ECE210 - PSD
Quiz 1
Marks: 10
Date: 19/02/2024
Time: 25 mins

ECE IIITD
DEPARTMENT OF ELECTRONICS & COMMUNICATIONS ENGINEERING

Answer all 6 questions
(keep your answer short and specific)

1. What are the Maxwell-Boltzmann (MB) and Fermi-Dirac (FD) distribution function of electrons and holes? What are the limiting factors that turn an FD distribution into an MB distribution? **[2 + 2 = 4]**

2. Does the current flow in a semiconductor at 0K temperature? Justify your answer. **[1]**

3. What is the significance of Bloch wave in a crystal? **[2]**

4. Solving the wave equation for a given periodic potential, u(x), can be challenging. In the lecture and in ref. Neaman, a periodic system of finite, rectangular quantum wells is solved. Even for this simple problem, the math is non-trivial, but the solutions display the general features of all periodic crystal potentials. What is the name of this classic model problem for bandstructure? **[1]**

5. Silicon, Germanium, and Gallium Arsenide have different bandstructures. Which of the following is true? **[1]**

   a) The conduction bands for them are similar in shape.
   b) The valence bands for them are similar in shape.
   c) The conduction and valence bands are different all three.
   d) Si and GaAs have similar conduction bands but different valence bands.
   e) Ge and GaAs have similar conduction bands but different valence bands.

6. The bandgap is an important property of a semiconductor, but the type of bandgap is also important. Out of three semiconductors, Ge, Si, and GaAs, which one has direct bandgap? **[1]**

ECE210 - PSD
Midsem exam
Marks: 30
Date: 24/02/2024
Time: 1.00 Hours

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Answer all questions
(keep your answer short and specific)

1) (a) Is a time-independent quantum wave function below traveling toward the positive or negative direction? Explain why.

$$\Psi(x) = Ae^{jkx}, \text{ where the } k \text{ is a real and positive number.}$$

An electron in free space is described by a plane wave given by $\Psi(x,t) = Ae^{j(kx-\omega t)}$ where $k = 1.5 \times 10^9\ m^{-1}$ and $\omega = 1.5 \times 10^{13}$ rad/s.

(b) Determine the phase velocity of this plane wave.

(c) Calculate the wavelength of the electron. **[2+2 +2 = 6]**

2) Consider the *E(k)* plot in Fig. 1, answer the following questions. **[1×12 = 12]**

(a) Is this a direct or indirect bandgap semiconductor?

(b) What is the bandgap of this semiconductor?

(c) If we shine solar light on this semiconductor, then which part of the solar spectrum (IR or visible or UV) will be absorbed more in this semiconductor?

(d) Where is the largest effective mass for electrons, point A or C?

(e) Where is the effective mass for electrons negative, point A, B, or C?

(f) What is the velocity of an electron at point D, positive, zero, or negative?

(g) Where do you expect the carrier mobility will be high, at point A, B, or C?

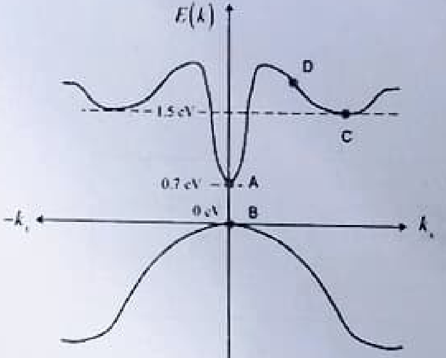

Fig.1

(h) If we apply an electric field in the $-x$ direction, which direction in *k-space* does the electron at point D move? (in the $+k_x$ direction or in the $-k_x$ direction).

(i) Can you guess the number of valley degeneracies at A, B, and C from the plot?

(j) Compare the density-of-states in energy, *D*(*E*), at points A and C. Which one is larger?

