SSP Exercise 8

To be handed in by 4pm, Thursday 22nd March.

Consider a case of a germanium quantum dot and evaluate the energy gap between the highest occupied state and the lowest unoccupied state for a cubic particle of 5 nm in size. Use an infinite square potential well as an approximation for the confining potential. Use the following values of the effective masses $m^*_e = 0.12m_e$ and $m^*_h = 0.21m_e$.
What would be the value of the wavelength of a photon emitted via recombination of the electron the lowest unoccupied state and hole at the highest occupied state?
Compare the results for germanium quantum dot with those for a silicon quantum dot of the same size ($m^*_e = 0.26m_e$ and $m^*_h = 0.36m_e$).

Answer:
For a cubic particle we have:

$$E^e_{111} \approx \frac{\pi^2\hbar^2}{2m^*_e}\left(\frac{3}{D^2}\right) \approx \frac{9.9*3*43.3*10^{-32}eV^2*s^2*9*10^{16}m^2/s^2}{2*0.12*0.5*10^6eV*25*10^{-18}m^2} \approx 0.39eV$$

$$E^h_{111} \approx \frac{\pi^2\hbar^2}{2m^*_h}\left(\frac{3}{D^2}\right) \approx 0.22eV$$

Where electron mass is given in eV/c^2, c is the velocity of light in vacuum. The energies obtained are relative to conduction and valence band respectively. The energy gap in the bulk Ge is 0.66 eV. Hence energy gap between the highest state in VB and lowest state in the CB is 0.66 + 0.39 + 0.22= 1.27 eV. This converted to a wavelength would give:

$$\lambda \approx \frac{1240}{1.27}nm \approx 976nm$$

For Si we will have:

$$E^e_{111}(Si) \approx E^e_{111}(Ge)\frac{m^*_e(Ge)}{m^*_e(Si)} = 0.18eV$$

$$E^h_{111}(Si) \approx E^h_{111}(Ge)\frac{m^*_h(Ge)}{m^*_h(Si)} = 0.13eV$$

The energy gap in the bulk Si is 1.12 eV. Hence the energy gap in the nanoparticle is 1.12+0.18+0.13 = 1.43 eV. Hence:

$$\lambda \approx \frac{1240}{1.43}nm \approx 867nm$$

[10 marks]