EPL213
Fundamentals of Semiconductors
Problem Sheet 5

1. In a silicon doped with $N_d=10^{15}cm^{-3}$, calculate the temperature at which the carrier concentration of doped silicon is equal to pure silicon.

1. $N_d = 10^{15}\ cm^{-3}$

$$N^+ = N_d \left[\frac{1}{1+\frac{1}{g}\exp[-E_g/kT]}\right]$$

$$N_d = n_i \text{ of pure Si} = N_c \exp\left\{\frac{-(E_F-E_c)}{kT}\right\}$$

2. Estimate the respective absorption coefficient ratios at the energies 1.97 and 1.6eV for both GaAs and Si. How about Urbach tails?

2. Near Urbach tails,

$$\alpha = K_o \exp[\sigma(E-E_g)/kT]$$

Direct $\alpha \propto \sqrt{E-E_g}$. Indirect $\alpha \propto (E-E_g)^2$

GaAs $= \frac{(1.97-1.42)^{1/2}}{(1.6-1.42)^{1/2}}$ Si $= \frac{(1.97-1.12)^2}{(1.6-1.12)^2}$ Urbach $= \exp[\sigma(1.97-1.6)/kT]$

3. If GaAs and Si absorption coefficients are 10^4 and 10^3cm^{-1} close to the band edge, find the minimum thickness required to have 90% transmission from the respective samples.

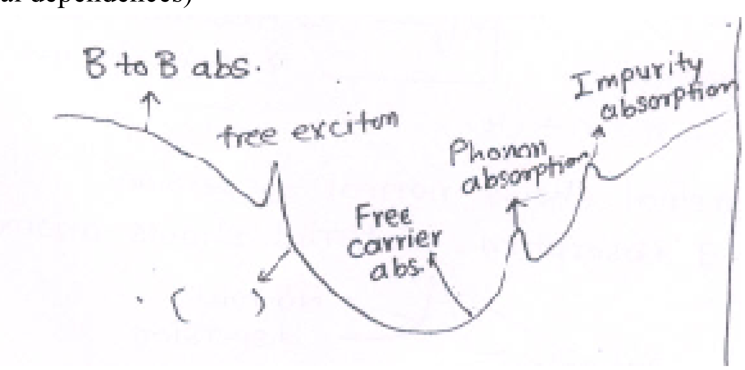
3. $I = I_o \exp(-\alpha x)$

$\therefore 0.9 = \exp(-10^4 x)$ x in cm —① ... for $\alpha = 10^4\ cm^{-1}$

$0.9 = \exp(-10^3 x)$ x in cm —② ... for $\alpha = 10^3\ cm^{-1}$

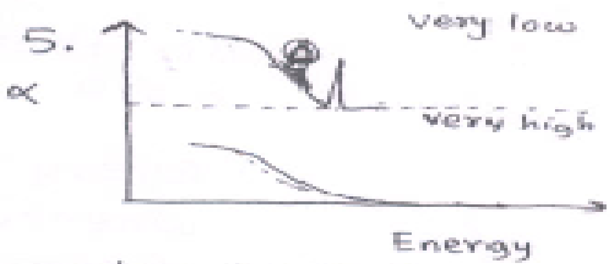
4. Explain the typical absorption processes in semiconductors (specify regions of electromagnetic spectrum and typical dependences)

4.

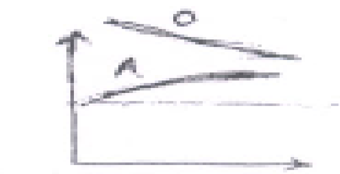


5. Sketch the absorption spectrum that you would expect to observe near the fundamental absorption edge of a direct gap semiconductor in the following two limits: (i) at very high temperatures; (ii) at very low temperatures

5.



Let's take GaAs.



Low:
- Excitons.

High:
- Band gap ↓ses
- Urbach tails ↑se.

