

You must provide your name on the answer sheet. In addition, you are asked to voluntarily "provide" your social security number in order to verify your identity and avoid confusion between "two students" with the same name. Your social security number is sought for identification purposes pursuant to Public Law 93-579 and is being used as part of a system of "student" records that has been in effect prior to 1970. If you do not want to provide your social security number, you must write on the answer form an alternative identifier. [An alternative choice "would be" the University 'Net-ID' (network identification name) or the 9-digit blue number on each person's I-card].

ECE 340 – Spring 2003

Name sol'n

Net ID# _____

Section _____

ECE 340 - EXAM No. 1

Thursday February 27, 2003

7:00-9:00 p.m.

ROOM ASSIGNMENTS

Room 124 Burrill Hall

G. Timp, Section A

Room 112 Chem Annex

K. Kim, Section C

C. Liu, Section E

Room 213 Gregory Hall

K.C. Hsieh, Section X

J. Tucker, Section G

Conflict Exam #1 – Thursday, February 27, 2003, 4:00-6:00 p.m.

Room 365 Everitt Lab.

NOTE: This is a closed book and closed notes exam. Unless stated otherwise, do your work on the page of the problem and if necessary on the preceding blank page. It is mandatory that proper units be included explicitly along with the numerical value for each term in a quantitative calculation, showing how the units of the final answers are derived. Failure to do this will result in no credit. Circle your answer. Be neat!

For each problem, you must show complete work and indicate your reasoning. No credit will be given if you do not show the complete work and describe your procedure, even if the answer is correct. Write your name, ID#, and section on this page and sign below.

	1-4	5	6	7-10	11
	20 pts.	20 pts.	20 pts.	20 pts.	20 pts.
a	---	7	4	---	5
b	---	7	5	---	5
c	---	6	6	---	6
d	---	---	5	---	4
e	---	---	---	---	---
T					

Signature: _____

Your Exam Score: _____

You must give a reason along with your answer to receive ANY credit.

1. (5 points) What is the probability that a state $3kT$ below the Fermi level will be occupied by a hole assuming that the Fermi-Dirac distribution holds?

- (a) 0.00
 (b) 0.0474
 (c) 0.453
 (d) 0.953
 (e) none of the above

The probability for an electron to occupy a state $3kT$ below the Fermi level is

$$f(E) = \frac{1}{1 + \exp\left(\frac{E - E_F}{kT}\right)}$$

$$= \frac{1}{1 + \exp\left(\frac{-3kT}{kT}\right)} = \frac{1}{1 + \exp(-3)} = 0.953$$

Therefore the probability for a hole to occupy that state

$$\text{is } 1 - f(E) = 1 - 0.953 = 0.0474$$

2. (5 points) A silicon sample is doped $1.0000 \times 10^{15} \text{ cm}^{-3}$ with Phosphorus and $9.9999 \times 10^{14} \text{ cm}^{-3}$ with Boron. Assume that the intrinsic concentration is $n_i = 1.5 \times 10^{10} \text{ cm}^{-3}$ at room temperature. What is the hole concentration at room temperature?

- (a) $p = 2.08 \times 10^{10} \text{ cm}^{-3}$
 (b) $p = 9.99 \times 10^{14} \text{ cm}^{-3}$
 (c) $p = 1.08 \times 10^{10} \text{ cm}^{-3}$
 (d) $p = 1.00 \times 10^{15} \text{ cm}^{-3}$
 (e) $p = 1.00 \times 10^{10} \text{ cm}^{-3}$

charge neutrality requires

$$n_0 + N_A = p_0 + N_D$$

$$\Rightarrow n_0 + 9.9999 \times 10^{14} = p_0 + 1 \times 10^{15}$$

$$\therefore n_0 = p_0 + 1 \times 10^{10} \quad \text{--- (1)}$$

$$\text{also } n_0 p_0 = n_i^2 = (1.5 \times 10^{10})^2 \quad \text{--- (2)}$$

Solve (1) & (2)

$$\Rightarrow p_0 \cdot (p_0 + 1 \times 10^{10}) = 2.25 \times 10^{20}$$

$$\Rightarrow p_0 = \frac{-1 \times 10^{10} + \sqrt{(1 \times 10^{10})^2 + 4 \times 2.25 \times 10^{20}}}{2}$$

$$= \left(\frac{-1 + \sqrt{10}}{2} \right) \times 10^{10}$$

$$= 1.08 \times 10^{10} / \text{cm}^3$$

3. (5 points) The resistivity of a silicon wafer measured at 300K is found to be $8 \Omega\text{-cm}$. The impurity concentration, N_i , in this wafer is approximately: (circle the closest answer)

