EE 207 (MBP): Question Set 1

1. For a semiconductor in equilibrium at 300 K, $E_g = 1.4\,e\text{V}$ and $E_F = E_c - 0.2\,e\text{V}$. What is the probability that an electron state with energy $E = E_c + 0.1\,e\text{V}$ is occupied?

   (A) 6.76×10^{-2} (B) 5.52×10^{-3} (C) 3.24×10^{-5} (D) 9.12×10^{-6}

2. For a semiconductor in equilibrium at 300 K, $E_g = 1.4\,e\text{V}$ and $E_F = E_c - 0.2\,e\text{V}$. What is the probability that an electron state with energy $E = E_v - 0.1\,e\text{V}$ is occupied?

   (A) 1 (B) 1.22×10^{-1} (C) 5.74×10^{-3} (D) 2.62×10^{-4}

3. For a semiconductor in equilibrium at 300 K, $E_g = 1.1\,e\text{V}$ and $E_F = E_v + 0.08\,e\text{V}$. What is the probability that an electron state with energy $E = E_v - 0.1\,e\text{V}$ is *not* occupied?

   (A) 7.22×10^{-1} (B) 3.74×10^{-3} (C) 9.45×10^{-4} (D) 5.68×10^{-6}

4. Consider an n-type silicon sample in which $E_F = E_c - 0.15\,\text{eV}$. Consider an electron state in the conduction band with energy E. What is E (with respect to E_c) for the probability of occupation of that state to be 10^{-3}? ($T = 300\,\text{K}$.)

   (A) 8.8 meV (B) 16.4 meV (C) 21.9 meV (D) 28.5 meV

5. Consider a uniformly doped silicon sample at $T = 300\,\text{K}$ with the minority carrier concentration $p_0 = 6.8 \times 10^3\,\text{cm}^{-3}$. What is n_0 (the equilibrium electron concentration)?
   ($n_i = 1.5 \times 10^{10}\,\text{cm}^{-3}$, $N_c = 2.8 \times 10^{19}\,\text{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\text{cm}^{-3}$.)

   (A) 3.3×10^{16} cm^{-3} (B) 1.9×10^{17} cm^{-3} (C) 2.2×10^{15} cm^{-3} (D) 1.5×10^{18} cm^{-3}

6. For the conditions given in Q-5, what is the position of the Fermi level (with E_c taken as 0 eV)?
   ($n_i = 1.5 \times 10^{10}\,\text{cm}^{-3}$, $N_c = 2.8 \times 10^{19}\,\text{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\text{cm}^{-3}$.)

   (A) -0.085 eV (B) -0.112 eV (C) -0.174 eV (D) -0.198 eV

7. Consider a uniformly doped silicon sample at $T = 300\,\text{K}$. For $E_F = E_c - 0.3\,\text{eV}$, what are the equilibrium concentrations n_0 and p_0?
   ($n_i = 1.5 \times 10^{10}\,\text{cm}^{-3}$, $N_c = 2.8 \times 10^{19}\,\text{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\text{cm}^{-3}$.)

   (A) $n_0 = 3.2 \times 10^{15}$ cm^{-3}, $p_0 = 4.5 \times 10^{5}$ cm^{-3}
   (B) $n_0 = 6.8 \times 10^{14}$ cm^{-3}, $p_0 = 3.2 \times 10^{6}$ cm^{-3}
   (C) $n_0 = 2.6 \times 10^{14}$ cm^{-3}, $p_0 = 8.8 \times 10^{5}$ cm^{-3}
   (D) $n_0 = 2.1 \times 10^{15}$ cm^{-3}, $p_0 = 8.3 \times 10^{4}$ cm^{-3}

8. Consider a uniformly doped silicon sample at $T = 300\,\text{K}$. For $E_F = E_v + 0.25\,\text{eV}$, what are the equilibrium concentrations n_0 and p_0?
   ($n_i = 1.5 \times 10^{10}\,\text{cm}^{-3}$, $N_c = 2.8 \times 10^{19}\,\text{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\text{cm}^{-3}$.)

