ISD 2023 - Week 12 Assignment

There are 10 questions for a total of 20 marks.

1. (2 marks) In a two-level system, N_1, N_2 denotes carrier density in the ground and excited state, and A_{ij}, B_{ij} are Einstein's A, B coefficients, respectively (i and j represent a transition from $i \rightarrow j$). Choose the correct rate equation for the spontaneous emission process.

Refer to the lecture.

   A. $\frac{dN_2}{dt} = A_{21}N_2$

   B. $\frac{dN_2}{dt} = B_{21}N_2$

   C. $\frac{dN_2}{dt} = -A_{21}N_2$

   D. $\frac{dN_2}{dt} = -B_{21}N_2$

   E. $\frac{dN_2}{dt} = -B_{21}N_1$

2. (2 marks) The radiative and non-radiative lifetimes of an emitter are given by τ_r and τ_{nr}, respectively. In which of the following cases will the material be an efficient light emitter?

Refer to the lecture

   A. $\tau_r >> \tau_{nr}$

   B. $\tau_r = \tau_{nr}$

   C. $\tau_r << \tau_{nr}$

   D. Emission efficiency of a material is independent of τ_r and τ_{nr}.

> **Reflect and remember:** If the radiative lifetime is larger than the non-radiative lifetime, the light emission becomes inefficient and generates heat. The radiative and non-radiative transition rates, being independent of each other, and their sum result in a total transition rate, which is the inverse of the actual level lifetime.

3. (2 marks) Given below are two statements.

   $S1$: Photo-luminescence is a phenomenon of re-emission of light after absorbing a photon of higher energy.

   $S2$: Electro-luminescence is a phenomenon of emission of photons by supplying current to the semiconductor.

   A. Both $S1$ and $S2$ are true.

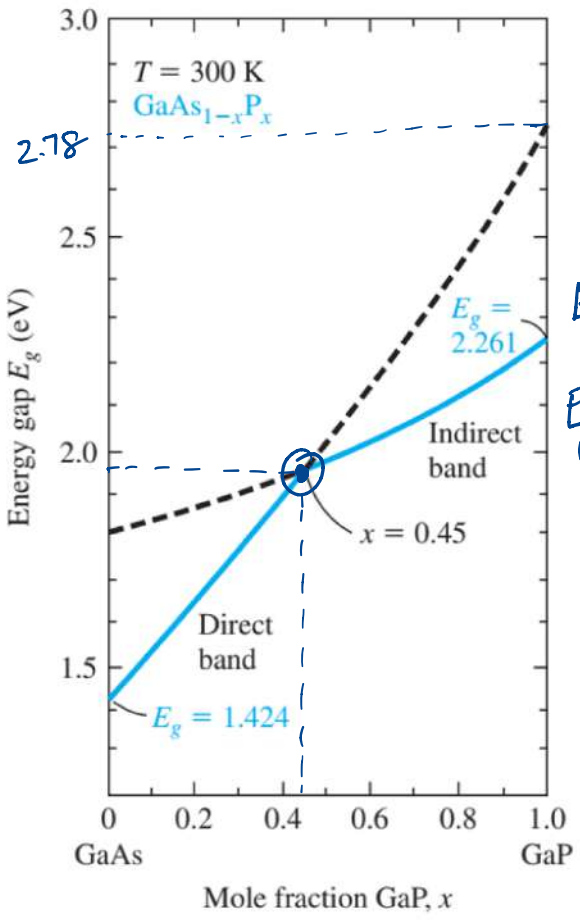
   B. $S1$ is true and $S2$ is false.

C. $S1$ is false and $S2$ is true.

D. Both $S1$ and $S2$ are false.

4. (2 marks) GaP has an indirect bandgap at $2.27\ eV$ and a direct bandgap at $2.78\ eV$. The band gap of the alloy semiconductor $GaAs_{1-x}P_x$ varies approximately linearly with composition and is a direct bandgap for $0 \leq x \leq 0.45$. The energy gap when $x = 0.45$ and makes alloy composition a direct bandgap material is approximately _____ eV. (bandgap of $GaAs$ is $1.42\ eV$)

$E_g - GaAs_{0.55}P_{0.45}$ - ?



Mathematical approx.

$E_g(x) = 1.42 + 1.36x$.

$E_g(0.45) = 1.42 + 1.36 \times 0.45$
$\approx 2\ eV$.

A. 1.42

B. 2.78

C. 2.27

D. 1.95

Reflect and remember: Consider the case $x > 0.45$, where the semiconductor bandgap becomes indirect and becomes less efficient for optoelectronic devices. For more details, refer to the "Semiconductor Physics and Devices - Basic Principles" by Donald A. Neamen, Fourth Edition Chapter 14.

5. (2 marks) Given below are three statements about bulk materials:

   $S1$: LEDs made from Si and Ge are more efficient than LEDs made of GaAs.

   $S2$: Si and Ge LEDs cannot emit efficient light as they are indirect bandgap materials.