- (a) $N_i = 1 \times 10^{15} \text{cm}^{-3}$
 (b) $N_i = 1 \times 10^{16} \text{cm}^{-3}$
 (c) $N_i = 1 \times 10^{17} \text{cm}^{-3}$
 (d) $N_i = 1 \times 10^{18} \text{cm}^{-3}$
 (e) $N_i = 1 \times 10^{19} \text{cm}^{-3}$

$$\rho = \frac{1}{\sigma} = \frac{1}{q(n\mu_n + p\mu_p)}$$

$$\Rightarrow n\mu_n + p\mu_p = (q \times \rho)^{-1} = (1.6 \times 10^{-19} \times 8)^{-1} = 7.8125 \times 10^{17} \Omega\text{-cm}^{-1}$$

if it were n-type

$$\Rightarrow n\mu_n \approx 7.8 \times 10^{17}$$

$$n = 2 \times 10^{15}, \mu_n = 1260, n\mu_n = 2.5 \times 10^{18}$$

$$n = 1 \times 10^{15}, \mu_n = 1320, n\mu_n = 1.3 \times 10^{18}$$

$$n = 8 \times 10^{14}, \mu_n = 1330, n\mu_n = 1.06 \times 10^{18}$$

$$\odot n = 6 \times 10^{14}, \mu_n = 1340, n\mu_n = 8 \times 10^{17}$$

$$n = 4 \times 10^{14}, \mu_n = 1350, n\mu_n = 5.4 \times 10^{17}$$

if it were p-type

$$\Rightarrow p\mu_p \approx 7.8 \times 10^{17}$$

$$p = 1 \times 10^{16}, \mu_p = 400, p\mu_p = 4 \times 10^{18}$$

$$p = 4 \times 10^{15}, \mu_p = 430, p\mu_p = 1.7 \times 10^{18}$$

$$\odot p = 2 \times 10^{15}, \mu_p = 450, p\mu_p = 9 \times 10^{17}$$

$$p = 1 \times 10^{15}, \mu_p = 460, p\mu_p = 4.6 \times 10^{17}$$

In either case, $N_{\text{impurity}} = 1 \times 10^{15} / 3$ is the most reasonable choice.

4. (5 points) The intrinsic carrier concentration found in Ge at room temperature is approximately a factor of 10^7 larger than the intrinsic concentration found in GaAs. This difference is largely due to:

- (a) The light effective electron and hole masses in GaAs relative to those found in Ge and the corresponding difference in the effective density of states
 (b) The difference in the diamond (Ge) and zinc-blende (GaAs) lattice structure
 (c) The ratio of the heavier hole mass compared to the electron mass in Ge, and the associated displacement of the intrinsic Fermi level from the center of the band gap.
 (d) The difference in the band gap energy between Ge and GaAs
 (e) The direct bandgap found in GaAs versus the indirect bandgap in Ge

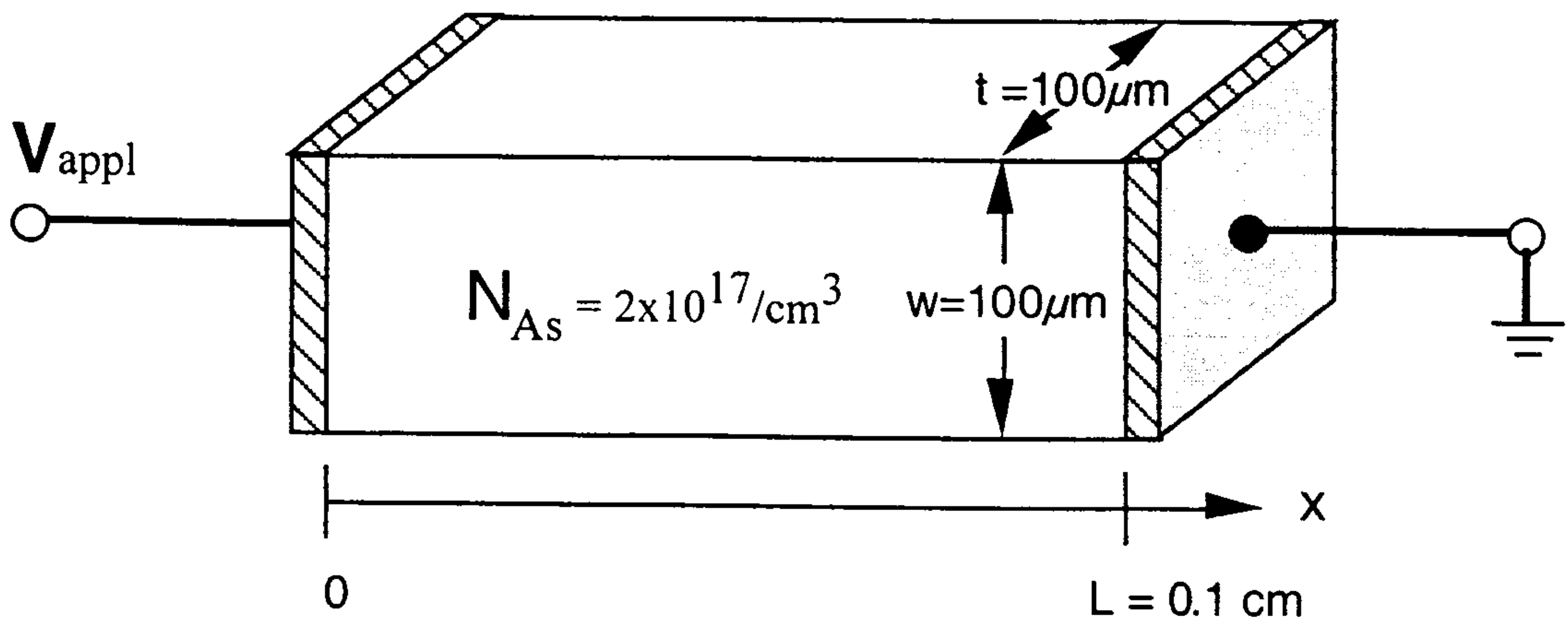
$$\odot n_i = \sqrt{N_c N_v} \exp(-E_g / 2kT)$$

$$\text{where } N_c = 2 \left(\frac{2\pi m_n^* kT}{h^2} \right)^{3/2}$$

$$N_v = 2 \left(\frac{2\pi m_p^* kT}{h^2} \right)^{3/2}$$

Since m_n^* and m_p^* may vary among different crystals but not as drastically as the dependence of E_g which is exponential, E_g difference results in the big difference of intrinsic carrier concentration between GaAs and Ge.