   (A) $n_0 = 3.4 \times 10^{5}$ cm^{-3}, $p_0 = 6.6 \times 10^{14}$ cm^{-3}
   (B) $n_0 = 5.4 \times 10^{6}$ cm^{-3}, $p_0 = 4.5 \times 10^{13}$ cm^{-3}
   (C) $n_0 = 9.2 \times 10^{5}$ cm^{-3}, $p_0 = 1.8 \times 10^{14}$ cm^{-3}
   (D) $n_0 = 7.8 \times 10^{6}$ cm^{-3}, $p_0 = 1.4 \times 10^{13}$ cm^{-3}

9. Consider a uniformly doped silicon sample at $T = 300\,\mathrm{K}$. For $E_F = E_i + 0.28\,\mathrm{eV}$, what are the equilibrium concentrations n_0 and p_0?
($n_i = 1.5 \times 10^{10}\,\mathrm{cm}^{-3}$, $N_c = 2.8 \times 10^{19}\,\mathrm{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\mathrm{cm}^{-3}$.)

(A) $n_0 = 1.2 \times 10^{14}$ cm^{-3}, $p_0 = 8.9 \times 10^5$ cm^{-3}
(B) $n_0 = 5.6 \times 10^{13}$ cm^{-3}, $p_0 = 7.6 \times 10^6$ cm^{-3}
(C) $n_0 = 8.8 \times 10^{15}$ cm^{-3}, $p_0 = 2.6 \times 10^4$ cm^{-3}
(D) $n_0 = 7.6 \times 10^{14}$ cm^{-3}, $p_0 = 3.0 \times 10^5$ cm^{-3}

10. Consider a uniformly doped silicon sample at $T = 300\,\mathrm{K}$. For $E_F = E_i - 0.35\,\mathrm{eV}$, what are the equilibrium concentrations n_0 and p_0?
($n_i = 1.5 \times 10^{10}\,\mathrm{cm}^{-3}$, $N_c = 2.8 \times 10^{19}\,\mathrm{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\mathrm{cm}^{-3}$.)

(A) $n_0 = 6.7 \times 10^5$ cm^{-3}, $p_0 = 1.3 \times 10^{15}$ cm^{-3}
(B) $n_0 = 2.0 \times 10^4$ cm^{-3}, $p_0 = 1.1 \times 10^{16}$ cm^{-3}
(C) $n_0 = 8.4 \times 10^5$ cm^{-3}, $p_0 = 2.3 \times 10^{14}$ cm^{-3}
(D) $n_0 = 8.9 \times 10^4$ cm^{-3}, $p_0 = 5.5 \times 10^{15}$ cm^{-3}

11. For a uniformly doped silicon sample at $300\,\mathrm{K}$, $N_d = 5 \times 10^{16}\,\mathrm{cm}^{-3}$, $N_a = 0$. Assuming complete ionisation of donor and acceptor atoms, what is the location of the Fermi level?
($n_i = 1.5 \times 10^{10}\,\mathrm{cm}^{-3}$, $N_c = 2.8 \times 10^{19}\,\mathrm{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\mathrm{cm}^{-3}$.)

(A) $E_c - E_F = 0.254$ eV
(B) $E_c - E_F = 0.206$ eV
(C) $E_c - E_F = 0.164$ eV
(D) $E_c - E_F = 0.086$ eV

12. For a uniformly doped silicon sample at $300\,\mathrm{K}$, $N_a = 3.5 \times 10^{15}\,\mathrm{cm}^{-3}$, $N_d = 0$. Assuming complete ionisation of donor and acceptor atoms, what is the location of the Fermi level?
($n_i = 1.5 \times 10^{10}\,\mathrm{cm}^{-3}$, $N_c = 2.8 \times 10^{19}\,\mathrm{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\mathrm{cm}^{-3}$.)

(A) $E_F - E_v = 0.083$ eV
(B) $E_F - E_v = 0.125$ eV
(C) $E_F - E_v = 0.176$ eV
(D) $E_F - E_v = 0.206$ eV

13. For a uniformly doped silicon sample at $300\,\mathrm{K}$, $N_a = 5 \times 10^{15}\,\mathrm{cm}^{-3}$, $N_d = 3 \times 10^{15}\,\mathrm{cm}^{-3}$. Assuming complete ionisation of donor and acceptor atoms, what is the location of the Fermi level?
($n_i = 1.5 \times 10^{10}\,\mathrm{cm}^{-3}$, $N_c = 2.8 \times 10^{19}\,\mathrm{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\mathrm{cm}^{-3}$.)

