INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

AV212 Semiconductor Devices

Department of Avionics

Final Exam (02/12/2022)

Semester: III

Maximum Marks: 100, Answer ALL questions

A. Your answer should be brief and to the point. Wherever explanations are required, two or three convincing sentences are enough.

B. Draw diagrams wherever required. Every axes of the graph must be labeled.

C. For answers that require "List" or "Mention" simply write down the terms without any explanation.

D. For derivations, every intermediate steps should be shown with proper logical explanations on how you arrive at the result. Any assumptions made should be properly justified.

E. Suitable assumptions can be made for any missing parameters.

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1. **(A)** Draw the energy band diagram for GaAs when GaAs is doped with Si on (a) Ga sites, (b) As sites.
   (B) Explain how temperature affects the bandgap of a semiconductor. What would be the implication of temperature variation on the emission wavelength of a laser diode? **[Total 6]**

2. Eight Si atoms are placed in along a straight line. The lattice constant of this arrangement is a_0 and assume that the bandgap is 1.1 eV. (a) Draw the potential function and the band diagram for this atomic arrangement. (b) The fourth silicon atom from the left is replaced with an Arsenic atom. Redraw the potential function for this new arrangement. (c) For this new arrangement, explain with a figure how the band diagram would be modified. (d) Also explain how the conductivity of the lattice is modified due to the replacement of Si with As atom. **[Total 4]**

3. Draw the IV characteristics of an Esaki diode and explain its operation in the forward bias with band diagrams. What is the main constructional difference between a normal diode and an Esaki diode? **[Total 5]**

4. **(A)** Draw the band diagram of a heterostructure formed between intrinsic $Al_xGa_{1-x}As$ and intrinsic GaAs.
   (B) You are given a heterostructure made out of p^+- $Al_{0.3}Ga_{0.7}As$, p-GaAs and n-$Al_{0.3}Ga_{0.7}As$. The doping density of p^+ is 10 times that of p region, while p and n regions have the same doping densities. The bandgap of $Al_xGa_{1-x}As$ for $0<x<0.45$ is given by $1.424+1.247x$ (eV) where x is the Aluminium composition, and that of GaAs is 1.42 eV. Given that $\Delta E_c = 60\%$ of ΔE_g and $\Delta E_v = 40\%$ of ΔE_g; where ΔE_g is the bandgap difference between $Al_xGa_{1-x}As$ and GaAs. Draw the band diagram of this heterostructure. Your plot should indicate the numerical values of ΔEc, ΔEv and respective bandgaps of each material along with the Fermi level. You should also qualitatively show the dimension of the depletion regions formed at the junctions. **[Total 8]**

5. **(A)** Stating any assumptions you make, derive the Shockley diode equation for a *p-n* diode.
   (B) Assume that a p-n Silicon diode (bandgap=1.12eV) is formed between an p-type and n-type

material.

The doping density at the n side (N_d) is one-half that of p side, and the intrinsic carrier concentration

is

n_i. Use this information to draw the carrier densities on both sides as a function of distance under equilibrium at T=300K.

(C) Now assume that the diode is forward biased by a voltage V. Draw the profile for the carrier densities inside the diode. Also write down the carrier densities at the edges of the depletion region.

Qualitatively indicate the respective depletion widths. **(you need not calculate them)**

(D) Draw the band diagram of a p-n homojunction diode under (1) equilibrium, (2) forward bias of voltage V. In your diagram, indicate the separation between the Fermi levels. Also indicate the position of intrinsic Fermi level and all other relevant parameters. For drawing (1) and (2), assume a symmetric junction.

(E) For the diode under equilibrium, write down the relationship between the various current components for electrons and holes. Also, indicate the directions of the particle movement and their corresponding currents in the drawn figure.

(F) Draw the I-V curve of a diode in log scale. Mention what additional information can be obtained from the logarithmic plot. **[Total 16]**

6. (A) You have studied that at the junction, there is a built-in voltage (V_{bi}) due to carrier migration. You are given a highly sensitive multimeter and you are asked to measure the built-in voltage. Can you measure this voltage? Explain your reasoning.

(B) Define internal quantum efficiency, extraction efficiency and external efficiency of an LED.**[Total 5]**

7. (A) Using a diagram, show the various current components flowing across the junctions of an npn transistor under active mode of operation. Also show the direction of particle flux that flows across the junctions. In this figure, also label the transistor terminal currents and their direction.

