Data Provided: List of Formulae

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2015-16 (2.0 hours)

EEE337 Semiconductor Electronics

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. **a.** Sketch and label the current-voltage characteristics of a p-n junction solar cell in the dark and when illuminated with a strong light. **(2)**

b. The so-called Passivated Emitter & Rear Locally-diffused (PERL) solar cell produces a very high conversion efficiency.

i. Describe how the Silicon PERL cell achieve high absorption efficiency.

ii. Explain the design features that maximise the photocurrent generated in the PERL cell. **(7)**

c. Discuss one major advantage as well as a disadvantage of using a narrow bandgap semiconductor, such as InGaAs, for constructing a solar cell. **(4)**

d. i. Describe manufacturing modifications required to reduce the cost of Si solar cell so that large area solar panels can be manufactured.

ii. Explain major drawbacks of the modifications you proposed in (i).

iii. Propose and describe a method to overcome the drawbacks discussed in (ii). **(7)**

2. **a.** List the two essential conditions to achieve lasing in a GaAs pn diode. **(2)**

b. With the aid of diagrams, describe the key features of a GaAs-AlGaAs Fabry Perot laser. In your answer you should discuss how the features help to improve the laser performance. **(10)**

c. In fiber optic communication, wavelength division multiplexing (WDM) is a technique that combines a number of signals at different wavelengths into a single fiber to increase the data transmission.

i) Explain why a simple stripe laser is not suitable for WDM.
ii) Describe a laser structure that can be used in WDM.
iii) Discuss the advantages and disadvantages of the laser structure in (ii) over a Fabry Perot laser. **(8)**

3. **a.** Using a band diagram discuss the origin of the broad spectrum of light emitted by a simple LED. **(4)**

b. An LED is not suitable for high modulation rate, required for optical communication. Explain why? **(2)**

c. The bandgap of $Al_xGa_{1-x}As$ is given by 1.42 +1.247*x*. Describe in detail a design for an LED which can achieve bright emission of near infrared light with a wavelength of 800 nm. A band diagram should be included in your answer. **(7)**

d. The injection efficiency of an LED is given by $\gamma_{inj} = \dfrac{J_e}{J_e + J_{GR} + J_h}$, where J_e is due to electron injection, J_h is due to hole injection and J_{GR} is due to generation-recombination process. Clearly the injection efficiency improves as J_h and J_{GR} are suppressed. For an LED p-i-n structure, discuss

i) two approaches to reduce J_h
ii) how the doping concentration in the i-layer will influence the injection efficiency
iii) how temperature will affect the injection efficiency **(7)**

4. **a.** Describe why is a negative differential resistance of interest to electronic engineers? **(2)**

b. Discuss how the Gunn effect leads to a negative differential resistance in semiconductors. **(6)**

c. i) Propose a suitable diode structure to achieve Gunn effect.

ii) With the aid of velocity vs. electric field diagrams, explain how high frequency oscillation is produced in this Gunn diode. **(8)**

d. Conventional Gunn diodes provide useful microwave power up to around 150 GHz. Describe an alternative microwave device that is used for applications at higher frequencies. **(4)**

CHT/TWANG

List of formulae

$$f^e(E) = \frac{1}{\exp\left(\frac{E - E_{Fn}}{kT}\right) + 1}$$

$$f^h(E) = \frac{1}{\exp\left(\frac{E_{Fp} - E}{kT}\right) + 1}$$

$$I_d = I_s\left[\exp\left(\frac{qV}{kT}\right) - 1\right]$$

$$I_s = qAN_cN_v\left[\frac{1}{N_A}\sqrt{\frac{D_e}{\tau_e}} + \frac{1}{N_D}\sqrt{\frac{D_h}{\tau_h}}\right]\exp\left(-\frac{E_g}{kT}\right)$$

$$J_e = \frac{qD_e n_p}{L_e}\exp\left(\frac{qV}{kT}\right)$$

$$J_h = \frac{qD_h p_n}{L_h}\exp\left(\frac{qV}{kT}\right)$$

$$J_{GR} = \frac{qn_iW}{2\tau}\left[\exp\left(\frac{qV}{2kT}\right) - 1\right]$$

$$V_{bi} = \frac{kT}{q}\ln\left(\frac{N_aN_d}{n_i^2}\right)$$

$$V_{OC} = \frac{kT}{q}\ln\left(1 + \frac{I_{ph}}{I_s}\right)$$

$$W = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{N_a + N_d}{N_aN_d}\right)V_{bi}}$$

$$L_{e(h)} = \sqrt{D_{e(h)}\tau_{e(h)}}$$

$$D_{e(h)} = \frac{kT}{q}\mu_{e(h)}$$

$$I_{tot} = I_s\left[1 - \exp\left(\frac{q(V - I_{tot}R_s)}{kT}\right)\right] + I_{ph}$$

$$I_{ph} = qAG(L_e + W + L_h)$$

$$\eta = \left(\frac{I_{ph}}{q}\right)\left(\frac{P_{opt}}{h\nu}\right)^{-1}$$

$$\eta = (1 - R)[1 - \exp(-\alpha W)]$$

$$R_{res} = \frac{\eta q\lambda}{hc}$$

$$I_{ph} = \frac{\eta\lambda P_{opt}}{1.24}$$

$$t_{diff} = \frac{4x^2}{\pi^2 D_p}$$

$$f_{RC} = \frac{1}{2\pi RC}$$

$$f_{3dB\_tr} = \frac{0.4}{t_r} = \frac{0.4v_s}{W}$$

$$f_{IMP} = \frac{v_{sat}}{2(w - x_a)}$$

$$M = \frac{1}{1 - \left(\frac{V - IR}{V_b}\right)^{n_m}}$$

$$V_B = E_m x_a + \left(E_m - \frac{qQ_c}{\varepsilon_s}\right)(w - x_a)$$

$$SNR = \frac{I_{ph}^{\,2}}{< i_s^{\,2} > + < i_{th}^{\,2} >} = \frac{(q\eta P_{opt}/h\nu)^2}{2qI_TB + 4kTB/R_{eq}}$$

$g(h\nu) = G_{las}[f^e(E^e) + f^h(E^h) - 1]$ cm^{-1} where $G_{las} = 5.6\times10^4\,\dfrac{(h\nu - E_g)^{1/2}}{h\nu}$ for GaAs

$$J_{th} = \frac{qd_{las}n_{th}}{\tau_r(J_{th})}$$

PHYSICAL CONSTANTS

Quantity	Symbol	Value
Boltzmann constant	k	1.38066×10^{-23} J/K
Electron rest mass	m_o	9.1095×10^{-31} kg
Electronic charge	q	1.60218×10^{-19} C
Permeability in vacuum	μ_0	1.25663×10^{-8} H/cm
Permittivity in vacuum	ε_0	8.85418×10^{-14} F/cm
Planck constant	h	6.62617×10^{-34} Js
Speed of light in vacuum	c	2.99792×10^{10} cm/s
Thermal voltage at 300 K	kT/q	0.0259 V

Dielectric constant = 11.9 (Si), 12.4 (GaAs), 13.9 (InGaAs)