x) = -3.86e15\, x^2 + 3.86e12\, x \ \text{cm}^{-3}}$$



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Bonus: (5 points) In problem 16, could you solve the problem if the equilibrium carrier concentration was given as,

$$p(x)=10^{18}\, e^{(-x/(2\text{ um}))}\ \text{cm}^{-3}$$

Support your answer.

p(x) ~~not~~ not constant will result in an Electric field which violates the assumptions used to derive/solve the minority carrier diffusion equation.