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Subject - Advanced process and materials. M6X00414

1a. The band structure of semiconductors form when isolated atoms come together due to the intermixing/sharing of electrons in the valence shell, as a result the number of permissible energy levels are formed.

Three energy bands are: -



Conduction band (empty - (lowest un-occupied energy level))

Gap band



Valence band. (Highest occupied energy level)

1b With intrinsic semiconductors $N=P$, with an intrinsic semiconductor being an undoped/pure material the number of hole + electrons are equal

1c With extrinsic semiconductor the electrical properties are dictated by its impurities (doping), if a dopant material for example of 5 valence electrons is added to a 4 valence electron base material, this causes a free ~~electron~~ valence electron thus causing an N-type semiconductor. $N \gg P$

1d For intrinsic semiconductors $N=P$, for extrinsic $N \gg P$ or $P \gg N$, so the charge carrier concentration changes due to the amount of free electrons (N) or free holes (P).

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1E

Compound material semiconductor

- 1) A compound semiconductor is a semiconductor made of 2 or more elements, a good example of this is SiC (Silicon Carbide).
- 1) Elemental semiconductor comprises of a single element, a good example of elemental semiconductor is germanium or carbide.

2. Introducing Boron atoms to a silicon as a group 4 semiconductor would increase positive charge as boron is a group 3, this would make extra holes in the atomic structure increasing the positive charge.

3

$T = 400K$ Free electrons?

$$Z_{Si} = 2.33$$

$$A_{Si} = 28.09$$

$$N_A = 6.023 \times 10^{23}$$

$$N_{Si} = 2.5 \times 10^{19}$$

$$N = \frac{N_A Z}{A}$$

$$Z_{Ge} = 5.32$$

$$A_{Ge} = 72.59$$

$$N_{Ge} = 1.8 \times 10^{21}$$

$$N_{Ge} = \frac{6.023 \times 10^{23} \times 5.32 \times 10^6}{72.59} = \frac{4.41 \times 10^{28}}{72.59}$$

$$N_{Si} = \frac{6.023 \times 10^{23} \times 2.33 \times 10^6}{28.09} = 4.99 \times 10^{28}$$

$$\text{Free electrons/atom} = \frac{N_i}{N}$$

$$Ge = \frac{1.8 \times 10^{21}}{4.41 \times 10^{28}} = 4.08 \times 10^8 \text{ electron/atom}$$

$$Si = \frac{2.5 \times 10^{19}}{4.99 \times 10^{28}} = 1.248 \text{ electrons/atom}$$

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4

$$\sigma = 33.5$$

$$\mu_e = 0.06$$
$$\mu_h = 0.02$$

$$\sigma = n|e|\mu_e$$

$$\text{electrons}$$
$$\sigma = n|e|\mu_e$$

$$\sigma = p|e|\mu_h$$
$$\sigma = \epsilon n|e|\mu_e$$

$$\mu_e = \frac{V_d}{E}$$

$$\text{holes}$$
$$\sigma = p|e|\mu_h$$

$$n = \frac{\sigma \cdot p|e|\mu_h}{e|\mu_e}$$

$$a \quad \sigma = 33.5 = p|e|\mu_h$$

$$33.5 = n|e|\mu_e$$

$$p = \frac{33.5}{1.6 \times 10^{-19} \times 0.02} = 4.188 \times 10^8$$

$$n = \frac{33.5}{1.6 \times 10^{-19} \times 0.06} = 1.25 \times 10^9$$

b From the calculations above ~~NSD~~ ^{NSD} therefore Gas is a ~~N~~ type semiconductor.

5.

$$n = 8 \times 10^{14}$$
$$V_d = 175 \text{ m/s}$$
$$E = 1250$$

$$\mu_e = \frac{V_d}{E} = 0.14$$

$$\sigma = n|e|\mu_e \therefore \sigma = 8 \times 10^{14} \times 1.6 \times 10^{-19} \times 0.14 = 1.792 \times 10^{-5} \text{ } \Omega^{-1} \text{ m}^{-1}$$

$$b. K = 8.62 \times 10^{-5}$$

$$\sigma_{\text{Insb}} = 2 \times 10^4 \text{ } \Omega^{-1} \text{ cm}^{-1} \text{ at } 25^\circ \text{C or } 298 \text{ K}$$

$$E_g = 0.17$$

$$T = 25^\circ \text{C or } 298 \text{ K}$$

Use logs

$$\ln \sigma = \ln C - \frac{3}{2} \ln T - \left(\frac{E_g}{2KT} \right)$$

Transpose

$$\ln C = \ln \sigma + \frac{3}{2} \ln T + \left(\frac{E_g}{2KT} \right)$$

$$\ln C = \ln(2 \times 10^4) + \frac{3}{2} \times (\ln 298) + \frac{0.17}{2 \times 8.62 \times 10^{-5} \times 298} \quad 3.3$$

$$= 18.449 + 2.183 \times 10^3 \quad 3.3$$
$$\ln C = 22.175$$

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6, Continued. $T = 478K$

$$\ln \sigma = \ln C - \frac{3}{2} \ln T - \frac{E_g}{2KT}$$

$$\ln \sigma = \frac{21.75}{\cancel{22.415}} - \frac{3}{2} \times \ln(478) - \frac{0.17}{2 \times 8.62 \times 10^{-5} \times 478}$$

$$\ln \sigma = \frac{12.49}{\cancel{11.92}} - \frac{\cancel{3.5} \times 10^3}{\cancel{3.5} \times 10^3} = 2.063$$

