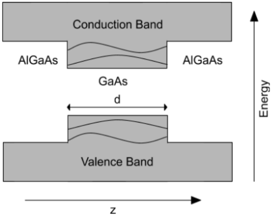
FEFG density of states

DOS in quantum wells and quantum wires in the ground state

July 1, 2021

Quantum wells, wire and dots

- A quantum well is a potential well, whose solutions admits only discrete energy values.
- The classic model used to demonstrate a quantum well is to confine particles, which were initially free to move in three dimensions, to two dimensions, by forcing them to occupy a planar region. The effects of quantum confinement take place when the quantum well thickness becomes comparable to the de Broglie wavelength of the carriers
- Hence to create quantum wells, wire , dots we confine in 2D, 1D, 0D the particles.
- The presence of a well will discretise the energy levels. Hence, an important quantity to look at is the Density of states.



DOS

- Let's start studying the quantum well, where the electrons are confined along the z-direction and free to move in the xy-plane. This means that in the reciprocal lattice the spacing between k-vectors in the xy-plane is very small, on the contrary in the z-direction the k-spacing is much much bigger.
- Setting the energy zero at the bottom of the conduction band, we know that the minimum energy level available is given by the fundamental state inside the well: from that energy to the next well level we have that one state is available (in k_z), with the same confinement energy and many possible values of kinetic energy each corresponding to one $k_x^2 + k_y^2$.
- What we can then say is that the density of states is given by a stair-like function that increases of a discrete value each time a well level threshold is met in energy. Increasing $|k|$ means increasing energy. This is a different result from the bulk semiconductor condition, where the density of states trend is square-root-like; the differences are fundamental for the applications of quantum wells.(significant discretisation of the energy)
- The DOS_{2D} is given by: $\mathrm{DOS}(E) = \frac{m^* L_x L_y}{\pi \hbar^2} \sum_n \Theta\left[E - E_n\right]$

DOS

- We can develop analogously the model for wires and dots, decreasing the number of degrees of freedom to one or zero; the wavefunctions change in an obvious way, introducing, respectively, two and three quantum numbers in analogy with the n of quantum wells.
- The density of states for a quantum wire is:
$$\mathrm{DOS}_{1D}(E) \propto \sum_{n,m} \frac{1}{\sqrt{E - E_{nm} - E_C}}$$
- The density of states for a quantum dot is:
$$\mathrm{DOS}_{0D}(E) \propto \sum_{n,m,l} \delta\left[E - E_{nml} - E_C\right]$$

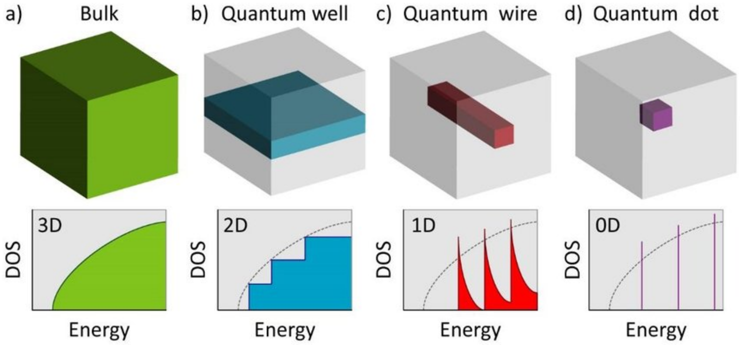


Figure 1: Bulk, quantum well, quantum wire, quantum dot