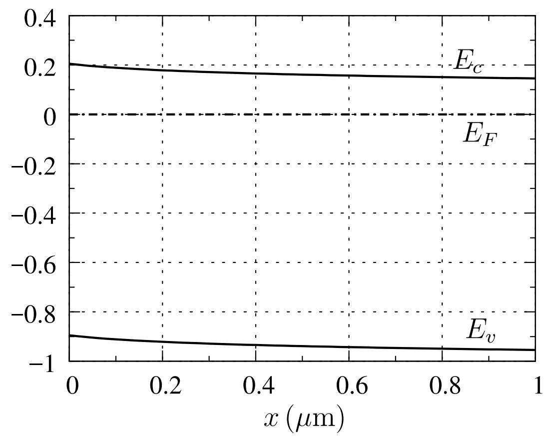
(A) $E_F - E_v = 0.078$ eV
(B) $E_F - E_v = 0.135$ eV
(C) $E_F - E_v = 0.221$ eV
(D) $E_F - E_v = 0.253$ eV

14. A uniformly doped n-type silicon region with $N_d = 1.2 \times 10^{16}\,\mathrm{cm}^{-3}$ (and $N_a = 0$) is made p-type by doping it with $N_a > N_d$. Assume N_a to be uniform in this region. This

compensated region is found to have $n_0 = 1.25 \times 10^4\,\text{cm}^{-3}$. What is N_a? ($n_i = 1.5 \times 10^{10}\,\text{cm}^{-3}$.)

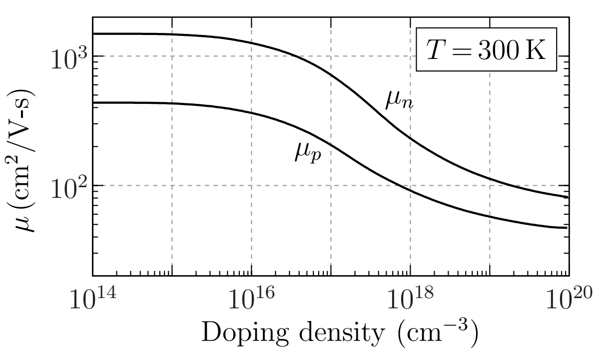
(A) 1.8×10^{16} cm^{-3}
(B) 2.2×10^{16} cm^{-3}
(C) 2.6×10^{16} cm^{-3}
(D) 3.0×10^{16} cm^{-3}

15. The band diagram for a semiconductor region is shown in the figure. Assume that all quantities vary only in the x direction. Which of the following statements is true?



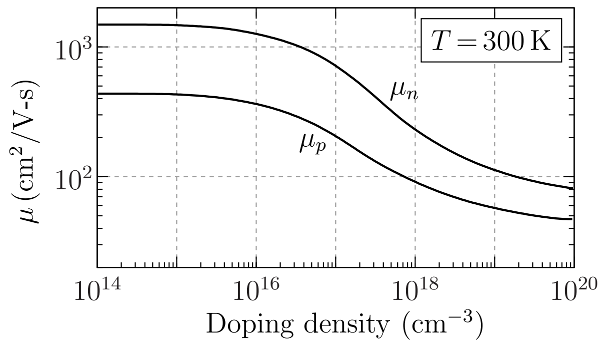
(A) J_n^{diff} points in the negative x direction.
(B) The hole concetration increases as x is increased.
(C) J_n^{drift} and J_n^{diff} are equal and opposite for all values of x.
(D) J_p^{diff} and J_n^{diff} are comparable in magnitude.

16. Consider a uniformly doped n-type silicon sample with $N_d = 5 \times 10^{17}\,\text{cm}^{-3}$ at $300\,K$. Use the μ_n-N_d plot in the figure to estimate the low-field mobility. For an applied electric field of 100 V/cm, what is J_n^{drift} (magnitude)?



(A) 3.2×10^3 A/cm^2
(B) 5.8×10^2 A/cm^2
(C) 6.5×10^3 A/cm^2
(D) 1.9×10^4 A/cm^2

17. A rectangular bar of n-type silicon at 300 K with length 50 μm and a cross-sectional area of 200 μm^2 conducts a current of 20 mA when a voltage of 4 V is applied. Assume that the current is entirely due to J_n^{drift}. The dependence of μ_n on N_d is shown in the figure. What is N_d?