(B) Derive an expression for the common emitter current gain of an npn transistor. **[Total 8]**

8. (A) Draw the I-V characteristics of an unbiased *p-n* junction illuminated with light connected to a resistor R. In the figure, mark the current when the terminals of p-n diode is shorted, and the voltage across p-n diode terminals when the resistance is made infinity, and obtain expressions for both of them. Can you simultaneously maximize this current and voltage? Justify your answer.

(B) What is a multi-junction solar cell, and why is it preferred over single junction cell? Why is the widest bandgap material placed on the top of the solar cell in a multi-junction solar cell?**[Total 8]**

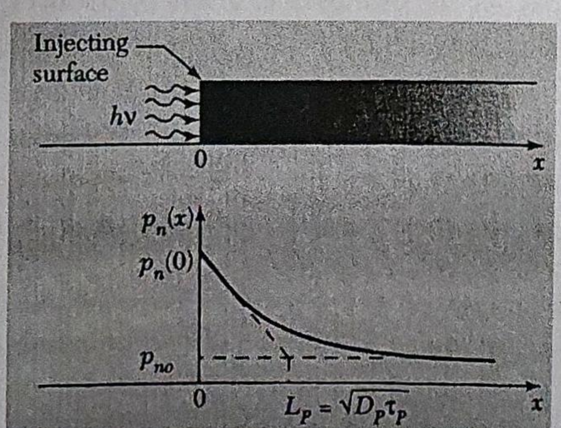
9. (A) Draw and explain the CV characteristics of a MOS capacitor (formed on *p* substrate). **[Total 6]**

10. (A) Design a technique to experimentally determine the bandgap of a semiconductor material.

(B) Based on Prof Nakamura's video what you all had seen [Homework], explain the drawbacks of introducing dislocations in light emitting devices? Dislocations need not be always bad for a device. Explain any instance in which dislocations are deliberately introduced to improve the device performance.

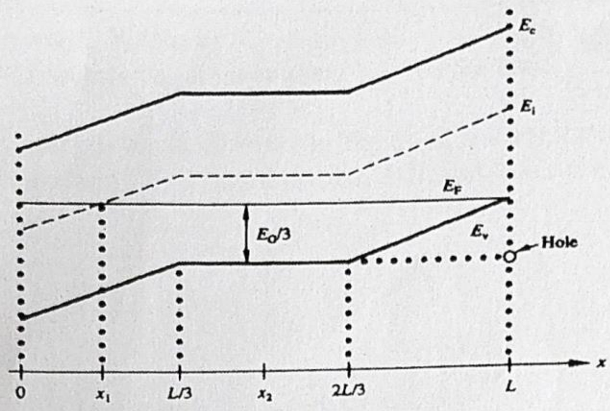
(C) In a solar cell, photons are absorbed generating electrons and holes. Comment on the magnitude of the life time of carriers generated so as to maximize the efficiency. Justify your answer. **[Total 8]**

11.



For an n-type semiconductor sample of infinite length as shown in previous page, excess minority carriers are injected from one side by shining a laser beam. Assuming that light penetration is negligible and there is no electric field inside the sample, set-up the continuity equation for the excess minority carrier inside the sample. Use appropriate boundary conditions to solve the continuity equation. **[Total 5]**

12. Assume that an n-p homojunction is formed between an n-type and p-type material. The doping density at the n side is one-half that of p side. Use this information to draw the charge density, electric field, potential and the band diagram of the formed junction. Mention how you obtain them. Indicate the respective depletion widths. **(For your drawing, the n-region MUST be at the left side, if not, no points will be awarded) [Total 8]**



13. The above diagram shows the energy band diagram of a Silicon sample at 300K.

(A) Plot the electrostatic potential inside the sample as a function of distance
(B) Plot the electric field inside the sample as a function of distance
(C) Is the sample under equilibrium? Justify your answer
(D) Is the semiconductor degenerate at any point? If so where?
(E) At x_2 what is the value of hole concentration?
(F) At x_1 what is the electron current?
(G) What is the Kinetic Energy of a hole situated at x=L? **[Total 7]**

14. An abrupt p-n junction is formed using Si having a bandgap of 1.12eV. What would be the maximum value of built-in voltage at room temperature without having degenerate Silicon? Explain how you obtained the answer. **[Total 6]**

Good luck and Happy Holidays to all of you!!!