Brief Article

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Problem I. An infinite semiconductor wafer \((N_D = 10^{17} \text{ cm}^{-3} \text{ and } N_A = 0)\) has been uniformly illuminated for a long time with the generation rate equal to \(G_o\). Suddenly the light intensity is doubled. The minority carrier lifetime is \(\tau_p = \tau_n = 10^{-12} \text{ seconds}\).

1. Which is the minority carrier?
   (a) Holes
   (b) Electrons
   (c) Cannot tell with the information given

2. What is the general solution?
   (a) \(\Delta p, n(t) = Ae^{-\frac{t}{\tau_{p,n}}} + 2 * G_o\tau_{p,n}\)
   (b) \(\Delta p, n(x) = Ae^{-\frac{x}{\tau_{p,n}}} + Be^{\frac{x}{\tau_{p,n}}} + 2 * G_o\tau_{p,n}\)
   (c) \(\Delta p, n(t) = Ae^{-\frac{t}{\tau_{p,n}}} + G_o\tau_{p,n}\)
   (d) \(\Delta p, n(x) = Ae^{-\frac{x}{\tau_{p,n}}} + Be^{\frac{x}{\tau_{p,n}}}\)
   (e) None of the above

3. What are the boundaries and boundary conditions?
   (a) \(\Delta p, n(t = 0) = 0\)
   (b) \(\Delta p, n(t = 0) = G_o\tau_{p,n}\)
   (c) \(\Delta p, n(t = 0) = 2 * G_o\tau_{p,n}\)
   (d) \(\Delta p, n(x = 0) = -p, n_0; \Delta p(x = \infty) = G_o\tau_{p,n}\)
   (e) \(\Delta p, n(x = 0) = 0; \Delta p(x = \infty) = G_o\tau_{p,n}\)

4. What is the exact solution?
   (a) \(\Delta p, n(t) = G_o\tau_{p,n}(1 + e^{-\frac{t}{\tau_{p,n}}} )\)
   (b) \(\Delta p, n(x) = 2 * G_o\tau_{p,n}(1 - e^{-\frac{x}{\tau_{p,n}}} )\)
   (c) \(\Delta p, n(x) = G_o\tau_{p,n}(1 - e^{-\frac{x}{\tau_{p,n}}} ) - p, n_0 e^{-\frac{x}{\tau_{p,n}}}\)
   (d) \(\Delta p, n(t) = 2 * G_o\tau_{p,n}e^{-\frac{t}{\tau_{p,n}}}\)
   (e) \(\Delta p, n(t) = G_o\tau_{p,n}(2 - e^{-\frac{t}{\tau_{p,n}}} )\)
5. What is the largest value $G_o$ can have such that all the semiconductor is in low injection all the time?
   (a) $2^*G_o = 10^{17}$
   (b) $2^*G_o = 5 \times 10^{23}$
   (c) $2^*G_o = 5 \times 10^{27}$
   (d) $2^*G_o = 10^{29}$
   (e) None of the above

6. What is the minority carrier current at x=0 (remember that $D_{p,n} \tau_{p,n} = L_{p,n}^2$)?
   (a) Zero.
   (b) $J_{p,n}(t) = qD_{p,n}G_o/\tau_{p,n}$
   (c) $J_{p,n}(t) = -qD_{p,n}G_o/\tau_{p,n}$
   (d) $J_{p,n}(x) = qD_{p,n}G_oL_{p,n}$
   (e) $J_{p,n}(x) = -qG_oL_{p,n}$

Problem II. Carrier concentrations

7. A silicon wafer with $N_D = 5 \times 10^{18}$ cm$^{-3}$ and $N_A = 0$ cm$^{-3}$ has $p_o = 2 \times 10^5$ cm$^{-3}$. What is the temperature?
   (a) 280K
   (b) 300K
   (c) 370K
   (d) 400K
   (e) None of the above

8. Where is the Fermi level for this situation?
   (a) Above $E_D$ but below $E_c$
   (b) Above $E_i$ but below $E_D$
   (c) Below $E_i$ but above $E_A$
   (d) Below $E_D$ but above $E_v$
   (e) None of the above

9. Now dopants are added so that $N_A = 10^{19}$ cm$^{-3}$. What is the hole concentration?
   (a) $10^{19}$ cm$^{-3}$
   (b) $10^{18}$ cm$^{-3}$
   (c) $2 \times 10^1$ cm$^{-3}$
   (d) $5 \times 10^{18}$ cm$^{-3}$
   (e) None of the above
10. What is the electron concentration?
   (a) $10^{19}$ cm$^{-3}$
   (b) $2 \times 10^5$ cm$^{-3}$
   (c) $10^{18}$ cm$^{-3}$
   (d) $2 \times 10^1$ cm$^{-3}$
   (e) None of the above

