Data Provided: List of Formulae

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2013-14 (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.** The absorption coefficients at the wavelength of 633 nm for GaAs and Si are ~5×10^4 cm^{-1} and 2×10^3 cm^{-1} respectively.

i) Calculate the minimum thickness of each sample required to absorb 90 % of the incident light. Is the thickness required easily manufactured?

ii) Despite its smaller absorption coefficient, Si is the preferred option in commercial solar cells. Provide two reasons for this. **(5)**

b. Discuss how the doping concentration in each epilayer of a Si p-i-n diode solar cell affects the output power. **(4)**

c. The solar cell structure shown in figure 1.1 is known as Passivated Emitter & Rear Locally-diffused (PERL) cell. Describe the key features of the PERL cell that enables it to achieve high conversion efficiency.

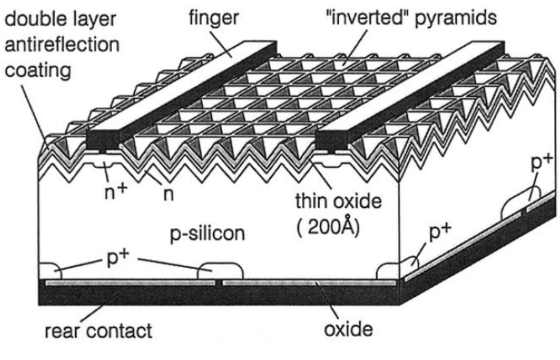

Figure 1.1: Schematic of a PERL cell (Zhao et. al., Solar Energy Materials and Solar Cells 41/42(1996) 87-89) **(6)**

d. The efficiency of Si solar cell is limited to ~ 25 %. Therefore the so-called triple junction tandem solar cell is invented to improve the efficiency. Describe how this tandem solar cell achieves higher efficiency and explain the most popular semiconductor materials used to construct this type of solar cell. **(5)**

2. **a.** Consider a typical avalanche photodiode (APD) with the following parameters

Quantum efficiency = 90%

Breakdown voltage = 30 V

Parameter n_m for the empirical multiplication model = 2

Series resistance = 10 Ω

For an applied voltage of 29 V, the APD has a dark current of 10 nA.

i) Calculate the avalanche multiplication factor produced by this APD.

ii) Assuming that the incident signal is 5 nW and the wavelength is 850 nm, calculate the total photocurrent produced by the APD with an optimised anti-reflection coating. **(6)**

b. In a high speed optical communication receiver module, the APD in part (b) is amplified by an amplifier with a bandwidth of 0.1 GHz and an input noise current of 10 pA/Hz$^{1/2}$.

i) What is the minimum multiplication factor that the APD should provide in order to overcome the amplifier noise?

ii) Is your calculated gain factor achievable and can the gain stability be maintained? **(4)**

c. APDs are routinely used optical communication systems at 10 Gb/s. Due to increasing internet traffic, bit rates in excess of 100 Gb/s are required. Discuss why current commercial APDs are incapable of responding to such high bit rates. **(4)**

d. Suggest the best detector configuration for a 100 Gb/s optical fiber communication. Explain the choice of material used and the design features required to achieve high quantum efficiency and high bandwidth. **(6)**

3. **a.** i) Discuss why a homojunction diode is not an ideal laser structure. **(3)**

ii) Improvements that can be achieved using a double heterostructure laser. **(3)**

b. Describe how a quantum well laser achieves the advantages listed below;

i) a low threshold current
ii) a wider wavelength tuning range **(6)**

c. An infrared laser can be used in spectroscopy systems to measure various properties of materials. InSb is an example of a narrow bandgap material that can be produced with high purity. Discuss whether InSb can be made into an infrared laser with high efficiency. **(3)**

d. Propose and describe the operating principles of an efficient semiconductor laser technology for gas sensing application in the midwave infrared wavelengths of 3-5 µm. You may use a band diagram when describing the operating principles of your proposed laser. **(5)**

4. **a.** IMPATT diodes are used in many high speed applications such as RADAR and high frequency oscillators. Sketch an ideal IMPATT diode structure and use it to explain the working principles of an IMPATT diode. **(4)**

b.

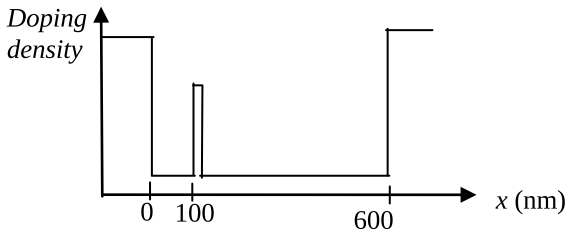

Figure 4.1

A GaAs IMPATT diode with a lo-hi-lo electric field profile is shown in figure 4.1. The breakdown field in GaAs is 600 kV/cm and the doping density of 3×10^{12} cm^{-2} in the field control layer. Assuming negligible voltage drop across the field control layer calculate

i) the oscillation frequency
ii) the breakdown voltage of the IMPATT diode
iii) the field in the drift region

[Note: the relative dielectric constant of GaAs is 12.4] **(6)**

c. Discuss the factors that currently prevent IMPATT diodes from achieving oscillating frequency above 1 THz. **(4)**

d. With the aid of band diagrams describe how a tunnel diode works. Sketch the current-voltage characteristics of the tunnel diode. **(6)**

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List of formulae

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

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

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

$$I_s = qAN_cN_v\left[\frac{1}{N_A}\sqrt{\frac{D_e}{\tau_e}}+\frac{1}{N_D}\sqrt{\frac{D_h}{\tau_h}}\right]$$

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

$$I_{SC}=I_{ph}$$

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

$$W=\sqrt{\frac{2\varepsilon_s}{q}\left(\frac{N_A+N_D}{N_AN_D}\right)V_{bi}}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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