SEMICONDUCTOR OPTOELECTRONICS
Questions & Problems for Revision

PART-II: Light Emission & Absorption, Amplification & Modulation in Semiconductors

<u>Note:</u> The bold numbers in brackets indicate typical marks allocated to the question in a one-hour written test for 25 marks (or 2 hr written-test for 50 marks)

1) Using the *E*-***k*** diagram, depict the phenomena of radiative-, nonradiative-, and phonon-assisted radiative transitions from the conduction band to the valance band in a direct bandgap semiconductor. (Draw three separate diagrams to depict the three cases) **(3)**

2) What is a '*phonon-assisted radiative transition*'? Depict such a transition in the **E–k** diagram, and write down the corresponding momentum conservation equation. What is the role of the phonon? Explain briefly. **(3)**

3)
   a) How is the *optical joint density of states*, ρ, different from the *density of states* ρ_c and ρ_v in a semiconductor? (Explain briefly the need to define ρ in *Optoelectronics*) **(3)**

   b) Given ρ_c and ρ_v, obtain an expression for ρ in a direct bandgap semiconductor, under the parabolic approximation of the band structure. **(2)**

4) Silicon is an indirect bandgap semiconductor with E_g = 1.1 eV, and InP is a direct bandgap material with E_g = 1.35 eV at 300 K. Draw a qualitatively correct plot representing the variation of absorption coefficient as a function of wavelength for these two materials. Briefly reason out the nature of the curves. **(3)**

5)
   a) Consider a lightly doped direct bandgap semiconductor, with E_g = 1.42 eV at 300K, in thermal equilibrium. Starting from the definition of *probability of emission* $f_e(\nu)$, estimate the numerical value of $f_e(\nu)$ for photons of energy $h\nu \approx E_g$. **(3)**
   b) Show that the probability of emission (in a) above) can be increased by orders of magnitude by 'pumping' the semiconductor into *quasi-equilibrium*. **(2)**

6) The spontaneous emission spectrum of a particular semiconductor is given by

$$r_{sp}(\nu) = K_0\, x^{1/2}\, e^{-x}\ ; \qquad x = (h\nu - E_g)/(2kT) \qquad \text{Eq.(1)}$$

   where K_0 is a constant.
   a) Obtain an expression for the wavelength at which peak emission would occur. **(2)**
   b) If the above semiconductor has a bandgap E_g = 1.35 eV at 300K, and $K_0 = 10^9$ (photons/s/cc/Hz), draw qualitatively the emission spectrum corresponding to Eq.(1). What are the (numerical values of the) coordinates of the peak? **(3)**

7) A particular semiconductor material of bandgap E_g = 1.35 eV at 300 K behaves as a *laser amplifier* when pumped suitably. If the amplification bandwidth is 6 THz, draw qualitatively the variation of gain with photon energy. (Indicate the range of photon energy over which amplification is possible). **(2)**

8) The gain coefficient of a semiconductor laser amplifier is given by

$$\gamma = \frac{\lambda^2}{8\pi}\frac{1}{\tau_r}\rho(\nu) f_g(\nu)$$

where $f_g(\nu)$ is the *Fermi inversion factor*, and $\rho(\nu)$ is the *optical joint density of states*

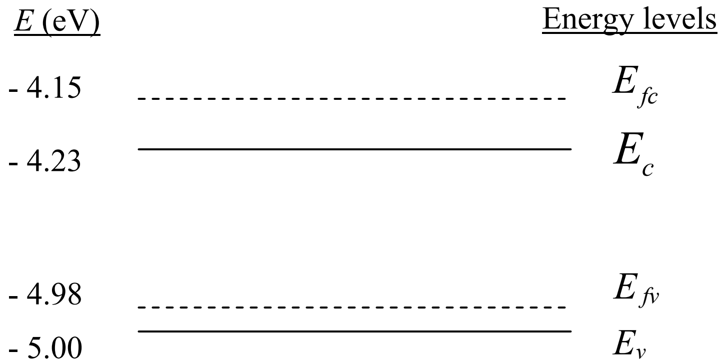
$$\rho(\nu) = \frac{1}{\pi\hbar^2}(2m_r)^{3/2}(h\nu - E_g)^{1/2}$$

a) Considering a GaAs laser amplifier operating at 300K (Eg = 1.42 eV), if the injection current through the device is such that the separation between the quasi Fermi levels is 1.48 eV, draw a schematic representing the variation of gain with photon energy. (Briefly explain the nature of the curve) **(2)**

b) What is the amplification frequency-range ($\Delta\nu$) of this amplifier? **(1)**

c) If the gain medium (at *a)* above) is cooled to 200K, what qualitative changes one would see in the gain variation? (Show this change in the same diagram drawn at *a)* above. Neglect the temperature dependence of Eg.) **(1)**

9) The energy band diagram (indicating the various energy levels) of the active medium of a particular semiconductor laser amplifier is shown in the figure below:



Laser light from a 'coarse WDM system', operating with three different wavelengths – 1.45, 1.55, and 1.65 μm – pass through the above amplifier. If the input powers at the three wavelengths are 1 mW each, then what qualitative changes can we expect in the output powers at each of these wavelengths? (Briefly justify your answer.) **(5)**

10)

a) What is meant by 'gain saturation' in an optical amplifier? (Explain briefly the physical reason for gain saturation) **(2)**

b) The small-signal gain coefficient (γ_0) of an SOA at a particular frequency is 60 cm^{-1} and the length of the gain medium is 500 μm. If the saturation power P_s = 10 mW for this amplifier, then how would you determine the *saturation characteristics*? (Calculate the saturation characteristics of this SOA) **(3)**

11) What is Franz-Keldysh effect? Draw a neat schematic of an electro-absorption modulator based on the Franz-Keldysh effect. (Indicate in the figure, typical dimensions of the various layers, and the materials employed.) Also, estimate the typical extinction ratio of the modulator if used for digital communication. **(1+3+1)**

12) What is meant by 'quantum confined Stark effect' (QCSE)? How does one make use of QCSE to realize high-speed modulators for optical communication? (Explain clearly with the help of relevant schematic diagrams). **(1+4)**