A small Si bar at 300 K is uniformly doped with As at $2 \times 10^{17} / \text{cm}^3$ as sketched below.



- (a) (7 points) Determine the average drift velocity of the carriers (including sign) for $V_{\text{appl}} = 5.0$ volts. Use your result to calculate the current density inside the bar.

$$\mu_n \approx 600 \frac{\text{cm}^2}{\text{V}\cdot\text{s}} \text{ for } N_d + N_a \sim 2 \times 10^{17} / \text{cm}^3 \text{ in Si}$$

$$\text{and } \mathcal{E}_x = \frac{V_{\text{appl}}}{L} = \frac{5.0 \text{ V}}{0.1 \text{ cm}} = 50 \frac{\text{V}}{\text{cm}}$$

$$\begin{aligned} V_{\text{drift}} &= -\mu_n \mathcal{E}_x = -600 \frac{\text{cm}^2}{\text{V}\cdot\text{s}} \cdot 50 \frac{\text{V}}{\text{cm}} \\ &= -30000 \frac{\text{cm}}{\text{s}} \\ &= -3 \times 10^4 \frac{\text{cm}}{\text{s}} \end{aligned}$$

$$\begin{aligned} J_x &= J_n(\text{drift}) = -q n V_n^{\text{drift}} \\ &= (-1.6 \times 10^{-19} \text{ C}) \cdot (2 \times 10^{17} \text{ cm}^{-3}) \cdot (-3 \times 10^4 \frac{\text{cm}}{\text{sec}}) \\ &= 9.6 \times 10^2 \frac{\text{A}}{\text{cm}^2} \end{aligned}$$

$$V_d = -3 \times 10^4 \frac{\text{cm}}{\text{s}}$$

$$I/A = J = 9.6 \times 10^2 \frac{\text{A}}{\text{cm}^2}$$

(b) (7 points) Calculate the conductivity of the bar and its resistance.

$$\begin{aligned}\sigma &= q n_o \mu_n \\ &= (1.6 \times 10^{-19} \text{ C}) \times (2 \times 10^{17} \text{ cm}^{-3}) \times (600 \frac{\text{cm}^2}{\text{Vs}}) \\ &= 19.2 \frac{\text{C}}{\text{V} \cdot \text{s} \cdot \text{cm}} = 19.2 \left(\frac{\text{Amp}}{\text{V} \cdot \text{cm}} \right) = 19.2 \left(\frac{1}{\Omega \cdot \text{cm}} \right)\end{aligned}$$

$$\begin{aligned}R &= \rho \frac{l}{A_{\text{cm}}} \\ &= \frac{1}{\sigma} \cdot \frac{l}{A} \\ &= \frac{1 \text{ cm}}{19.2} \cdot \frac{0.1 \text{ cm}}{(100 \times 10^{-4} \text{ cm}) \times (100 \times 10^{-4} \text{ cm})} \\ &= \frac{1000}{19.2} \Omega \\ &= 52.1 \Omega\end{aligned}$$

(c) (6 points) If a second uniform doping density $N_{\text{Ga}} = 1 \times 10^{17} / \text{cm}^3$ has been added to the bar in addition to $N_{\text{As}} = 2 \times 10^{17} / \text{cm}^3$, how would the following quantities be affected (higher or lower) and why?

	Higher/lower	why
Carrier density :	<div style="border: 1px solid black; padding: 5px; display: inline-block;">lower</div>	because $n_o = N_d - N_a = 1 \times 10^{17} / \text{cm}^3$
Mobility:	<div style="border: 1px solid black; padding: 5px; display: inline-block;">lower</div>	because there are more ion scattering due to the larger sum of $N_A + N_d = 3 \times 10^{17} / \text{cm}^3$
Conductivity:	<div style="border: 1px solid black; padding: 5px; display: inline-block;">lower</div>	because both carrier density and mobility are lower

6. A piece of Si sample is doped with $5 \times 10^{18} \text{ cm}^{-3}$ donor and $2 \times 10^{18} \text{ cm}^{-3}$ acceptor. At room temperature (300K) and under thermal equilibrium, the sample is an extrinsic material. Under thermal equilibrium, the thermal generation and recombination rate is $3.375 \times 10^8 \text{ EHP/cm}^3/\text{s}$.

At $t=0$, it is illuminated with a steady flash of light with the energy exceeding that of the bandgap. Under steady state, the excess EHP concentration is $2 \times 10^{16} \text{ cm}^{-3}$. At $t=10 \text{ s}$, the light is suddenly turned off. Direct recombination is assumed.