(k) For common cubic semiconductors, what is the shape of the constant energy surface near point A? (spherical or ellipsoidal)

(l) For common cubic semiconductors, what is the shape of the constant energy surface near point C? (spherical or ellipsoidal)

3) InSb is a semiconductor with a very small bandgap of 0.18 eV and the conduction and valence band extrema are spherical with $m_e^* = 0.0116m_0$ and $m_h^* = 0.40m_0$. For intrinsic InSb, do you expect the intrinsic Fermi level to lie at $(E_C + E_V)/2$, above $(E_C + E_V)/2$, or below $(E_C + E_V)/2$ at 0K and 300K? Explain your answer. **[1.5+1.5 = 3]**

4) Determine the Miller indices of the plane sketched in Fig. 2 and find out the spacing between equivalent planes of this kind (in terms of the lattice parameter, a). **[1.5+1.5 = 3]**

5) If you have a crystal with a lattice constant 'a' in one-dimension, then what will be its lattice constant in reciprocal space? If we do a Fourier transform of the Wigner Cell of a Silicon crystal, will it look the same as before? **[1.5+1.5 = 3]**

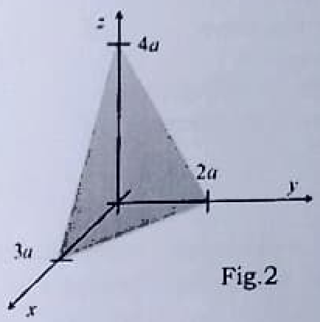

Fig.2

6) Suppose one electron is traveling from left to right with energy E in Fig. 3. Which one will have a higher tunneling probability and why? **[3]**

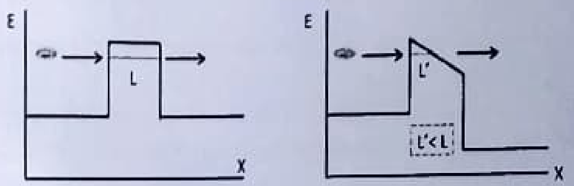

Fig.3

* Constants, if required
Electron charge = 1.6×10^{-19} Coulombs
Electron mass = 9.1×10^{-31} kg
Planck's constant = 6.62×10^{-34} kg m^2/s
1 eV = 1.6e^{-19} Jule

Quiz 3

ECE210: PSD

Date: 08/04/2024

Duration: 25 mins

Marks: 10

1. For a compound semiconductor like $Al_xGa_{(1-x)}As$, if the electron affinity and energy bandgap are defined as, $\chi = (4.07 - 1.1x)\,eV$ and $E_g = (1.424 + 1.247x)\,eV$ for $(x<0.45)$, then, draw the energy band diagram for N-p and P-n heterojunction of $Al_{0.3}Ga_{0.7}As$: GaAs before and after making the contact. **[2+2=4]**

2. Draw the energy band diagram of a n-p-n and p^{++}-i-n^{+} device structure? Can you guess the electron transport mechanisms from the energy band diagram of those two different cases? **[2+2=4]**

3. What is an amphoteric dopant? Give an example. **[2]**

$$\begin{array}{r} 1247 \\ \times\ 3 \\ \hline 0.3641 \\ 1.424 \\ \hline 1.7881 \end{array}$$

ECE210 – PSD
Quiz 4
Marks: 10
Date: 22/04/2024
Time: 25 mins

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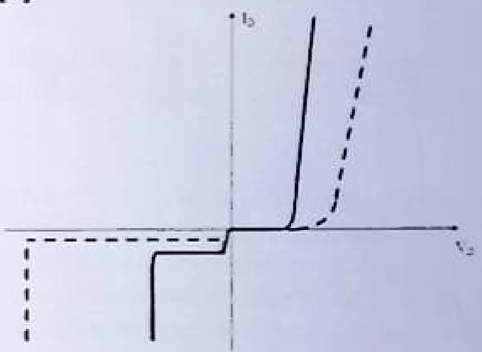
Answer all 5 questions
(keep your answer short and specific)

1. The forward bias current in a typical (a) Schottky and (b) p-n junction is due to what physical transport mechanism? **[2]**