6. Cadmium telluride (CdTe) is a direct gap semiconductor with a relative dielectric constant of 9.0 and a low temperature band gap of 1.605 eV. The electron and hole effective masses are 0.099 *m*e and 0.3 *m*e respectively.
   (i) Calculate the wavelength of the $n = 1$ exciton transition at low temperatures.
   (ii) Explain why the exciton in bulk CdTe is unstable in a strong DC electric field and estimate the largest value of the electric field that could be applied before the exciton is ionised.

7. Explain the meaning of the terms *photocurrent, fluorescence*, *phosphorescence*, *photoluminescence* and *electroluminescence*.
8. GaAs and InAs are both direct band gap semiconductors with band gaps of 1.42 eV and 0.35 eV at room temperature respectively. Estimate the composition *x* of a Ga*x*In1−*x*As light emitting diode that is designed to operate at 1550 nm, stating the assumptions that you make. Semiconductor lasers with a wavelength of 1550 nm are widely used in fibre optical telecommunication systems. Why is this wavelength so important?

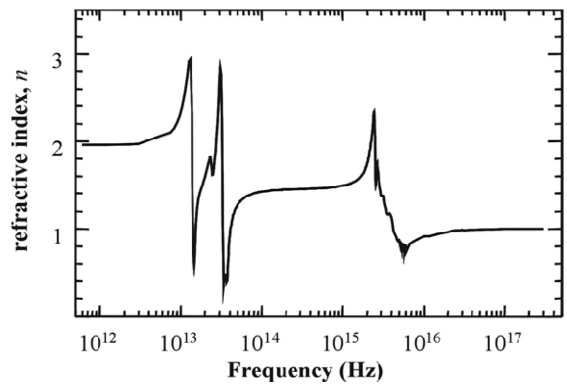
8. GaAs $E_{GaAs} = 1.42\,eV$ $E_{InAs} = 0.35\,eV$

$$E_{Ga_xIn_{1-x}As} = \frac{hc}{1550\,nm} =$$

9. The bonding in silicon is purely covalent. Why is this important for understanding its infrared optical properties?

9. In infrared region, phonon and impurity absorption are dominant. Phonon absorption will give info. about bond strength. More covalent bond strength → More phonon strength. ∴ For Si, infrared region is imp.

10. (a) Can you excite a pure silicon with a (a) green light (λ~530nm) and (b) λ~1300nm. Explain your result and also suggest what you have to do to excite with the impossible wavelength.



10. λ~ 530 nm ✓ ∵ E > E_g

λ ~1300 nm ✗ ∵ E < E_g.

If we still want to excite using λ~ 1300 nm,

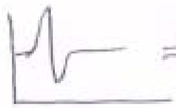
- change (↑se) temp → Not sufficient.
- Instead of using crystalline Si, use amorphous Si → more Urbach tails → More phonons → easy absorption.

11. Can you explain (with your course knowledge only) why the optical band gap (E_g) of these semiconductors follow the trend? CdTe (1.47eV) < CdSe (1.71eV) < CdS (2.45eV) (hint : similar is the case for Zn, Hg semiconductors with VI group elements)

11. Optical bg. follows the trend CdTe (1.47 eV) < CdSe (1.71 eV) < CdS (2.45 eV) → Size of the lattice is ↓sing → lattice constant ↓sing → in Kronig-penning model, bandgap is increasing → Bandgap is more for CdS than CdSe than for CdTe.

12. Explain why you would expect *n* to be complex in an absorbing medium. The diagram above shows the real part of the refractive index of SiO_2 glass. (i) Account for the shape of the graph. (ii) Draw a sketch of the imaginary part of the refractive index over the same frequency range. (iii) Use the graph to explain what is meant by *normal dispersion* and *anomalous dispersion*. (iv) Estimate the transmissivity of a thick window made from this glass at a wavelength of 600 nm.

12. $\alpha = 2\omega k / c$



⇒ Resonant condition

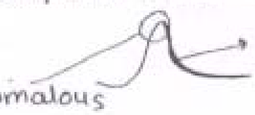
⇒ Some λs are getting absorbec

At these points

$\kappa \neq 0$, $n = n + ik$.

- Every material shows normal dispersion.

whenever ∃ absorption, material shows anomalous dispersion.



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