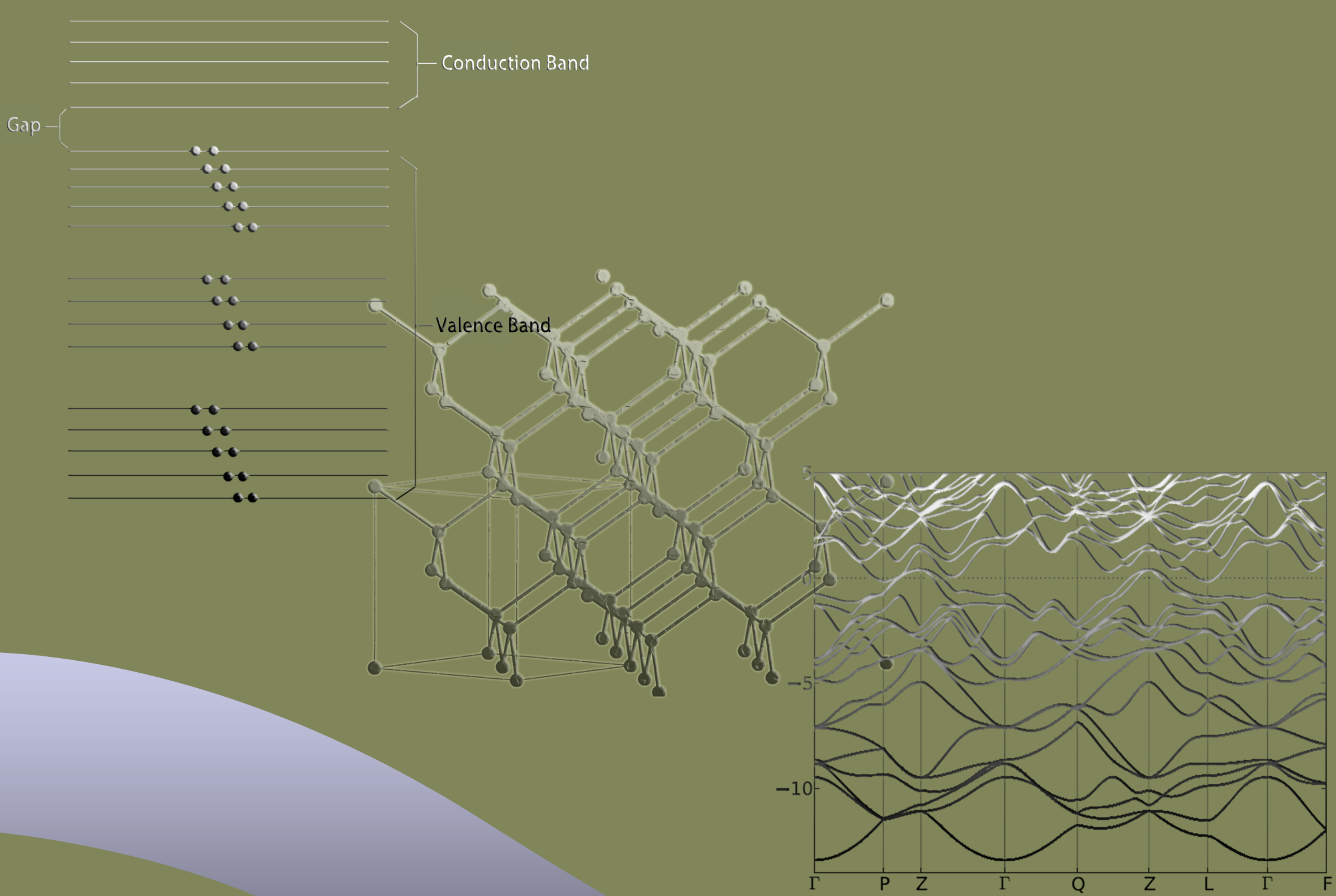
Queen Mary, University of London

School of Physics and Astronomy

Quantum Dots Related Summary



Ge High Pressure Phases

There are many Ge high pressure phases reported in literature, however the symbol used in history is a bit complex. There are several high pressure phases possessing different short names, which sometimes causes confusion. Hereby, short names for several high pressure phases of Ge is listed.

tP12 ⟶ ST12 ⟶ Space Group: $P4_32_12$

hP8 ⟶ Space Group: $P63/mmc$ (hexagonal close packing, hcp)

tI4 ⟶ β-tin ⟶ Space Group: I41/amd

cF8 ⟶ diamond ⟶ Fd–3m

cI16 ⟶ BC8 ⟶ Space Group: Ia–3 (γ-silicon)

hR8 ⟶ Space Group: R–3H

cF136 ⟶ Space Group: Fd–3mZ (dense form of 'Fd–3m')

Ge QDs application on transducer

There are many applications of Ge quantum dots which utilize the optical property and environmentally friendly properties(especially for bio-application). Basically, the applications include photosensors, bio-markers, cell-targeting assistant, etc. One of the typical application of quantum dots is the QDs based photo transducer, which is discussed in the following paper: Click Me. Following are the figures given in the above paper showing the enhancement of photocurrent induced by the quantum dots.