   A. Both $S1$ and $S2$ are true.

   B. $S1$ is true and $S2$ is false.

   C. $S1$ is false and $S2$ is true.

   D. Both $S1$ and $S2$ are false.

6. (2 marks) Given below are two statements.

   $S1$: It is difficult to build a blue laser compared to a red laser.

   $S2$: Spontaneous emission becomes stronger with decreasing wavelength.

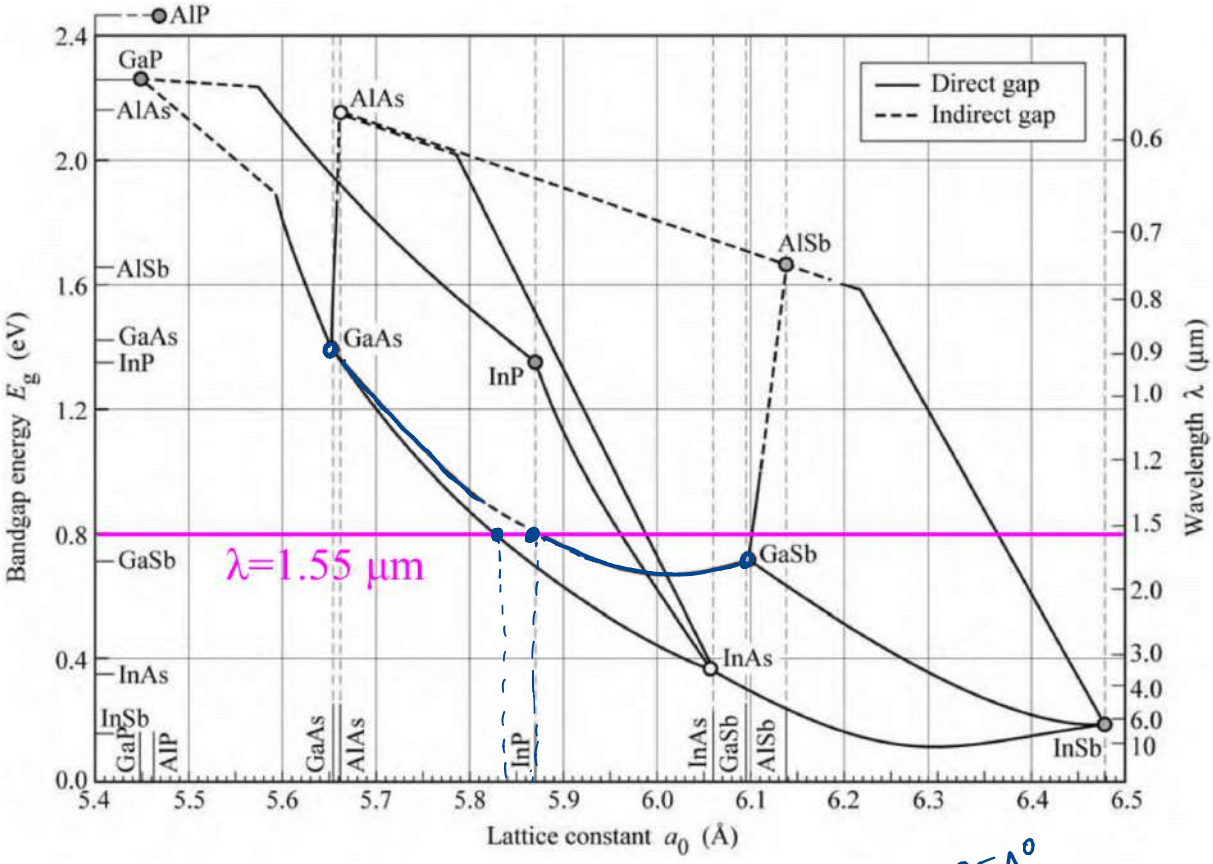
   A. $S1$ and $S2$ are true. $S2$ is the correct explanation of $S1$.

   B. $S1$ and $S2$ are true. $S2$ is not the correct explanation of $S1$.

   C. Both $S1$ and $S2$ are false.

   D. $S1$ is false and $S2$ is true.

7. (2 marks) Consider the bandgap-composition graph of III-V compound semiconductors shown in the figure below. Referring to the data in the figure, which compound will you suggest to choose to fabricate a lattice-matched LED on InP substrate at $1.55\ \mu m$?



Lattice matching. $a_0 \sim 5.85$ Å.

(i) GaAs – InAs

(ii) GaAs – GaSb.