- (a) (4 points) Find the electron and hole concentrations under steady light illumination ($0 < t < 10 \text{ s}$).

$$N_D - N_A = 5 \times 10^{18} - 2 \times 10^{18} = 3 \times 10^{18} / \text{cm}^3 \gg n_i$$

$$\Rightarrow n_0 \approx 3 \times 10^{18} / \text{cm}^3 \quad \therefore p_0 = \frac{n_i^2}{3 \times 10^{18}} = 75 / \text{cm}^3$$

At steady state

$$\begin{aligned} n &= n_0 + \Delta n_{ss} \\ &= 3 \times 10^{18} + 2 \times 10^{16} \\ &= 3.02 \times 10^{18} / \text{cm}^3 \end{aligned}$$

$$\begin{aligned} p &= p_0 + \Delta p_{ss} \\ &= 75 + 2 \times 10^{16} \\ &= 2 \times 10^{16} / \text{cm}^3 \end{aligned}$$

- (b) (5 points) Find the hole recombination lifetime (τ_p).

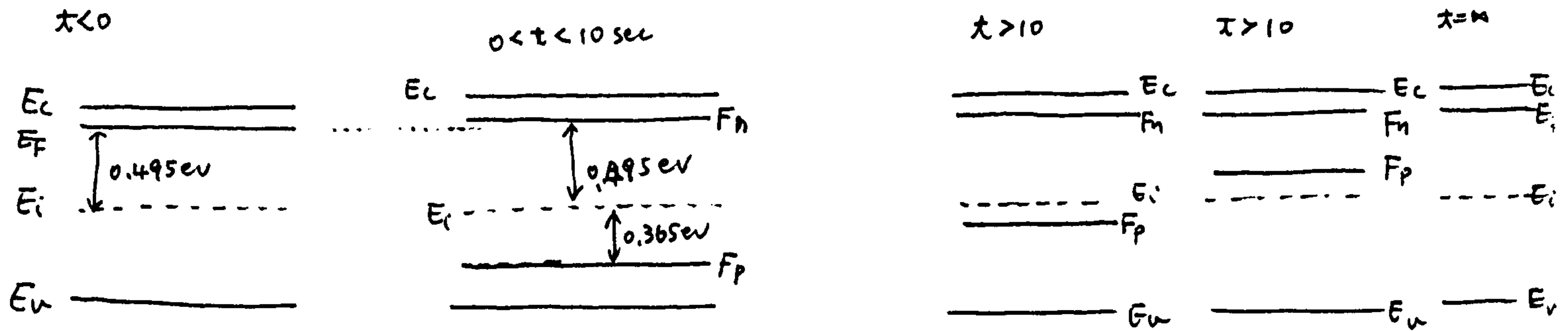
$$g_{th} = r_{th} = 3.375 \times 10^8 = \alpha_r \cdot n_0 \cdot p_0 = \alpha_r \cdot n_i^2 = \alpha_r \cdot 2.25 \times 10^{20}$$

$$\Rightarrow \alpha_r = 1.5 \times 10^{-12} \left(\frac{\text{cm}^3}{\text{sec}} \right)$$

$$\tau_p = \frac{1}{\alpha_r \cdot (n_0 + p_0)} = \frac{1}{1.5 \times 10^{-12} \cdot 3 \times 10^{18}} = 2.22 \times 10^{-7}$$

$$= 0.222 \mu\text{s}$$

- (c) (6 points) Plot the energy band diagram of the Si sample for three phases: $t < 0$, $0 < t < 10\text{s}$, and $t > 10\text{s}$. Draw E_c , E_v , E_i , and all Fermi levels. For the second phase, find the difference between two quasi Fermi levels.



$$E_F - E_i = kT \ln \frac{n_0}{n_i}$$

$$= kT \ln \frac{3 \times 10^{18}}{1.5 \times 10^{10}}$$

$$= 0.495 \text{ eV}$$

$$F_n - E_i = kT \ln \frac{n}{n_i}$$

$$= kT \ln \frac{3.02 \times 10^{18}}{1.5 \times 10^{10}}$$

$$= 0.495 \text{ eV}$$

$$-(F_p - E_i) = kT \ln \frac{p}{n_i}$$

$$= kT \ln \frac{2 \times 10^{16}}{1.5 \times 10^{10}}$$

$$= 0.365 \text{ eV}$$

$$F_n - F_p = 0.86 \text{ eV}$$

Depending on time elapsed
both quasi-Fermi-level approach
and merge with the equilibrium Fermi
level.

- (d) (5 points) Find the time t at which the minority carrier concentration equals the intrinsic value.

$$\delta p(x) = \delta p(x=0) e^{-x/\tau_p}$$

$$\text{for } n_i = 2 \times 10^{16} e^{-x/\tau_p}$$

$$\Rightarrow x/\tau_p = \ln \frac{2 \times 10^{16}}{1.5 \times 10^{10}}$$

$$= 14.1$$

$$\Rightarrow t = 14.1 \times \tau_p$$

$$= 3.13 \mu\text{s}.$$

7. A Si sample is doped with donors such that $n_0(x) = Gx^2$ for $1 \mu\text{m} < x < 100 \mu\text{m}$ and $n_0(x) \gg n_i$, where G is a constant $= 10^{12} / \text{cm}^5$. Find the built-in electric field in the sample at $x = 3 \mu\text{m}$ at 300 K. Provide the answer in unit of V/cm.