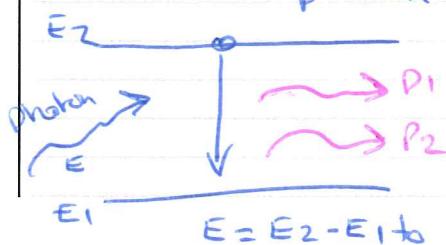
$$\therefore \sigma = \frac{10.427}{33.75 \times 10^3} \text{ m}^{-1}$$

7.
i Monochromatic - Concentrated in a narrow range of wave length.

Coherent - All the emitted photons bear a constant phase relationship with each other in both time and phase.

Directional - A very tight beam which is very strong and concentrated.

7b Stimulated emission - Controlled decay of electrons from high to low level energy levels causing photon emission.



* Photon does not get absorbed (1 photon in, 2 photons out).

Same wavelength + direction.

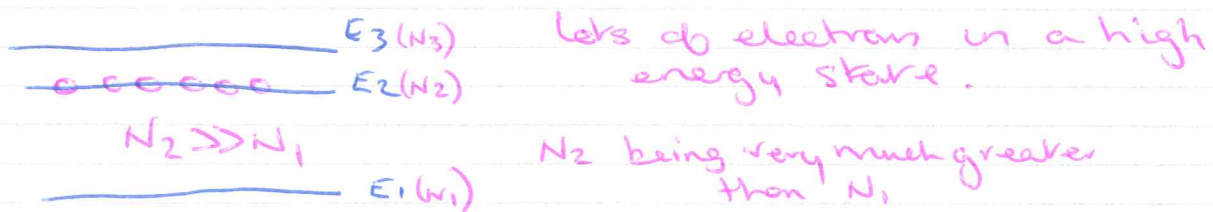
allow emission to occur.

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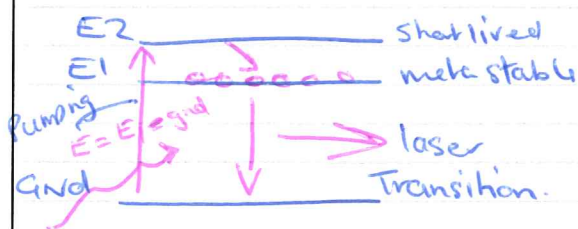
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7bii Population inversion - The process by which light is used to raise (pump) electrons from a lower state to a higher energy level to achieve population inversion.

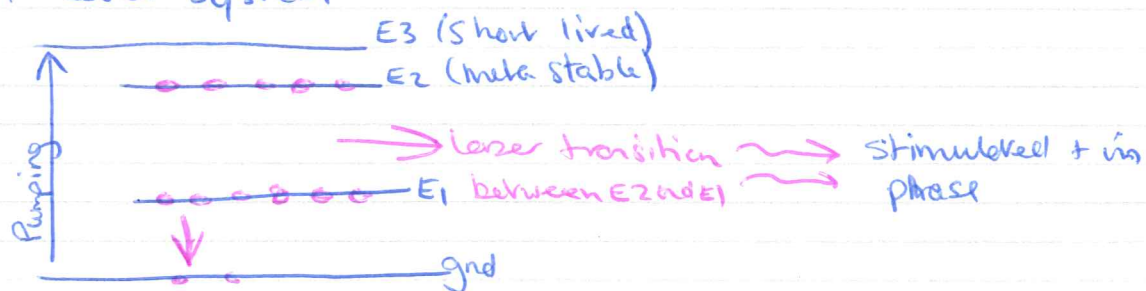


7C 3 Level System. - Initially excited to a short level state then quickly decays to the intermediate meta stable state, and this is where population inversion occurs, between ground + metastable state.



This can cause some absorption of incoming photon

4 Level System



Laser transition between E_1 and E_2 , as laser emission occurs between $E_2 + E_1$ for a 4 level system, this means there is no absorption and stimulated emissions making the laser more efficient and less energy is required in a 4 level system than a 3 level system.

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8a.

$$2.29 - 0.42 = 1.87 = E.$$

$$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.87 \times 10^{-19}} = 1063 \times 10^{-9} = 1063.6 \text{ nm.}$$

ii, At this wavelength may be absorbed

8b Photon reflected

$$\text{Photon incident} = 7 \times 10^{15}$$

$$\text{i, } m_2 \text{ reflection} = 90\% = 90\% \text{ of } 7 \times 10^{15} \\ = \underline{6.3 \times 10^{15}}$$

$$\text{ii, Photons transmitted} = 10\% \text{ of } 7 \times 10^{15} \\ = \underline{7 \times 10^{14}}$$

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8d. With stimulated emission you get a controlled decay from high to low energy levels, during this decay there is no absorption so you get more photons at $m2$ as these photons are coherent as they have the same frequency, phase + direction.