LED Review Questions

1. Consider two samples in the form of powders: sample A is a physical mixture comprising equal moles of pure Ge and pure Si; sample B is a solid solution of composition $Si_{0.5}Ge_{0.5}$. For which of the following measurements will the two samples appear identical?

   A. X-ray diffraction
   B. elemental analysis
   C. band gap energy measurement based on absorption of light
   D. none of the above

2. Both of the semiconductors GaAs and GaP have the zinc blende structure. From X-ray diffraction, one sample has a cubic unit cell size of 5.45 Angstroms and the other has a cubic unit cell size of 5.65 Angstroms.

   a) Which is which based on position in the periodic table?

   Since As is below P in the periodic table, and both elements are being combined with the same element, Ga, in the same structure, we would expect the bigger atom (farther down in the periodic table) to result in a bigger unit cell. Thus, GaAs should be the 5.65 Å unit cell and GaP the 5.45Å unit cell.

   b) From the relationship between atomic spacing and the resulting diffraction spots, which sample, GaAs or GaP, would have given the larger diffraction pattern and why?

   From your previous lab experiments, recall that the larger the spacing between features (dots on your optical transform slide; atoms in a crystal), the smaller the diffraction pattern. Thus, GaP with its smaller cubic unit cell should give a larger diffraction pattern than GaAs with its larger cubic unit cell.

3. Is Ga or Al more electronegative? Considering only the electronegativity difference, would GaAs or AlAs have a larger band gap energy? Explain.

   Al is less electronegative than Ga. The increased electronegativity difference between Al and As relative to Ga and As suggests a greater ionic contribution to the bond and hence a larger band gap energy. Thus, AlAs would be expected to exhibit a larger band gap energy than GaAs, and it does.

4. Considering only atomic radii, rank the following in order of increasing band gap energy: $GaP_{0.40}As_{0.60}$, $GaP_{0.65}As_{0.35}$, $GaP_{0.85}As_{0.15}$, $GaP_{1.00}As_{0.00}$

   In order of increasing band gap energy:
   $GaP_{0.40}As_{0.60} < GaP_{0.65}As_{0.35} < GaP_{0.85}As_{0.15} < GaP_{1.00}As_{0.00}$

5. Considering only electronegativity, rank the following in order of increasing band gap energy: $Al_{0.35}Ga_{0.65}As$, $Al_{0.25}Ga_{0.75}As$, $Al_{0.15}Ga_{0.85}As$, $Al_{0.05}Ga_{0.95}As$

   In order of increasing band gap energy:
   $Al_{0.05}Ga_{0.95}As < Al_{0.15}Ga_{0.85}As < Al_{0.25}Ga_{0.75}As < Al_{0.35}Ga_{0.65}As$

6. What usually happens to the bond distances of a material when it is cooled? Considering only bond distance, would a material's band gap energy be larger when warm or cold? Explain.

   Bond distances will usually contract as the material is cooled, and the band gap energy is expected to increase, since shorter bond distances usually correlate with better orbital overlap and a larger band gap energy.

7. Some LED materials can be prepared by combining Ga, In, As, and P in the zinc blende structure. If the formula of the solid is $Ga_{0.45}In_xAs_{0.75}P_y$, what are x and y equal to, and how would you interpret this formula based on the zinc blende structure?

   X = 0.55 and y = 0.25, Based on the zinc blende structure, Ga and In make up one part of the structure, while As and P make up the second part of the structure. Together Ga + In must be in a 1:1 ratio with As + P together.

8. Give a brief explanation for the following:
   Why does squeezing some LED's (applying pressure to them) make their spectrum move to shorter wavelengths?

   Applying pressure causes the LED to contract, bringing the atoms closer together. The shorter distances between atoms correspond to stronger bonds. If the energy of the emission is higher, the equation, $E = h\nu$, indicates that the frequency is higher (h is Plank's constant). From $c = \nu\lambda$, if the frequency increases, then the wavelength must decrease to maintain this relationship.

9. In a recent news clipping from *Science* magazine, a breakthrough in making blue LEDs was described. Samples of gallium nitride, GaN, can give blue emission. In our lab, the green LED was GaP. If both GaP and GaN are emitting at about their band gap energies, discuss why it is reasonable that GaN would emit in the blue part of the spectrum.

Since N is a smaller atom than P, the Ga-N bonds in GaN should be shorter and stronger than the Ga-P bonds in GaP. We thus expect a larger band gap energy for GaN (harder to remove an electron from a bond, and more energy released when the electron returns to the bond); and blue light is more energetic than green light, as would be predicted on this basis.

10. Predict what would happen to the emission spectrum of the GaN LED if it were run at low temperatures (e.g., a cold Madison day) and why.