- (a) + 260
(b) - 260
(c) - 170
(d) - 85
(e) None of the above

$$n = n_i \exp \frac{E_F - E_i}{kT}$$

$$\Rightarrow \frac{\partial n}{\partial x} = n \cdot \frac{1}{kT} \cdot \frac{\partial (E_F - E_i)}{\partial x}$$

at equilibrium E_F is uniformly indep of position

$$\therefore \frac{\partial E_F}{\partial x} = 0$$

$$\Rightarrow \frac{1}{n} \frac{\partial n}{\partial x} = \frac{1}{kT} \left(- \frac{\partial E_i}{\partial x} \right)$$

$$= \frac{q}{kT} \left(\frac{-1}{q} \frac{\partial E_i}{\partial x} \right) = \frac{-q}{kT} \bar{E}(x)$$

$$\text{or } \bar{E}(x) = - \frac{kT}{q} \cdot \frac{1}{n} \left(\frac{\partial n}{\partial x} \right)$$

$$\therefore \bar{E}(x) = -0.0259 \cdot \frac{1}{Gx^2} \cdot 2Gx$$

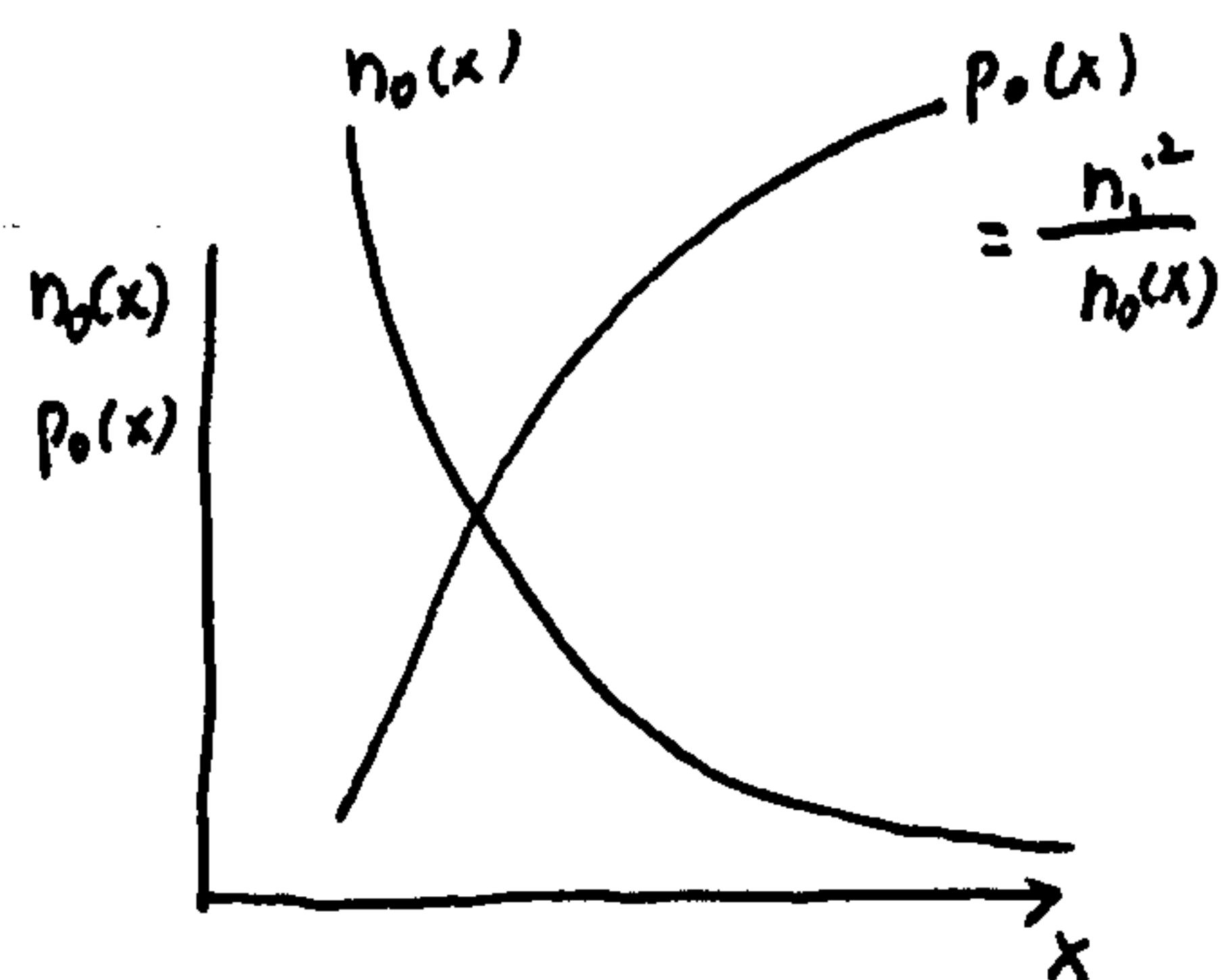
$$= \frac{-0.0259 \cdot 2}{x}$$

$$\text{at } x = 3 \mu\text{m} = 3 \times 10^{-4} \Rightarrow \bar{E}(x) = - \frac{259 \times 2}{3}$$

$$= -170 \frac{\text{V}}{\text{cm}}$$

8. An n-type semiconductor has the electron concentration distribution $n_0(x) = G/x^2$ at equilibrium ($1 \mu\text{m} < x < 100 \mu\text{m}$). What are the directions of the electron and hole current densities in the sample assuming that the arrow pointing to right means +x direction and the arrow pointing to left means -x direction.