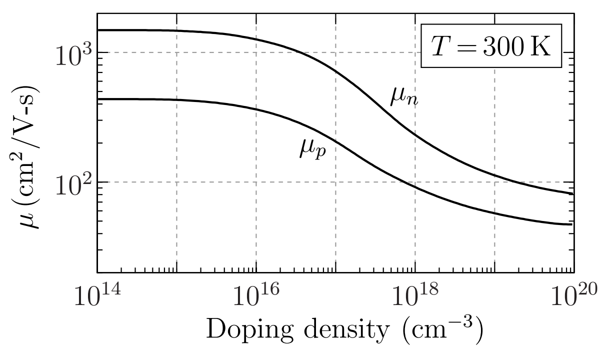


(A) 5.0×10^{17} cm^{-3}
(B) 7.0×10^{16} cm^{-3}
(C) 1.0×10^{17} cm^{-3}
(D) 3.5×10^{16} cm^{-3}

18. For the conditions given in Q-17, What is the hole current? ($n_i = 1.5 \times 10^{10}$ cm^{-3}.)

(A) 6.9×10^{-10} A
(B) 4.2×10^{-12} A
(C) 1.5×10^{-14} A
(D) 1.1×10^{-16} A

19. The resistivity of a p-type silicon sample doped with boron atoms is 0.1 Ω-cm at 300 K. The dependence of μ_p on N_a is shown in the figure. What is p_0?



(A) 5.0×10^{17} cm^{-3}
(B) 5.8×10^{16} cm^{-3}
(C) 1.0×10^{17} cm^{-3}
(D) 3.5×10^{16} cm^{-3}

20. The dependence of hole drift velocity on electric field can be modelled as

$$v_d = \frac{\mu_p \mathcal{E}}{1 + \dfrac{\mu_p \mathcal{E}}{v_s^p}}\,.$$

For silicon at 300 K, $\mu_p = 210\,\mathrm{cm^2/V\text{-}s}$, $v_s^p = 1 \times 10^7\,\mathrm{cm/s}$ for $N_a = 10^{17}\,\mathrm{cm^{-3}}$. Consider a rectangular bar of p-type silicon with length $5\,\mu\mathrm{m}$, cross-sectional area of $100\,\mu\mathrm{m}^2$, and $N_a = 10^{17}\,\mathrm{cm^{-3}}$. What is the current conducted by the sample at 300 K for an applied voltage of 5 V? (Assume the electric field to be constant throughout the sample.)

(A) 6.5 mA (B) 13 mA (C) 19 mA (D) 28 mA

21. Consider a rectangular bar of intrinsic silicon at 300 K. We are interested in the variation of the resistivity of the bar with respect to temperature in a relatively small temparature range. Assume the carrier mobilities μ_n and μ_p to be constant. Treat the energy gap E_g to be constant (1.1 eV), but take into account the T-dependence of N_c and N_v. What is the temperature at which the resistivity of the sample is reduced by 25 % (compared to its value at 300 K)?

    (A) 320 K (B) 304 K (C) 312 K (D) 328 K

22. For an intrinsic semiconductor sample, the conductivity is found to be σ_0 and $1.5\sigma_0$ at $T = 300$ K and $T = 309$ K, respectively. Ignore the dependence of μ_n, μ_p on temperature. What is the energy gap of the semiconductor?

    (A) 0.64 eV (B) 1.1 eV (C) 1.42 eV (D) 2.05 eV

23. Consider the "balls and bins" example discussed in class. Let the number of balls in bin k be N_k at time t. Assume that the movement of the balls is governed by the following rule: In each time step, $0.4 \times N_k$ balls from bin k remain in bin k, $0.3 \times N_k$ balls move to bin $k+1$, and $0.3 \times N_k$ balls move to bin $k-1$. Initially, we have 5000 balls in the central bin (called bin 0). What is the population in bin 1 after the first three time steps (rounded off to an integer)?

    (A) 775 (B) 925 (C) 1125 (D) 1245

24. In a semiconductor, the electron diffusion current density at a certain location is $745\,\mathrm{A/cm^2}$ at 300 K. The electron mobility is $1800\,\mathrm{cm^2/V\text{-}s}$ at the same temperature. What is the concentration gradient dn/dx at this location?

    (A) $3.4 \times 10^{17}\,\mathrm{cm^{-4}}$
    (B) $6.8 \times 10^{18}\,\mathrm{cm^{-4}}$
    (C) $4.4 \times 10^{19}\,\mathrm{cm^{-4}}$
    (D) $1 \times 10^{20}\,\mathrm{cm^{-4}}$

25. The hole density in a semiconductor varies linearly from $p_1 = 10^{12}\,\mathrm{cm^{-3}}$ at $x = 0$ to $p_2 = 8 \times 10^{11}\,\mathrm{cm^{-3}}$ at $x = 0.1\,\mu\mathrm{m}$. The electric field $\mathcal{E}$ is negligibly small. If the hole current density is $12.4\,\mathrm{mA/cm^2}$, what is μ_p? ($T = 300$ K.)

