Problem 1 – (30 points: 5 points each)

Please respond to the questions below by circling T (for true) or F (for false). Please add comments if you think your answer needs an explanation:

a. A piece of aluminum is placed in a vacuum. This metal surface is exposed to light having an energy equal to 16eV. Therefore, the emitted electron will also have an energy equal to 16eV. T/F

The metal surface will have a work function,

\[ E_m = hf - q\phi \]

\[ \therefore E_m < hf = 16eV \]

b. Compared to photons of low wavelength light, photons of higher wavelength light have lower energy. T/F

\[ \lambda = C/f \quad \text{and} \quad E = hf \]

If \( \lambda \uparrow \) then \( f \downarrow \) and \( E \downarrow \)

c. The graph shown below is for an insulator (based on the bandgap value): T/F

![Graph of Si](image)

This is a graph of Si

d. SiB is an n-type material. T/F

Boron has less electrons than Si, so more holes.

So p-type material.

e. The Fermi level for intrinsic Ge is 0.335eV (ignore temperature or other perturbations). T/F

Intrinsic material has no impurities.

\[ \therefore E_F = \frac{1}{2} E_g \]

f. Doping Ga with As increases the value of \( E_F \) (ignore temperature or other perturbations). T/F

As has extra electrons and so "donates" them. There is a higher likelihood of an \( e^- \) being near the conduction band, and so \( E_F \) will be higher.
Problem 2 – (25 points) (hint: use data from the table)

Use the figure below:

(a) Draw the (110) surface. State the exact location of each atom's nucleus relative to the bottom left hand corner along with the type of atom at each location (13 points)

(b) What is the surface density (atoms/cm²) of just the Ga atoms on the surface of the (110) plane? (6 points)

\[ \frac{2 \text{ atoms}}{a}(\frac{a}{\sqrt{2}a}) = \frac{2 \text{ atoms}}{\sqrt{2}(5.65 \times 10^{-8} \text{ cm})^2} = 4.43 \times 10^{14} \text{ atoms/cm}^2 \]

(c) What is the surface volume (atoms/cm³) of just the As atoms? (6 points)

Corners: \( 8 \left(\frac{1}{8}\right) \) each corner

Faces: \( 6 \left(\frac{1}{2}\right) \) shared by 2 others

\[ \therefore \text{4 atoms} / \alpha^3 = \frac{4}{(5.65 \times 10^{-8} \text{ cm})^3} = 2.2 \times 10^{22} \text{ atoms/cm}^3 \]
Problem 3- (35 points)
The diagram shown below is of a narrow-gap material. Particles in such a narrow-gap material behave similar to those in a quantum well.

\[ \begin{align*}
\text{AIP} & \quad \text{InP} \quad \text{AIP} \\
\text{15 Angstroms} \\
E_c & = 2.45 \text{ eV} \\
E_g & = 1.35 \text{ eV} \\
E_v & = 0 \text{ eV} \\
E_3 & \\
\end{align*} \]

(a) Label the 2 missing dimensions on the Ec/ E_v diagram above. (4 points)

(b) Calculate the first 2 energy levels (E1 and E2) and label them on the above diagram of Ec (Assume that the electrons are free and not contained in a lattice) (10 points)

\[ \begin{align*}
E_1 & = \frac{\pi^2}{(15\text{A})^2} \frac{h^2}{2m} = \frac{\pi^2}{L^2} \frac{h^2}{2m} = \frac{h^2}{L^2 \cdot 8} \\
& = \frac{(6.63 \times 10^{-34})^2}{(15 \times 10^{-10})^2 (9.11 \times 10^{-31}) (8)} = 2.18 \times 10^{-20} \text{ J} \\
E_2 & = \frac{2^2 \ h^2}{L^2 \cdot 8m} = \frac{1672 \times 10^{-19} \text{ J}}{= 0.67 \text{ eV}} \\
\end{align*} \]

(c) State the allowed value of E3. (5 points)

\[ E_3 = 9 E_1 = 2.41 \times 10^{-19} \text{ J} = 1.51 \text{ eV} \]
d. Determine the temperature at which there is a 25% probability that a state 0.1 eV above the Fermi level is occupied by an electron. (8 points)

\[
\frac{1}{e^{2.5}} = \frac{1}{e^{\frac{0.1}{kT}}} = \exp \left( \frac{-0.1}{kT} \right)
\]

\[
\ln(3) = \frac{0.1 \text{ eV}}{kT}
\]

\[
T = 1056 \text{ K}
\]

e. Determine the wavelength and momentum of a photon during recombination. (8 points)

\[
E = hf = \frac{hc}{\lambda} \implies \lambda = \frac{hc}{E}
\]

\[
\lambda = \frac{4.14 \times 10^{-15} \text{ eV} \cdot \text{s}}{1.35 \text{ eV}} \cdot \frac{3 \times 10^8 \text{ m/s}}{1.35 \text{ eV}} \approx 920 \text{ nm}
\]

\[
p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34} \text{ Kg} \cdot \text{m}^2/\text{s}}{920 \text{ nm}} = 7.2 \times 10^{-28} \text{ Kg} \cdot \text{m/s}
\]
Problem 4 – (10 points)

Sketch energy band diagrams ($E$ versus $k$ in primary symmetry directions) for two hypothetical materials $A$ and $B$ which have the following properties.

(a) The bandgap of material $A$ is $0.67\text{eV}$.
(b) The effective mass of electrons is larger in material $A$ than in material $B$.
(c) Most recombination in Material $B$ results in photon emission.
(d) Material $B$ has a smaller lattice constant than material $A$.

Material $A$ can be direct or indirect. It was not specified.