	J_n (diff)	J_n (drift)	J_p (diff)	J_p (drift)
(a)	←	→	←	→
(b)	←	←	←	←
(c)	→	←	←	→
(d)	→	←	→	→
(e)	→	→	→	→

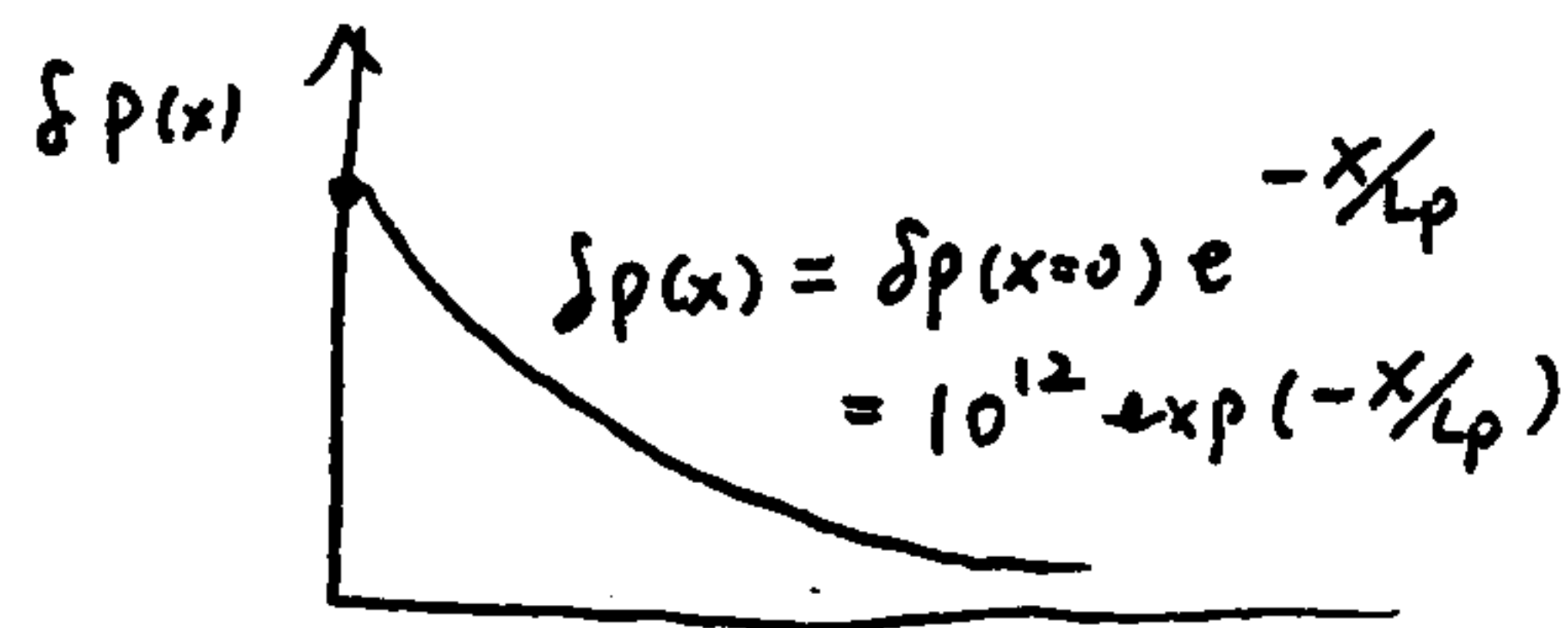


- Based on the carrier profile, electron particles diffuse to +x which implies J_n^{diff} is in "-x" direction. At equilibrium $J_n^{\text{diff}} + J_n^{\text{drift}} = 0 \Rightarrow J_n^{\text{drift}}$ is in "+x".
- Similarly one can identify the current flow of hole. Since $p_i = \frac{n_i^2}{n_0}$, one finds the concentration of hole is higher on the right. Therefore hole diffuses "-x" so is the hole diffusion current. Again $J_p^{\text{diff}} + J_p^{\text{drift}} = 0 \Rightarrow J_p^{\text{drift}}$ is in "+x". So the answer is (a)

9. Holes are injected at $x = 0$ into a semi-infinite n-type semiconductor sample extending to $x = \infty$ at a constant rate so that the excess hole concentration at $x = 0$ remains at 10^{12} cm^{-3} . If the hole mobility and recombination lifetime are $500 \text{ cm}^2/\text{V-s}$ and $1 \mu\text{s}$, respectively, answer the following two questions. The sample is at 300 K .

9-1. Determine the location in the sample where the excess hole concentration has reduced to $1/e (= e^{-1})$ of the value at $x = 0$. Give the answer in unit of μm .