    (A) 110 $\mathrm{cm^2/V\text{-}s}$
    (B) 150 $\mathrm{cm^2/V\text{-}s}$
    (C) 245 $\mathrm{cm^2/V\text{-}s}$
    (D) 308 $\mathrm{cm^2/V\text{-}s}$

26. The doping density in an n-type silicon sample varies as

$$N_d(x) = N_0\left(1 + a_1 x + a_2 x^2\right),$$

where $N_0 = 10^{16}\,\text{cm}^{-3}$. Assume $n(x) \approx N_d(x)$ and that the semiconductor is in equilibrium at 300 K. The conduction band edge E_c is $E_F + 0.18\,\text{eV}$ at $x = 1\,\mu\text{m}$ and $E_F + 0.12\,\text{eV}$ at $x = 2\,\mu\text{m}$. What is a_1?

($N_c = 2.8 \times 10^{19}\,\text{cm}^{-3}$, $N_v = 1.04 \times 10^{19}\,\text{cm}^{-3}$.)

(A) $-1.5\,/\mu\text{m}$ (B) $-6.8\,/\mu\text{m}$ (C) $-9.7\,/\mu\text{m}$ (D) $-12.3\,/\mu\text{m}$

27. For the conditions given in Q-26, what is a_2?

(A) $11.35\,/(\mu\text{m})^2$ (B) $8.43\,/(\mu\text{m})^2$ (C) $13.44\,/(\mu\text{m})^2$ (D) $5.87\,/(\mu\text{m})^2$

28. Consider a p-type silicon sample with $p_0 = 10^{16}\,\text{cm}^{-3}$, $n_i = 10^{10}\,\text{cm}^{-3}$, $\tau_p = 0.1\,\mu\text{s}$, $\tau_n = 0.2\,\mu\text{s}$. Excess carriers are injected into this sample such that $\Delta n = \Delta p = 5 \times 10^{14}\,\text{cm}^{-3}$. Let $n_1 = p_1 \approx n_i$ in the SRH equation. What is the net recombination rate?

(A) 5.5×10^{20} cm^{-3}s^{-1}
(B) 2.6×10^{20} cm^{-3}s^{-1}
(C) 5.0×10^{21} cm^{-3}s^{-1}
(D) 2.4×10^{21} cm^{-3}s^{-1}

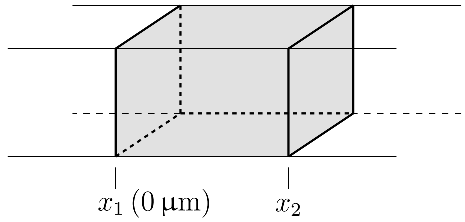
29. Consider a uniformly doped n-type silicon sample with $N_d = 5 \times 10^{17}\,\text{cm}^{-3}$, $\tau_n = 1\,\mu\text{s}$, $\tau_p = 0.5\,\mu\text{s}$, $n_1 = p_1 \approx n_i = 10^{10}\,\text{cm}^{-3}$. In a certain region of this sample, both electrons and holes are removed by some means such that $n \ll n_i$ and $p \ll n_i$. What is the SRH rate of generation?

(A) 5.4×10^{14} cm^{-3}s^{-1}
(B) 2.8×10^{16} cm^{-3}s^{-1}
(C) 6.7×10^{15} cm^{-3}s^{-1}
(D) 1.5×10^{17} cm^{-3}s^{-1}

30. Light of a certain wavelength is incident on an n-type silicon sample, giving rise to an optical generation rate of $G_{\text{opt}} = 6 \times 10^{20}\,/\text{cm}^3$-s throughout the sample. If $n_0 = 1.5 \times 10^{17}\,\text{cm}^{-3}$, what is Δp in the steady state? ($\tau_p = 0.1\,\mu\text{s}$, $\tau_n = 0.2\,\mu\text{s}$.)

