7a

Saturday, 1 December 2018 1:33 PM

Quantity	Semi-1	Semi-2
Type	Group IV element	Group II-VI compound
Bandgap [eV]	1.2	0.8
Bandgap type	Indirect	Direct
Intrinsic carrier density n_i [cm^{-3}]	4.02×10^{10}	3.46×10^{12}
Electron mobility μ_e [cm^{2}V^{-1}s^{-1}]	3000	9200
Hole mobility μ_h [cm^{2}V^{-1}s^{-1}]	400	300
N_C [cm^{-3}]	1.30×10^{22}	4.70×10^{19}
N_V [cm^{-3}]	2.66×10^{19}	7.00×10^{18}

Table 1: Room temperature properties of Semi-1 and Semi-2.

7. Consider two undoped semiconductors Semi-1 and Semi-2. Their properties temperature (300 K) are given in Table 1 above.

(a) Which material is the better intrinsic conductor at room temperature? Give numerical values to justify your answer? (2 marks)

Given that:

$$\rho = \frac{1}{q(n\mu_n + p\mu_p)} = \frac{1}{\sigma}$$

$$\sigma = q(n\mu_n + p\mu_p)$$

For both s1 & s2 :

$n = p = n_i$

so ;

$$\sigma = q n_i (\mu_n + \mu_p)$$

$$\frac{\sigma_1}{q} = n_{i1}(\mu_{n1} + \mu_{p1}) = 4\times10^{10}(3000 + 400)$$

$$\frac{\sigma_2}{q} = n_{i2}(\ldots) = 3.46\times10^{12}(9200 + 300)$$

$\sigma_2 >> \sigma_1$

σ_2 better conductor

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7. Consider two undoped semiconductors Semi-1 and Semi-2. Their properties temperature (300 K) are given in Table 1 above.

(b) Phosphorus (P, Group V element) atoms are incorporated into both materials.

(i) What type of doping will the resultant doped versions of Semi-1 and Semi-2 have? Why? (1 mark)

(ii) What is the minority carrier type in each case? (1 mark)

Semi	1	2	Dopant
Type	4	2 → 6	5
$\overline{\text{Type}}$	4	$\frac{6+2}{2} = 4$	5
why → $\overline{T_S} - T_D$	$4-5=-1$	$4-5=-1$	
(i) ∴ Doping type	n	n	
(ii) ∴ Minority carrier	p (holes)	p (holes)	

☐ ? Definitely Check Both Of these, particularly Semi 2

7c

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Table 1: Room temperature properties of Semi-1 and Semi-2.

7. Consider two undoped semiconductors Semi-1 and Semi-2. Their properties temperature (300 K) are given in Table 1 above.

(c) Assume dopant atoms are incorporated at a density of 1.0×10^{15} cm^{-3}, making both materials n-type. Assume a temperature of 300 K, all dopants are ionised, and there is no change in mobility.

(i) Which material is better suited to making an LED? Why? (2 marks)

(ii) What are the hole and electron concentrations? (2 marks)

(iii) Which of these semiconductors is a better conductor? Give numerical values to justify your answer. (2 marks)

(c)

(i) Semi-2 has direct BG ∴ better suited

(ii)

	1	2	N_D
n_i	4×10^{10}	3.46×10^{12}	1×10^{15}
$N_D >> n_i$?	✓	✓	
n	$= N_D$	N_D	
$p = \frac{n_i^2}{n}$	1.6×10^6	1.2×10^{10}	

(1e-6)*(4e10)^2/1e15=1.6
(3.46e12)^2/1e15=1.2E10

(iii)

$\frac{\sigma_1}{q} = n_1\mu_{n1} + p_1\mu_{p1}$ = 1e15*3000+1.6e6*400=3.0E18

$\frac{\sigma_2}{q}$ $n_2\mu_{n2} + p_2\mu_{p2}$ = 1e15*9200+12e10*300=9E18

$\sigma_2 \approx 3\times$ better than σ_1

S2 better

☐ ? Seems a little too easy - is this all there is to it?

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Table 1: Room temperature properties of Semi-1 and Semi-2.

8. Consider the properties of Semi-1 at room temperature (300 K) using the data in Table 1. S

(a) What is the intrinsic Fermi Energy of Semi-1? (2 marks)

(b) What is the Fermi Energy of Semi-1 if it is doped with 1.0×10^{15} atoms per cm^{-3}, making it n-type? (2 marks)

(4 marks)

(a)

$$E_F = \frac{E_C + E_V}{2} + \frac{kT}{2}\ln\left(\frac{N_V}{N_C}\right) + \frac{kT}{2}\ln\left(\frac{n}{p}\right)$$

middle of BG

$\ln\left(\frac{n_i}{n_i}\right) = 0$

Express Fermi level as relative to band gap:
(since we don't know absolute values of Ec / Ev)

$$E_F = E_{offset} + E_{bands} + E_{dopants}$$

$$= \frac{E_g}{2} + \frac{kT}{2}\ln\left(\frac{N_V}{N_C}\right) + \frac{kT}{2}\ln\left(\frac{n}{p}\right)$$

$$= \frac{1.2\,eV}{2} + \frac{8.617 \times 10^{-5} \times 300}{2}\ln\left(\frac{2.66 \times 10^{19}}{1.3 \times 10^{22}}\right)$$

(1.2+300*8.617e-5*ln(2.66e19/1.3e22))/2=0.519967974141311 eV

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(4 marks)

(b) Use prev eqn

$E_F = E_{offset} + E_{bands} + E_{dopants}$

Lemma of (8ai):

$E_{f\text{-}intr} = E_{offset} + E_{bands} = 0.52eV$

Lemma of (7):

$P_{dope} = 1.6 \times 10^6$

$N_{dope} = 1 \times 10^{15}$

∴

$Ef_{doped} = E_{f\text{-}int} + \frac{KT}{2} \ln\left(\frac{N_{doped}}{P_{doped}}\right)$

$= 0.52eV + \frac{300 \times K}{2} + \ln\left(\frac{1 \times 10^{15}}{1.6 \times 10^6}\right)$

≃ 0.52+300*8.617e-5*ln(1e15/1.6e6)/2=0.781783540665635 eV

$= 0.78 eV$