VIGNAN'S

FOUNDATION FOR SCIENCE, TECHNOLOGY & RESEARCH

(Deemed to be University) - Estd. u/s 3 of UGC Act 1956

Module Bank

Module 2

Academic Year 2025-26

Staff Name: Dr. Sreekar Guddeti

Program Name: B. Tech
Branch: AI/ML
Year: 1
Semester: 1
Course: EP
Code: 25PY101

Section number: 28, 34

Instructions:

1. Answer all questions.
2. BT stands for Blooms Taxonomy.

1. Quantum Free Electron Theory (QFET)

a) Compare and contrast the postulates of classical free electron theory with that of quantum free electron theory. [BT 1]
b) What are the merits of quantum free electron theory? [BT 1]
c) What are the demerits of quantum free electron theory? [BT 1]

2. Fermi-Dirac Distribution

a) Plot the probability of occupancy of energy level in the case of Maxwell-Boltzmann distribution and Fermi-Dirac distribution at

i. $T = 0K$,
ii. $T \neq 0K$, and
iii. $T = \infty\ K$ [BT 2]

b) Five free electrons exist in a three-dimensional infinite potential well with all three widths equal to $a = 12$ Å.
   i. Determine the Fermi energy level at $T = 0K$.
   ii. Repeat part (i) for 13 electrons. [BT 3]

c) Fermi level of a metal is 6.25 eV and electrons in this material follow the Fermi-Dirac distribution. Calculate the temperature at which there is 1% probability that a state 0.30 eV below the Fermi energy level will **not** contain an electron. [BT 4]

3. Electronic specific heat of solids

a) Define specific heat of a material. [BT 1]

b) What is the expression for specific heat capacity from classical free electron theory. [BT 1]

c) Derive the expression for specific heat capacity from classical free electron theory and quantum free electron theory. [BT 2]

4. Density of states

a) What is the meaning of density of states function? [BT 1]

b) If the density of states of a material is a constant $Z(E) = k$ and the electron density is n, what is the Fermi level at $T = 0K$? [BT 3]

c) Sketch the density of states function
   i. for the conduction band of an intrinsic semiconductor.
   ii. Repeat part (i) for the valence band. [BT 2]

5. E-k diagram

a) Sketch the $E\ vs\ k$ diagram for a free electron. [BT 1]

b) Sketch the $E\ vs\ k$ diagram for an electron in a periodic potential. [BT 1]

c) Consider an intrinsic semiconductor with all electrons occupying states in the lowest valence band at $T = 0K$. Plot the $E\ vs\ k$ showing occupancy of levels at both $T = 0K$ and $T \neq 0K$. [BT 2]

6. Fermi level in semiconductors

a) Sketch the energy band diagram showing the density of states, Fermi-Dirac probability function and areas representing electron and hole concentration for an intrinsic semiconductor at $T \neq 0K$. [BT 1, 2]

b) Repeat part (a) for the case of
   i. n-type semiconductor, and
   ii. p-type semiconductor. [BT 1, 2]

c) Draw, compare, and contrast the sketches of the energy band diagram for p-type semiconductor at $T = 0K$ and $T = 300K$. [BT 3]

7. p-n junction diode

a) Define the built-in potential voltage and describe how it maintains thermal equilibrium. [BT 1]

b) Why is an electric field formed in the space charge region? [BT 2]

c) Discuss the change in width of depletion region

i. at forward bias, and
ii. at reverse bias. [BT 2]

8. Solar cell

a) Sketch the $I - V$ characteristics of pn junction solar cell. [BT 1]
b) Define short circuit current and open circuit voltage. [BT 1]
c) The energy band gap of a semiconductor is 3 eV. Is this material useful for solar cell applications? Give reasons. [BT 4]

9. Direct and indirect band gap semiconductors

a) Sketch the E vs k diagram for
   i. a direct bandgap semiconductor, and
   ii. an indirect bandgap semiconductor. [BT 1]
b) Why is direct band gap semiconductor useful for solar cell application? Crystalline silicon is indirect band gap semiconductor. What is the process employed in industry to "convert" it into a direct band gap semiconductor for solar cell application? [BT 2]
c) Which material is used in blue LED? If the wavelength of blue photon is 0.4 μm, what is the bandgap of the material? [BT 3]

10. LED

a) What are the materials used for red, green, and blue LEDs? [BT 1]
b) What are the mechanisms that decrease the efficiency of an LED? How does heterojunction-based LED address the efficiency problem? [BT 1]
c) Calculate the critical angle at GaAs - air interface. The refractive index of GaAs is 3.8 at $\lambda = 0.70\ \mu m$. [BT 3]

End of module bank