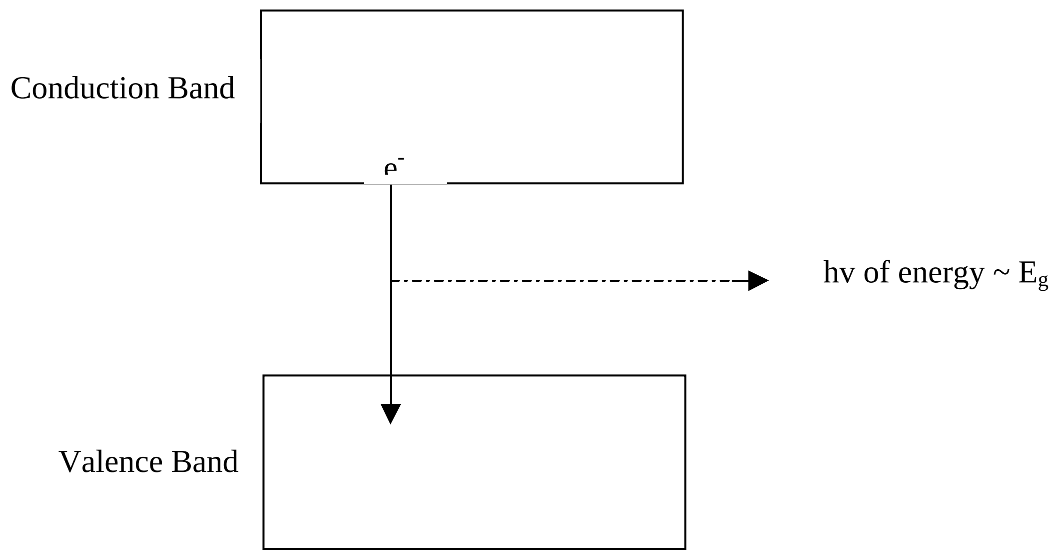
As demonstrated in class, cooling the semiconductor in a LED should cause it to contract, bringing the atoms closer together. The shorter distances between atoms corresponds to stronger bonds and a larger band gap energy. Thus, we would expect the energy of the emission to shift to higher energy (toward the violet end of the spectrum - a so-called "blue shift") if the LED were run under chilled conditions. If the LED were warmed, we would expect a shift toward the red part of the spectrum (a so-called "red-shift") for the same reason.

11. GaN is described as being harder (more resistant to mechanical damage) than ZnSe, which is also being used to construct blue LEDs. Suggest a reason why GaN is harder.

From their positions in the periodic table, we would expect shorter bonds with Ga-N relative to Zn-Se, since N is a second row element and the others are all fourth row elements. The shorter bond would be predicted to be stronger, making the material harder. Electronegativities also support a stronger bond, since there is more polarity to the Ga-N bond: Looking at the table of electronegativities, the Ga-N bonds are relatively ionic, as they have a difference in electronegativities of 1.3 (Ga is 1.7; N is 3.0); whereas the Zn-Se bonds are more covalent with a difference in electronegativities of only 0.8 (Zn is 1.6; Se is 2.4).

12. Explain with a sketch why the emission of an LED can give an estimate of the band gap energy of the solid.

In a band picture, electrons at the bottom of the conduction band drop to the top of the valence band, releasing a photon of roughly band gap energy.



13. Two LEDs are excited with the same amount of electrical energy from a battery and emit the same number of photons. One of these LEDs is emitting green photons at around 500 nm; and the other is emitting red photons at around 700 nm. Which is doing a better job of converting the electrical energy into light energy and why (i.e., which is more energy efficient?)?

Green photons are more energetic than red photons (recall that the energy of photons is inversely related to the wavelength: $E = hc / \lambda$), so if the same amount of electrical energy creates as many green as red photons, more energy is recovered when green photons are produced, and the overall efficiency of the green LED is higher.

14. An InP LED is connected between electrodes. Does it matter which side of the p-n junction is connected to which electrode and, if so, how do you connect it to make it glow?

Yes, It matters which side of the p-n junction is connected to which electrode. The LED should be attached with the n-type portion connected to the negative lead and the p-type portion connected to the positive lead. The only way the LED will work is if it is set up in this manner.

15. Suggest dopants that will substitute for In to make the p-type region of the LED and for P to make the n-type region. Explain your choices.

To make a p-type region the atom that you substitute must have fewer valence electrons so that more mobile valence band holes than mobile conduction band electrons result. Therefore, a Group 12 element like Zn could be used in place of In. To make an n-type region the substituting atom must have more valence electrons so that more mobile conduction band electrons than mobile valence band holes result. Therefore, in place of P a Group 16 element like Se might be used.

16. If a material has a band gap energy in the infrared portion of the spectrum, it will appear

a. black.

b. red.

c. green.

d. colorless.

A substance with a band gap in the infrared region of the electromagnetic spectrum will absorb light throughout the visible portion of the electromagnetic spectrum and appear black.

Figure 7.18 from the Companion