ECE 340 | Homework II | Spring 2003

Due: Monday, February 03, 2003
(20 points)

1. *(a) A GaAs semiconductor crystal is doped with silicon atoms. If the silicon atoms displace Ga atoms, does the crystal become an n-type or p-type material? Why?*

   (b) In contrast, when GaAs doped with carbon atoms, it tends to become p-type. Do the carbon atoms displace Ga or As atoms?

Solutions:

(a) n-type materials
Reasoning: Ga has 3 covalent electrons. Si has 4 covalent electrons. Because Si has one more covalent electron than Ga, when it replaces Ga atom, it introduces a free electron. The Si atom becomes donor atom and the crystal becomes n-type.

(b) As atom
Reasoning: As has 5 covalent electrons. Ga has 3 covalent electrons in outer shell. When carbon substitutes As, a hole is introduced, resulting in p-type materials. On the other hand, if the carbon substitutes Ga, the crystal will become n-type.

2. *(a) Using Appendix III, which of the listed semiconductors in Table 1-1 has the largest band gap? The smallest? Is there a noticeable pattern in the band gap energy of III-V compounds related to the column III element?*

   (b) Among the indirect materials listed in Appendix III, which one has the smallest bandgap energy, and what is that at room temperature? Which one has the largest bandgap energy, and what is that?

Solutions:

(a), From Table 1-1:

Largest bandgap energy	ZnS (3.6 eV)
Smallest bandgap energy	InSb(0.18 eV)

There is a pattern: Bandgap energy lowers as we go down column III.

(b),

Largest bandgap energy	SiC (2.86 eV)
Smallest bandgap energy	PbSe(0.27 eV)

3. (a) It was mentioned in Section 3.2 that the covalent bonding model gives false impression of the localization of carriers. As an illustration, calculate the radius of the electron orbit around the donor in Fig. 3-12c, assuming a ground state hydrogen-like orbit in Si. Compare with the Si lattice constant. Use $m_n^* = 0.26\ m_o$ *for Si.*
(b) Repeat part (a) for the radius of an electron orbiting around the donor in GaAs, assuming $m_n^* = 0.067\ m_o$ *for GaAs. Compare the radius with the GaAs lattice constant.*

Solutions:

(a), Use equation (2-10) from the book, radius of electron orbit can be calculated by:

$r_n = \frac{Kn^2\hbar^2}{mq^2}$, $K = 4pe_0e_r$, For Si, $\varepsilon_r = 11.8$, m: use effective mass m_n^*

Because we assume ground state hydrogen-like orbit, n = 1:

$$r_1 = \frac{4p \times 8.85\times10^{-12} \times 11.8 \times 1^2 \times \left(\frac{6.63\times10^{-34}}{2p}\right)^2}{0.26\times9.11\times10^{-31}\times(1.6\times10^{-19})^2} = 2.41\times10^{-9}\,m = 24.1\,\text{Å}$$

Silicon lattice constant: 5.43 Å. The orbit radius is about 4.4 times larger than the lattice constant.

(b), For GaAs, $\varepsilon_r = 13.2$. If assume ground state hydrogen-like orbit, n = 1:

$$r_1 = \frac{4p \times 8.85\times10^{-12} \times 13.2 \times 1^2 \times \left(\frac{6.63\times10^{-34}}{2p}\right)^2}{0.067\times9.11\times10^{-31}\times(1.6\times10^{-19})^2} = 1.046\times10^{-8}\,m = 104\,\text{Å}$$

GaAs lattice constant: 5.65 Å. The orbit radius is about 18.5 times larger than the lattice constant.