Indian Institute of Technology

PH205 (Nov 2023)

End-semester Examination

Full marks: 50 ***Time: 3 hours***

Section 1*: Write the answer(s) for each question in your answer script. Each question carry one mark.*

1. In a doped semiconductor sample of cross-sectional area A and length L, the doping density, N_D, varies with distance (x) as $N_D(x) = N_0 \exp\left(-\frac{x}{L}\right)$, where N_0 is a constant. Assuming that the mobility μ of the majority carrier remains constant, the electrical conductivity (σ) of the sample is given by (expression) $\sigma =$ ....

2. The energy E(**k**) of electrons of wave vector **k** in a solid is given by E(**k**)=Ak^2+Bk^4, where A and B are constants. The effective mass (m*) of the electron at |**k**| =k_0 is given by

m* = ...

3. When the PN junction is forward biased, the sequence of events (among diffusion, drift, injection and recombination) that take place are:

(a) ...., (b) ...., (c) ....

4. The junction capacitance (C) of linearly graded p-n junction varies with the applied reverse bias, V_R, as $C \propto$ ....

5. A GaAs LED emits light in the .... region and GaN emits light in the ....region of spectrum.

6. The sensitivity of a photo diode depends on parameters, such as : ...., ...

7. **Match** items in Group I with items in Group II, most suitably.

Group I

P. LED Q. Avalanche Photodiode R. tunnel diode S. LASER

Group II

1. Heavy doping, 2. Coherent radiation, 3. Spontaneous emission, 4. Current gain

P - ...., Q - ...., R - ...., S -.................................

8. Given that for GaAs, bandgap E_g=1.43 eV, and for AlAs, E_g=2.75 eV, using virtual crystal approximation, the bandgap of $Al_{0.3}Ga_{0.7}As$ alloy will be

$E_{g,\ alloy} =$ .... eV

9. Construction wise, MOSFETs can be categorized into four types as follows:

(a) .... (b) ....

(c) .... (d) ....

10. Transconductance (g) of a JFET is defined as (formula): g = ..., and its unit is ....

Section 2

11. A semiconductor sample is n-type doped. Briefly describe an experimental technique with schematic to determine its bandgap energy (E_g) and the donor energy level (E_D). Use a graphical method for the determination of E_g and E_D. [3]

12. Draw the schematic diagram of a quantum well laser for low threshold operation and briefly explain its working principle. [2+2]

13. The absorption coefficient near the band-edge of Si is ~10^3 cm^{-1}. What is the minimum thickness (in cm unit) of a sample that can absorb 90% of the incident light? [3]

14. In a p-type GaAs sample, electrons are injected from a contact. If the electron mobility is 4000 cm^2/V-s at 300K, calculate the diffusion length for electrons. Take recombination time as 0.6 ns. [3]

15. A Si diode is being used as a thermometer by operating it at a fixed forward (bias) current. The voltage is then a measure of the temperature. At 300K, the diode voltage is found to be 0.6V. How much will be the *voltage change* if the temperature changes by 1 K? [4]

16. Consider a semiconductor laser having an optical confinement factor of unity. If the threshold carrier density is 1.32×10^{18} cm^{-3} and the active layer thickness is 20 μm, calculate the threshold current density (J_{th}) for the lasing action to start. Assume a radiative recombination time of 2.4 *ns*. [3]

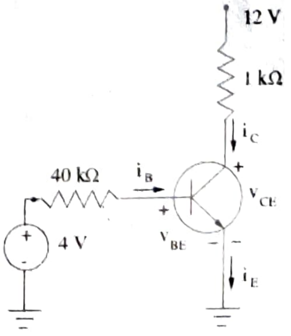
17. A Schottky barrier is formed between a metal having a work function of 4.3 eV and p-type Si (electron affinity χ=4 eV). The acceptor doping in the Si is 10^{17} /cm^3. (a) Calculate the work function of the semiconductor (φ_s). (b) Draw the equilibrium band diagram, showing numerical value of qV_0. [3+2]

18. Consider a Si solar cell with area=1 cm^2, acceptor doping density=5×10^{17} cm^{-3}, donor doping density=10^{16} cm^{-3} and photocurrent of 25 mA. If $D_n = 20$ cm^2/s, $D_p = 10$ cm^2/s, $\tau_n = 3\times10^{-7}\,s$, $\tau_p = 10^{-7}\,s$, calculate the open circuit voltage (V_{oc}) of the solar cell operated at 300K. [4]

19. Consider a GaAs p-n LED with the p-region on the top to emit light, and D_n=30 cm^2/S, D_p=15 cm^2/s, N_a=5×10^{16} cm^{-3} and N_d=5×10^{17} cm^{-3}, τ_n=10 ns, τ_p=100 ns. Calculate the diode injection efficiency (γ_{inj}). [3]

20. A Si p-n junction with cross-sectional area, A=0.001 cm^2 is formed with $N_a = 10^{15}$ cm^{-3}, $N_d = 10^{17}$ cm^{-3}. Calculate (a) built-in potential, V_0, (b) current I with a forward bias of 0.5 V. Assume that the current is diffusion dominated. Assume $\mu_n = 1500$ cm^2/V-s, $\mu_p = 450$ cm^2/V-s, $\tau_n = \tau_p = 2.5\,\mu s$. [2+3]

21. For the given circuit below for a Si NPN transistor with β=100, calculate the I_B, I_C and V_{CE}. [3]



Useful Formula:

$\gamma_{inj} = \frac{J_n}{J_n+J_p}$, $L_n=\sqrt{D_n\tau_n}$, $J_n=\frac{eD_n n_p}{L_n}$

$V_{oc}=\frac{mkT}{e}\ln(1+\frac{I_L}{I_0})$, $I_0 = A\left[\frac{eD_n n_p}{L_n}+\frac{eD_p p_n}{L_p}\right]$

$\alpha_{loss} = -\frac{1}{L}lnR$, $R=\frac{(n_2-n_1)^2}{(n_2+n_1)^2}$, $n_{th} = \frac{J_{th}\,\tau_r}{e\,d_{laser}}$

$I = I_0[\exp\left(\frac{eV}{kT}\right)-1]$

n_i=1.5×10^{10} /cc for Si

$V_0 = \frac{kT}{e}\ln(\frac{N_a N_d}{n_i^2})$