- (a) 3.6
(b) 9.5
(c) 36
(d) 95
(e) 0.4



at $x = 1 L_p$ the excess hole concentration reduces to $1/e$, and $L_p = \sqrt{D_p \tau_p}$

$$= \sqrt{\frac{kT}{q} \cdot \mu_p \cdot \tau_p} = \sqrt{0.0259 \cdot 500 \cdot 10^{-6}} \\ = 3.598 \times 10^{-3} \text{ cm} \\ = 36 \mu\text{m}$$

9-2. Determine the maximum hole diffusion current density in the sample in unit of $\mu\text{A}/\text{cm}^2$.

- (a) 3
(b) 30
(c) 60
(d) 600
(e) None of the above

The maximum hole diffusion current density occurs at $x=0$

$$p = p_0 + \delta p \approx \delta p$$

$$J_p^{\text{diff}} = q \cdot (-D_p \frac{\partial p}{\partial x}) \Big|_{x=0}$$

$$= q \cdot D_p \cdot \frac{1}{L_p} \cdot \delta p \Big|_{x=0}$$

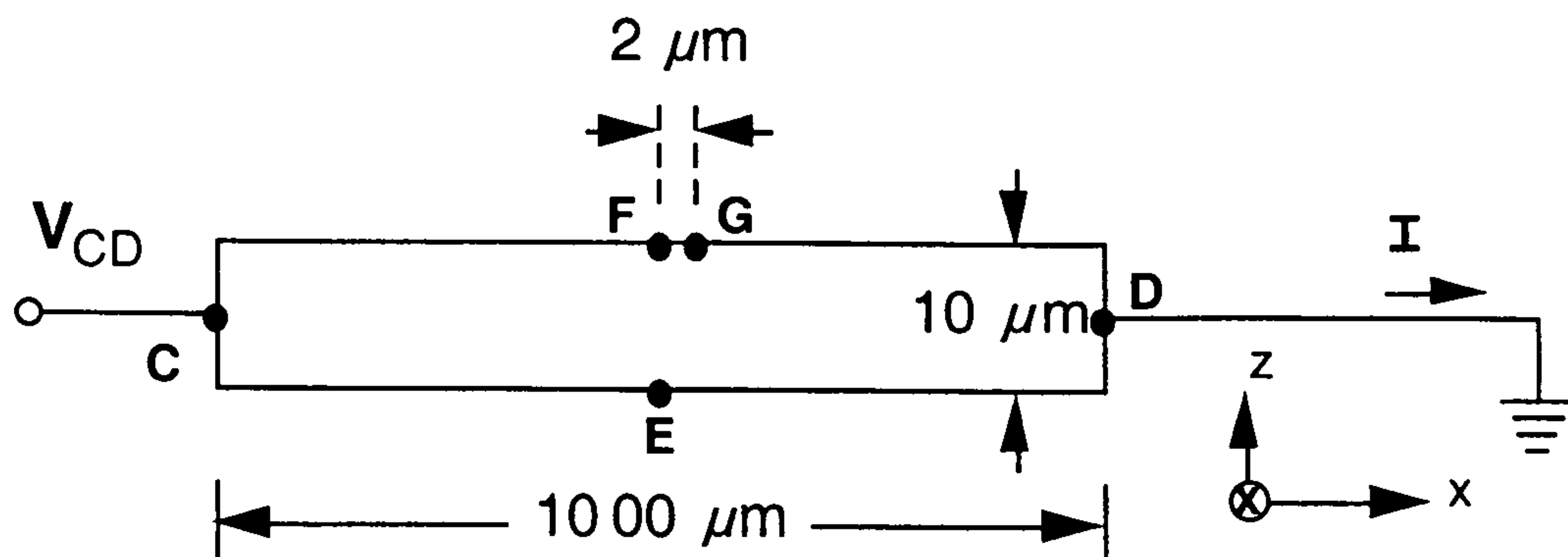
$$= (1.6 \times 10^{-19}) (0.0259 \cdot 500) \cdot \frac{10^{12}}{3.598 \times 10^{-3}}$$

$$= 5.758 \times 10^{-4} \left(\frac{\text{A}}{\text{cm}^2} \right)$$

$$= 575.8 \times 10^{-6} \frac{\text{A}}{\text{cm}^2}$$

$$= 576 \frac{\mu\text{A}}{\text{cm}^2}$$

11. A bar of silicon shown below has three contiguous sides along x, y and z axes. Its dimension along the y-axis is $20\ \mu\text{m}$. The manufacturing company claimed to have only doped the sample with $1.5 \times 10^{17}/\text{cm}^3$ phosphorous atoms. A Hall effect measurement is conducted at 300 K to verify the doping. In the set-up, points E and F are aligned along z-axis while F and G are along the x-axis. Note that the distance between F and G is $2\ \mu\text{m}$. A voltage $V_{CD} = V_C - V_D = 2$ volts is applied and a current I of 1 mA flows through the sample. The magnetic field B is along the $\pm y$ -axis. Assume that the strength of the magnetic field is $|B| = 25\ \text{kG}$. (Note: $1\ \text{kG} = 10^{-5}\ \text{Wb}/\text{cm}^2$; $h/q = 0.4136 \times 10^{-6}\ \text{Gauss}\cdot\text{cm}^2$; $h/q^2 = 25813\ \Omega$.)



- (a) (5 points) If the claim is true, what will be the expected voltage, $V_{EG} = V_E - V_G$, measured between E and G? Assume that the magnetic field is in the + y direction. Show your work.