11. Where is the Fermi level for this situation?
   (a) Above $E_D$ but below $E_c$
   (b) Above $E_i$ but below $E_D$
   (c) Below $E_i$ but above $E_A$
   (d) Below $E_D$ but above $E_v$
   (e) None of the above

12. Now one thing is changed, resulting in $n_o = 2 \times 10^1$ cm$^{-3}$. What was done?
   (a) The temperature was increased.
   (b) The temperature was changed to room temperature.
   (c) The acceptor concentration is now $5 \times 10^{18}$ cm$^{-3}$
   (d) The donor concentration was increased by $10^{19}$ cm$^{-3}$
   (e) The donor concentration was increased by $6 \times 10^{18}$ cm$^{-3}$

13. Where is the Fermi level for this situation compared to where it was at the previous step?
   (a) Lower but still above $E_i$
   (b) Higher and above $E_D$
   (c) Lower but still above $E_A$
   (d) Higher but still below $E_i$
   (e) None of the above

14. What would have to be changed from this situation for the Fermi level to be right at $E_A$?
   (a) Lower the temperature to between 50 and 100 Kelvin
   (b) Lower the temperature to 150 Kelvin
   (c) Lower the temperature to 0 Kelvin
   (d) Raise the temperature to 370 Kelvin
   (e) It can’t be done.
15. Now let’s start all over with a GaAs wafer at room temperature such that $N_A = 2 \times 10^{16} \text{ cm}^{-3}$ and $N_D = 10^{16} \text{ cm}^{-3}$. What is the hole concentration? Assume that $n_i = 10^6 \text{ cm}^{-3}$
   (a) $10^{16} \text{ cm}^{-3}$
   (b) $5 \times 10^{15} \text{ cm}^{-3}$
   (c) $10^{15} \text{ cm}^{-3}$
   (d) $2 \times 10^{16} \text{ cm}^{-3}$
   (e) None of the above

16. What is the electron concentration?
   (a) $10^4 \text{ cm}^{-3}$
   (b) $10^{-4} \text{ cm}^{-3}$
   (c) $3 \times 10^{16} \text{ cm}^{-3}$
   (d) $10^{16} \text{ cm}^{-3}$
   (e) None of the above

Problem III. (General questions.)

17. The temperature of a p-type silicon wafer is lowered from room temperature to 10 Kelvin? What happens to the mobility?
   (a) The mobility increases
   (b) The mobility decreases
   (c) The mobility does not change

18. For semiconductors A and B, $\mu_A > \mu_B$. Which of the following could be true?
   (a) Doping in semiconductor A is greater than the doping in semiconductor B.
   (b) The temperature in semiconductor A is greater than the temperature in semiconductor B.
   (c) Doping in semiconductor A is less than the doping in semiconductor B.
   (d) None of these explain $\mu_A > \mu_B$.

19. Which of the recombination mechanisms listed is present in silicon?
   (a) Auger recombination
   (b) Shockley-Read-Hall or thermal recombination
   (c) Radiative recombination
   (d) All are present.

20. Donors in silicon come from...
   (a) ...Column III.
   (b) ...Column V.
   (c) ...the column in periodic table to the left of the element it replaces.
   (d) None of the above
21. Which of the following is true in an n-type semiconductor with both donors and acceptors?
   (a) At all temperatures all donors are always ionized.
   (b) At all temperatures only some of the acceptors are always ionized.
   (c) Only some of the acceptors are ionized at very low temperatures (T<100 K).
   (d) All of the donors are ionized at room temperature.
   (e) None of the above

22. The temperature of a p-type silicon wafer is lowered from room temperature to 10 Kelvin? What happens to the conductivity?
   (a) The conductivity increases
   (b) The conductivity decreases
   (c) The conductivity does not change

23. Which of the following assumptions is NOT required to derive the minority carrier diffusion equations?
   (a) Non-degerate semiconductor
   (b) Low level injection
   (c) Uniform doping
   (d) Uniform generation
   (e) All of the above are required

Problem IV. (Band diagrams.)

24. Which sketch looks most like the potential?
   (a) (a)
   (b) (b)
   (c) (c)
   (d) None of the above

25. Which sketch looks most like the electric field?
   (a) (a)
   (b) (b)
   (c) (c)
   (d) None of the above

26. Which sketch looks most like the electron concentration?
   (a) (a)
   (b) (b)
   (c) (c)
   (d) None of the above
27. Which sketch looks most like the hole diffusion current?
   (a) (a)
   (b) (b)
   (c) (c)
   (d) None of the above

28. Is there a region where the semiconductor is intrinsic?
   (a) Yes.
   (b) No.
   (c) Cannot tell.

29. Is this semiconductor in equilibrium?
   (a) Yes.
   (b) No.
   (c) Cannot tell.

30. How many regions in this semiconductor have $pn \neq n_i^2$?
   (a) 0
   (b) 1
   (c) 2
   (d) 3
   (e) Cannot tell.