A. $Al_xIn_{1-x}P$

B. $Ga_xIn_{1-x}P$

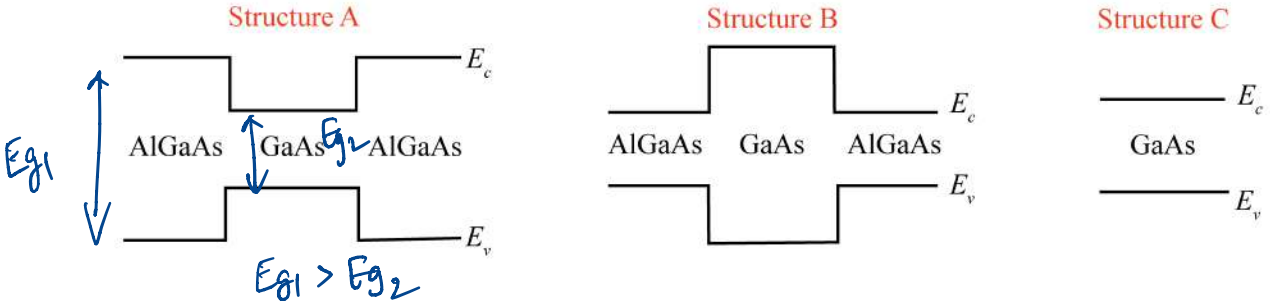
C. $Ga_xIn_{1-x}As$

D. $GaAs_xSb_{1-x}$

E. $(Al_xGa_{1-x})_{0.5}In_{0.5}P$

Reflect and remember: For a better light source, the lattice constant (a_0) of the two semiconductors have to be matched, which is referred as **Lattice matching**. As a practice, think about which combination of semiconductors can be used to make a source with $820\ nm$.

8. (2 marks) Consider the schematics of the structures A, B, C, and one of them can be used for fabricating a laser. Which of the following statements is true?



A. All the structures as they consist of direct bandgap GaAs material.

B. Structure A and B as they confine both electrons and photons, being double heterostructures.

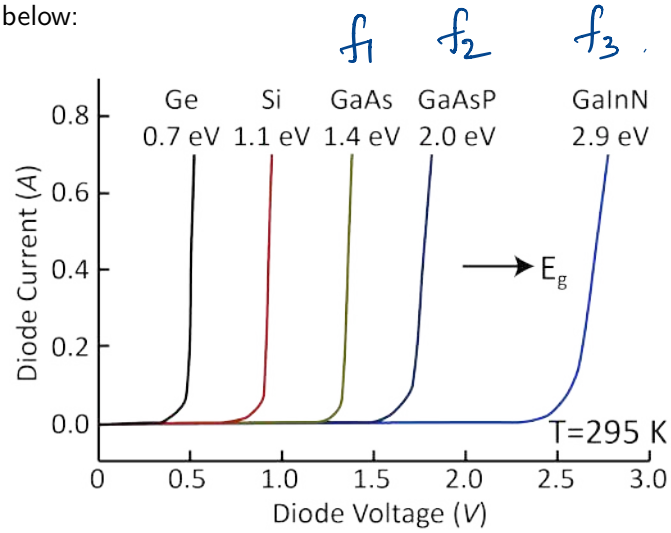
C. Structure A as it confines both electrons and photons, being a double hetero-structure.

D. Structure B as it confines both electrons and photons, being a double hetero-structure.

E. Structure C as it is easy to fabricate.

> **Reflect and remember:** Here, a double Hetero-junction (DH) laser structure consists of a thin layer of narrower bandgap III-V semiconductor (e.g. $E_{g-GaAs} = 1.42\ eV$) sandwiched between two alloy materials (e.g. p-AlGaAs and n-AlGaAs) with a wider bandgap ($E_{g-AlGaAs} = 2.1\ eV$), and moreover, the lattice should be matched. For more information, look into the "Semiconductor Physics and Devices - Basic Principles" by Donald A. Neamen Fourth Edition Chapter 14.

9. (2 marks) Consider the I-V characteristics of various light-emitting diodes made up of different materials, as shown in the figure below:



Choose the correct statement with respect to the frequency of light emitted by diodes.

A. $f_{GaAs} > f_{GaAsP} > f_{GaInN}$

B. $f_{GaAs} < f_{GaAsP} < f_{GaInN}$

C. $f_{Ge} > f_{Si} > f_{GaAs} > f_{GaAsP} > f_{GaInN}$

D. $f_{Ge} < f_{Si} < f_{GaAs} < f_{GaAsP} < f_{GaInN}$

E. $f_{GaAs} = f_{GaAsP} = f_{GaInN}$

Reflect and remember: LEDs are a type of PN junctions made of direct bandgap materials. The maximum threshold voltage is achieved when $E_{Fn} \rightarrow E_C$ and $E_{Fp} \rightarrow E_V$ and in the order of the bandgap ($V_{th} \approx E_g/q$). The emission frequency of light (equivalent to their bandgap) can be decided based on the threshold voltage of the diode.

10. (2 marks) Consider the following statements regarding the two-level system with E_1, E_2 denotes the energy levels & N_1, N_2 denotes carrier density in the ground and excited states, respectively.

S1: At equilibrium condition, $N_1 > N_2$ and follows Maxwell-Boltzmann distribution.

S2: When $N_1 < N_2$, population inversion is achieved, which is the necessary condition for stimulated emission.

Which of the following is true?

A. Both $S1$ and $S2$ are true.

B. Both $S1$ and $S2$ are false.

C. $S1$ is false and $S2$ is true.

D. $S1$ is true and $S2$ is false.