Quantum Transport FS 2014
Problem Set 1 Due: 08.04.14

1. Dimensionality

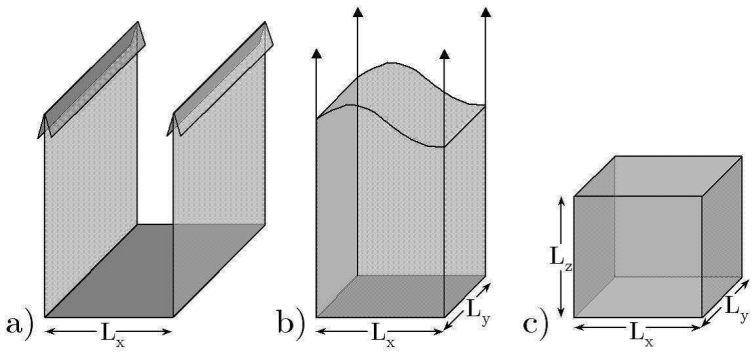
Imagine that you can produce quantum structures with dimensional control of plus or minus one monolayer, i.e. approximately 0.25 nm. Assume that the structures are made of GaAs ($m^* = 0.067\, m_0$) and that the barrier height is infinite. State both the nominal value of the energy level and its possible range of values in light of the dimensional uncertainty. Describe qualitatively what happens when the barriers become finite.

Calculate the energy above the conduction band edge for ...

(a) two quantum wells which are 10 nm wide and 30 nm wide, respectively, for the groundstates as well as for the first and second excited states ($n = 1,\ 2,\ 3$).

(b) a quantum wire with $(10\,\mathrm{nm})^2$ ("width and length").

(c) a quantum dot that is $(10\,\mathrm{nm})^3$.



(d) a quantum wire which has the same $n = 1$ energy level as the quantum well described in (a) ($\rightarrow 10\,\mathrm{nm}$). What are the dimensions of this wire?

(e) a quantum dot which has the same $n = 1$ energy level as the quantum well described in (a) ($\rightarrow 10\,\mathrm{nm}$). What are the dimensions of this dot?

2. A Quantum Well

(a) What is the maximum sheet electron density for a 9 nm wide GaAs quantum well with the $n = 2$ level unoccupied? In other words: How many states per unit area are in the $n = 1$ level between $E = E_1$ and $E = E_2$? Assume zero temperature ($T = 0\,\mathrm{K}$), $m^* = 0.067\,m_0$ and an infinitely deep well.

(b) Repeat 2.(a): How large is the sheet density to occupy the $n = 2$ level with the $n = 3$ level empty?

(c) Repeat 2.(a) for heavy holes with $m^* = 0.5\,m_0$.

3. Junctions *(optional)*

(a) Sketch and label the band diagram through a p-n heterojunction with $N_{\mathrm{AP}} = 5 \cdot 10^{17}\,\mathrm{cm}^{-3}$ (acceptor doping concentration) and $N_{\mathrm{DN}} = 10^{17}\,\mathrm{cm}^{-3}$ (donor doping concentration) at $T = 300\,\mathrm{K}$.

(b) Consider an n-p heterojunction with $N_{\mathrm{DN}} = 2{\cdot}10^{17}\,\mathrm{cm}^{-3}$ and $N_{\mathrm{AP}} = 6{\cdot}10^{17}\,\mathrm{cm}^{-3}$. Repeat 3.(a) for this junction.

(c) How much does the conduction band spike extend above the conduction band edge in the quasi-neutral region on the p-doped side for the junction described in 3.(b)?

	wider bandgap ($Al_{0.4}Ga_{0.6}As$)	narrower bandgap (GaAs)
electron affinity (eV)	3.63	4.07
energy gap (eV)	1.92	1.42
conduction band density of states N_C (cm^{-3})	$5.0 \cdot 10^{17}$	$4.7 \cdot 10^{17}$
valence band density of states N_V (cm^{-3})	$8.0 \cdot 10^{18}$	$7.0 \cdot 10^{18}$
relative dielectric constant ϵ_r	11.6	12.9