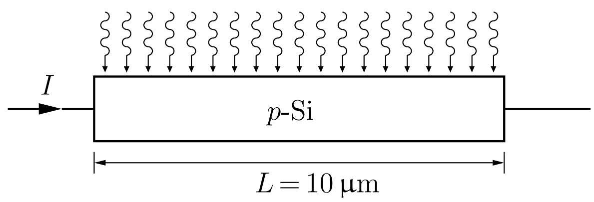
(A) 2.4×10^{15} cm^{-3}
(B) 6.0×10^{13} cm^{-3}
(C) 2.6×10^{16} cm^{-3}
(D) 1.2×10^{14} cm^{-3}

31. Consider the shaded rectangular volume of a semiconductor shown in the figure. An incident steady light produces carriers at the rate of $G_{\text{opt}} = 5 \times 10^{19}\,/\text{cm}^3$-s in this volume. The rate of net thermal recombination is constant throughout the volume and is given by $R - G = 2 \times 10^{19}\,/\text{cm}^3$-s. The hole current density at x_1 is $J_p(x_1) = 1\,\text{mA/cm}^2$. If $(x_2 - x_1)$ is $1\,\mu\text{m}$, what is $J_p(x_2)$? (Assume that there are no variations and therefore no currents in the y and z directions.)



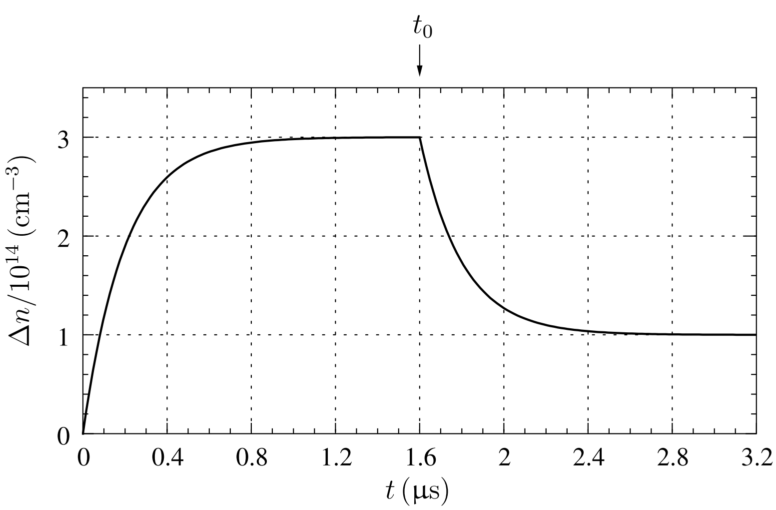
(A) $1.48\,\mathrm{mA/cm^2}$
(B) $1.04\,\mathrm{mA/cm^2}$
(C) $0.52\,\mathrm{mA/cm^2}$
(D) $4.33\,\mathrm{mA/cm^2}$

32. Consider a bar of p-type silicon with $N_a = 10^{16}\,\mathrm{cm^{-3}}$, illuminated uniformly (see figure) such that the optical generation rate is G_{opt}, assumed constant throughout the sample. The cross-sectional area of the bar is $50\,\mu\mathrm{m}^2$, and the material parameters are $\mu_n = 1000\,\mathrm{cm^2/V\text{-}s}$, $\mu_p = 400\,\mathrm{cm^2/V\text{-}s}$, $\tau_n = 0.1\,\mu\mathrm{s}$, $\tau_p = 0.5\,\mu\mathrm{s}$, $n_i = 1.5 \times 10^{10}\,\mathrm{cm^{-3}}$. For an applied voltage of 10 V, what is the change in the current ΔI (due to light) for $G_{\mathrm{opt}} = 10^{21}\,/\mathrm{cm^3\text{-}s}$? (Assume that n and p do not vary with x.)



(A) $40\,\mu\mathrm{A}$ (B) $56\,\mu\mathrm{A}$ (C) $80\,\mu\mathrm{A}$ (D) $112\,\mu\mathrm{A}$

33. A uniformly doped p-type silicon sample is subjected to a light pulse which produces a change in the excess minority carrier concentration as shown in the figure. Assuming the optical generation rate to be constant throughout the sample (for a given light intensity), what is G_{opt} in the interval $0 < t < t_0$?



(A) $1.5 \times 10^{21}\ \mathrm{cm^{-3}s^{-1}}$

(B) 9.3×10^{19} cm^{-3}s^{-1}
(C) 4.1×10^{20} cm^{-3}s^{-1}
(D) 7.5×10^{21} cm^{-3}s^{-1}

34. For the conditions given in Q-33, what is G_{opt} in the interval $t > t_0$?

(A) 3.2×10^{21} cm^{-3}s^{-1}
(B) 8.8×10^{19} cm^{-3}s^{-1}
(C) 0.5×10^{21} cm^{-3}s^{-1}
(D) 6.5×10^{20} cm^{-3}s^{-1}