Since the sample is doped with phosphorous, it is n-type. The majority carrier is electron. For a current of 1 mA in the +x direction, it indicates that electron drifts in the -x direction. The magnetic force $\vec{F} = (-q) \vec{v} \times \vec{B} = (-q) [v_d (-\hat{i}_x)] \times B_y \hat{i}_y = q v_d B_y \hat{i}_z$, i.e. electrons are pushed toward +z. Therefore, the Hall voltage is expected to be pointing from E to F along the +z direction, i.e. $V_{EF} > 0$.

$$V_{EF} = V_{Hall} = \mathcal{E}_H \cdot 10\ \mu\text{m} = v_d B_y \cdot 10\ \mu\text{m}$$

$$\text{Since } v_d = \frac{J_x}{qn} = \frac{I/A}{qn} = \frac{1\ \text{mA} / (20\ \mu\text{m} \times 10\ \mu\text{m})}{1.6 \times 10^{-19} \cdot 1.5 \times 10^{17}} = \frac{10^{-3}}{2.4 \times 2 \times 10^{-8}} = 2.08 \times 10^4 \frac{\text{cm}}{\text{sec}}$$

$$\therefore V_{EF} = 2.08 \times 10^4 \times B_y \cdot 10 \times 10^{-4} = 2.08 \times 10^4 \times 25 \times 10^{-5} \times 10 \times 10^{-4} = 5.2 \times 10^{-3} \text{ Volts}$$

$$= 5.2\ \text{mV}$$

To find $V_{EG} = V_{EF} + V_{FG}$ we need to find V_{FG} .

① approach #1

$$V_{FG} = \frac{2\ \mu\text{m}}{1000\ \mu\text{m}} \cdot V_{CD}$$

$$= 2 \times 10^{-3} \times 2$$

$$= 4\ \text{mV}$$

$$\therefore V_{EG} = 5.2 + 4 = 9.2\ \text{mV}$$

② approach #2 (assuming the claim of $1.5 \times 10^{17}/\text{cm}^3$ is correct)

We would expect $n_n = 640 \frac{\text{cm}^2}{\text{V}\cdot\text{s}}$

$$V_{FG} = I_x \cdot R_{FG} = I_x \cdot \frac{1}{\sigma} \cdot \frac{l}{A} = 1\ \text{mA} \times \frac{2 \times 10^{-4}}{8n\mu_n \cdot 10 \times 20 \times 10^{-8}}$$

$$= 10^{-3} \cdot \frac{2 \times 10^{-4}}{1.6 \times 10^{-19} \times 1.5 \times 10^{17} \times 200 \times 10^{-8} \times 640}$$

$$= 6.5\ \text{mV}$$

Both approaches are fine. $\therefore V_{EG} = 5.2 + 6.5 = 11.7\ \text{mV}$

- (b) (5 points) Determine again the voltage, V_{EG} , when the magnetic field is reversed toward the $-y$ direction.

With a reversed B field, we expect the Hall voltage to change sign

$$\Rightarrow V_H = -5.2 \text{ mV}$$

① approach #1

$$\begin{aligned} V_{EG} &= V_{EF} + V_{FG} \\ &= -5.2 + 4 \\ &= -1.2 \text{ mV} \end{aligned}$$

② approach #2

$$\begin{aligned} V_{EG} &= V_{EF} + V_{FG} \\ &= -5.2 + 6.5 \\ &= +1.3 \text{ mV} \end{aligned}$$

- (c) (6 points) Referring to the mobility/impurity-concentration diagram in the formula sheet, do you agree with the company's claim about phosphorous being the only dopant? Show your work to support your argument or to suggest possible dopant configurations.

If the claim is true, the electron mobility is $\sim 640 \frac{\text{cm}^2}{\text{V}\cdot\text{sec}}$ ①

$$\begin{aligned} \text{However, } V_{CD} &= 2 \text{ volts, } I = 1 \text{ mA} \Rightarrow R = 2000 \Omega = \rho \cdot \frac{L}{A} \\ &= \frac{1}{qn\mu_n} \cdot \frac{1000 \times 10^{-4}}{200 \times 10^{-8}} \\ \therefore n\mu_n &= \frac{1000 \times 10^{-4}}{1.6 \times 10^{-19} \times 2000 \times 200 \times 10^{-8}} \\ &= 1.5625 \times 10^{18} \end{aligned}$$

$$\text{For } n = 1.5 \times 10^{17} \Rightarrow \mu_n = 1041 \frac{\text{cm}^2}{\text{V}\cdot\text{sec}} \quad \textcircled{2}$$

~~X~~ Inconsistent mobilities suggest that the company's claim is not correct.

- (d) (4 points) Circle the incorrect statement(s).

- True (1) The Hall effect measurement allows one to determine the majority carrier type, concentration, and mobility.
- False (2) To determine the minority carrier concentration one needs to use a Hanyes-Shockley type experiment instead of the Hall effect measurement. ① H-S experiment can determine the minority mobility and diffusion constant
- True (3) Reversing the magnetic field exerts a reversed magnetic force on carriers resulting in a reversed polarity of the Hall voltage.
- False (4) One can use a Hall effect measurement to directly determine the diffusion coefficient of the majority carriers. No, Hall measurement cannot determine the diffusion coefficient. It can determine the majority carrier type, concentration and mobility. but not the concentration
- (5) None of the above. \rightarrow its concentration