PYL312: SEMICONDUCTOR OPTOELECTRONICS

Major Exam.
April 29, 2019

Max. Marks: 40
Duration: 2 hrs.

Answer *all* questions

Note: All symbols have their usual meaning

1. In the study of semiconductor optoelectronic devices, one normally refers to the *optical joint density of states*; how is this different from the electronic density of states, and what is its importance? (Explain briefly) **(2)**

2. What is meant by *bandgap engineering*? Name any two methods that could be employed to 'engineer' the bandgap of a semiconductor material, and explain briefly how these methods lead to bandgap engineering. **(4)**

3. Why is it necessary to use *direct bandgap materials* to realize efficient semiconductor photon source? Explain clearly with the help of relevant diagrams and the *physics* involved. **(3)**

4. Consider an $In_{0.72}Ga_{0.28}As_{0.6}P_{0.4}$ laser amplifier operating at room temperature ($E_g = 0.95$ eV). At the operating current of the laser amplifier, the excess carrier concentration in the active region is 1.44×10^{18} /cc, and the corresponding separation between the quasi Fermi levels is 0.98 eV. Given that the transparency carrier concentration = 1.20×10^{18} /cc, and material absorption coefficient = 500 cm^{-1}; neglect the dependence of E_g on carrier concentration.
   a) Calculate the *peak gain coefficient* and the amplification frequency-range ($\Delta\nu$) of this amplifier? **(2)**
   b) Draw a schematic representing the variation of gain with photon energy. Mark relevant points on the axes, and briefly explain the nature of the curve. **(2)**

5. a) The spectral distribution of an LED can be represented by an expression of the form:

$$I(\nu) = K(h\nu - E_g)^{1/2}\, e^{-(h\nu - E_g)/kT}; \quad h\nu \geq E_g$$

where K is a constant. Obtain an expression for the wavelength corresponding to the peak of the emission spectrum. **(2)**

b) Given that the *responsivity* of a $GaAs_{1-x}P_x$ LED, emitting radiation at 620 nm, is 20 µW/mA. If the current through the LED is 40 mA, calculate – 1) the output optical power, and 2) the *external quantum efficiency.* **(2)**

6. The *threshold current density* of a DH laser is given by -

$$J_{th} = J_T\left(1 + \frac{\alpha_r}{\alpha_a \Gamma}\right); \quad J_T = \frac{\Delta n_T e d}{\tau}$$

where symbols have their usual meaning. What role does the *confinement factor* play in determining the dimensions of the device structure of DH lasers? Explain briefly with the help of relevant illustrations. **(3)**

7. A laser diode, which operates just at the threshold, has a length of 1000 µm and cleaved end-facets of reflectivity 30% each. If the end facets are now coated with reflective films, so that the reflectivity is increased to 90% (each), calculate the minimum length of the laser necessary to operate the laser diode at the threshold. **(3)**

P.T.O.

8.

a) If you were to design a DFB laser for operation at 1.55 μm, which semiconductor material system would you choose, and why? Estimate (approximately) the period of the grating that is required to realize the DFB laser. **(2)**

b) Why does one employ high-reflectivity Bragg stacks in the construction of VCSELs? (Explain logically using relevant analytical expressions) **(3)**

c) High-power laser diodes are typically fiber-pigtailed in butterfly packages. Give any two important reasons (in one or two sentences) for the choice of the package with the above (underlined) features. **(2)**

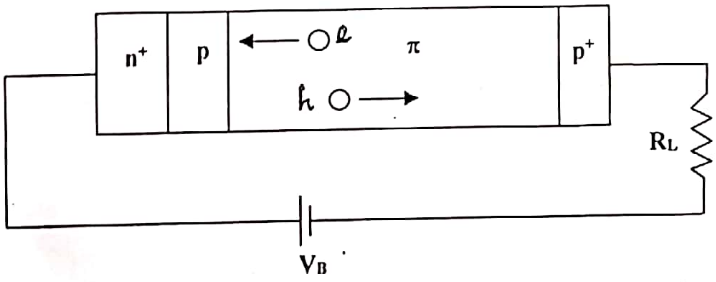
9.

a) What is meant by *quantum efficiency* of a semiconductor photodetector? What are the measures employed to maximize the quantum efficiency? Explain briefly with analytical reasoning. **(3)**

b) A particular InGaAs photodiode with an AR coating (designed for 1240 nm) has a responsivity of 0.6 A/W at 1240 nm. Given that the absorption coefficient of InGaAs at 1240 nm is 10^4/cm, and the thickness of the detector material is 1 μm. What percentage of the generated carriers will contribute to the photocurrent in the external circuit? **(2)**

c) A particular Si PIN diode has a junction capacitance of 20 pF at the operating voltage. The diode is to be used in an application to detect very low levels optical signals, with a maximum frequency content of 50 kHz. Assuming that effect of all other circuit elements are negligible, what would be a suitable value of the load resistance for the above application? **(2)**

10. Figure shows the structure of a silicon *reach-through* APD. Given that the ratio of the *impact ionization coefficients* $\alpha_e/\alpha_h \approx 30$, when the electric field is ~ 10^5 V/cm.



(a) Draw qualitatively the variation of the electric field along the detector medium (i.e. from n⁺ end to p⁺ end). **(1)**

(b) Give 2 important reasons (explaining briefly) for using such a structure in the fabrication of an APD. **(2)**

Some Physical Constants:

$$h = 6.626\times10^{-34}\ \text{J.s},\quad e = 1.602\times10^{-19}\ \text{C}$$

$$m_0 = 9.109\times10^{-31}\ \text{Kg},\quad k_B = 1.381\times10^{-23}\ \text{J/K}$$

Some useful formulae:

$$\gamma_p = \alpha_a\left(\frac{J}{J_T}-1\right) = \alpha_a\left(\frac{i}{i_T}-1\right);\qquad \alpha_r = \alpha_c + \frac{1}{2l}\left(\ln\frac{1}{R_1R_2}\right)$$