2. In the attached I-V plot, can you guess, which one is the Schottky and which one is the p-n junction diode characteristics? Explain your answer with proper justification. **[2]**



3. Among Schottky and p-n diode, which one is the majority and which one is the minority carrier device? Explain your answer with proper justification. **[2]**

4. Among Schottky and p-n junction diode, which one is unipolar and which one is bipolar device? Explain your answer with proper justification. **[2]**

5. What is contact resistance and when does it arise? **[2]**

ECE210 - PSD
Endsem exam
Marks: 30
Date: 01/05/2024
Duration: 2.00 Hours

ECE
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DEPARTMENT OF ELECTRONICS & COMMUNICATIONS ENGINEERING

Answer all questions
(keep your answer short and specific)

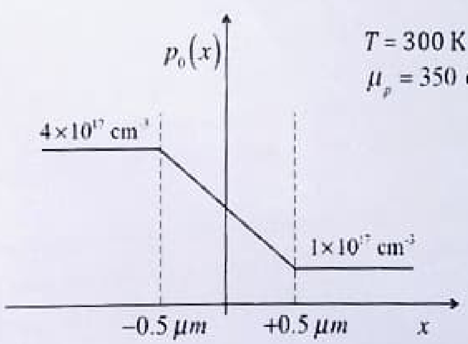
1) (a) Determine the wavelength of radiation that can be emitted or absorbed by (a) Si (E_g = 1.12 eV), (b) GaAs (E_g = 1.42 eV) and (c) GaP (E_g = 2.3 eV) and indicate the region of the spectrum corresponding to these wavelengths. Among these materials, which one has the potential for visible light emitting applications? **[3 +1 = 4]**

2) A Si sample is doped with 10^{16} boron atoms/cm^3. (a) What is the equilibrium electron concentration n_0 at 300K? (b) Where is E_F relative to E_i? Assume for Si at 300K, n_i = 1.5×10^{10} cm^{-3} and Eg = 1.12 eV. **[2+2 = 4]**

3) Assume that in a given semiconductor, there is only one scattering mechanism present with a relaxation time of 0.2 ps. (a) Determine the electron mobility in the sample. Now, if there were another scattering mechanism present with a relaxation time 0.3 ps, determine its solo effect on electron mobility. What is the overall electron mobility in the sample if both scattering events were present simultaneously? (b) Comment on your observation of the mobility values that you obtained. Assume $m_e^* = 0.5m_0$. **[3 +1 = 4]**

4) (a) In room-temperature, if the electron mobility of a semiconductor is higher than the hole mobility, then which one will be higher, the electron or hole diffusion coefficient?

(b) Consider a *p*-type semiconductor in equilibrium with a non-uniform doping density resulting in the hole concentration as shown below. What will be the numerical value of the total current density at *x=0*? What will be drift and diffusion current density at *x =0*? What will be the electric field at *x=0*? **[1+1+1+1=4]**



5) (a) What is pinch-off condition of a MOSFET?
(b) Among MNOS and PMOS, which one is faster and why? **[2+2 = 4]**

6. (a) What is transconductance and why is it a key parameter of a MOSFET?
(b) What is subthreshold slope (SS) and what is the limiting value of it in a MOSFET? **[2+2 = 4]**

7. (a) Given an energy band diagram, how do we find the electric field and the electrostatic potential? **[1 + 1 = 2]**

(b) What is temperature dependence of the mobility due to ionized impurity and lattice vibration? **[1 + 1 = 2]**

(c) What is Fermi level pinning? If there is a Fermi level pinning present in a MOSCAP, then what will be its impact on threshold voltage? **[1 + 1 = 2]**

* Constants, if required
Electron charge = 1.6×10^{-19} Coulombs Electron mass = 9.1×10^{-31} kg Planck's constant = 6.62×10^{-34} kg m^2/s 1 eV = $1.6e^{-19}$ Jule Velocity of light (c) = 3×10^8 m/s

$K = 1.38 \times 10^{-23}$ J/K

$kg\, m^2 s^{-2}$