In Fig. 1. , the gate voltage applied is negative, and Fig. 2. describes the case where the gate voltage is positive.

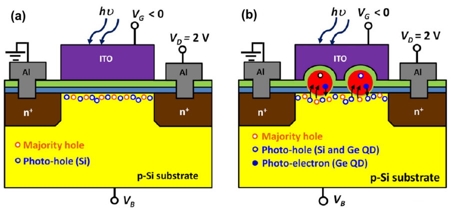


Figure. 1. The comparison of (a) the traditional MOSFET (without QDs) and (b) the MOSFET with QDs embedded. — Negative bias voltage.

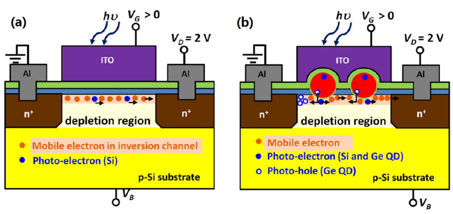


Figure. 2. The comparison of (a) the traditional MOSFET (without QDs) and (b) the MOSFET with QDs embedded. — Positive bias voltage.

Basically, it is the photoelectrons generated in the quantum dots that enhance the photocurrent flowing in the conduction channel of the MOSFET, and detailed discussion about the mechanism is given in the above given paper of the original paper published on Nanotechnology.

Simple model for quantum confinement effect

Basically, the quantum confinement effect refers to the changing of band structure (especially the bandgap) as the function of the particle size, when the size of the particle is down to nanometer level. Here is given a simple model describing the quantum confinement effect within the frame of 'particle-in-a-box'. In this model, the dependence of the bandgap on the particle size is simply given as:

$$E_{gap} = E_{bulk} + \alpha / R^n \tag{0-1}$$

where R is the particle size, α is a confinement factor and n is usually $1 < n < 2$, depending mostly on the surface termination and host material. Brief description of this model is given in the following paper: Click Me (P2). (Also the corresponding references given in that paper — Ref. 9 & 10).

DOS in Quantum Confined structures

In the following summary, it was given the discussion about the density of states in different quantum structures (i.e. quantum sheet – 2D, quantum wire – 1D and quantum dot – 0D): Click Me. There in the summary, the specific equation of the corresponding quantum structures is not given, and here are they:

$$\rho_{3D} = \frac{1}{\pi^2}\left(\frac{m^*}{\hbar^2}\right)^{3/2}\sqrt{2E} \tag{0-2}$$

$$\rho_{2D} = \frac{m^*}{\pi\hbar^2}\sum_{n_x}\Theta(E - E_{n_x}) \tag{0-3}$$

$$\rho_{1D} = \frac{1}{\pi\hbar}\sqrt{2m^*}\sum_{n_x,n_y}(E - E_{n_x,n_y})^{-1/2} \tag{0-4}$$

$$\rho_{0D} = 2\sum_{n_x,n_y,n_z}\delta(E - E_{n_x,n_y,n_z}) \tag{0-5}$$

where m^* is the effective mass, $\Theta(E)$ i the step function, E is the energy of the particular state, E_{n_i} with $i = x, y, z$ is the quantized energy of the particular confinement direction, and $E_{n_x,n_y} = E_{n_x} + E_{n_y}$, etc. The equations given here are from the following reference: Click Me.

Wave function overlapping by quantum confinement

Generally, for indirect bandgap material, the $k = 0$ transition is not allowed without the phonon assistance. However, when the size of the material goes to nanometer magnitude (or more exactly, compared to the corresponding Bohr exciton radius), quantum confinement effect may make the indirect transition happen. And mathematically this can be explained by the overlapping of the wave functions of the holes and electrons. In the Gaussian confinement approximation, the electron and hole wave function is given by:

$$\Psi_{\mathbf{k}} = \frac{(2\pi)^{3/2}}{V}\Pi_{i=x,y,z}\left(\frac{\sigma_i}{\pi^3}\right)^{1/4} e^{-\frac{k_i^2\sigma_i^2}{2}} \tag{0-6}$$

where V is the volume of the crystal and σ_i is the Gaussian width parameter. And Fig. 3. illustrates

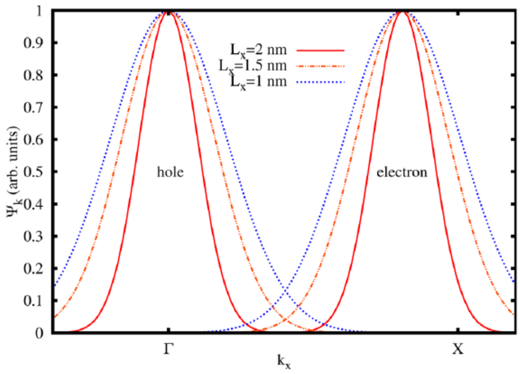


Figure. 3. Plot of a Gaussian envelope function for a single confinement direction in k-space with an electron centred at 0.8 × X-point and a hole at the C-point in the Brillouin zone, as appropriate for Si. The plot is not normalized and is shown for three different values of confinement dimension, L_x.

that as the confinement dimension L_x is reduced, the width in momentum space is increased, which then lead to the overlapping between the wave functions of the holes and electrons increasing — which makes the indirect transition happen.