QUANTUM DOTS IN MEDICAL PHYSICS

MATTHEW BUTLER

SUPERVISOR: PROF. SEAN RYAN

Introduction

This investigation looks at quantum dots and their application within medical physics. Particular interest will be in the scintillation of quantum dots, this is the process in which quantum dots emit light when struck by ionising radiation.

Quantum Dots

Quantum dots are semiconducting spheres typically with diameters ranging from 1-10nm[1]. They are made from the pairing of elements from groups II-VI or III-V.

Due to the scale, quantum dots exhibit properties like that of singular atoms, rather than the properties it would have in a bulk semiconductor, this is where the quantum confinement effect comes into play.

Mechanism of semiconductors:

There are two type of bands within semiconductors: The valence band – a band that contains most of the electrons, in the low energy state and the conduction band – a band which an excited electron will move to. When an electron is excited (an exciton) it moves to the conduction band, leaving a 'hole' (See Figure 1). The distance between the exciton and the newly formed hole is the exciton Bohr radius.

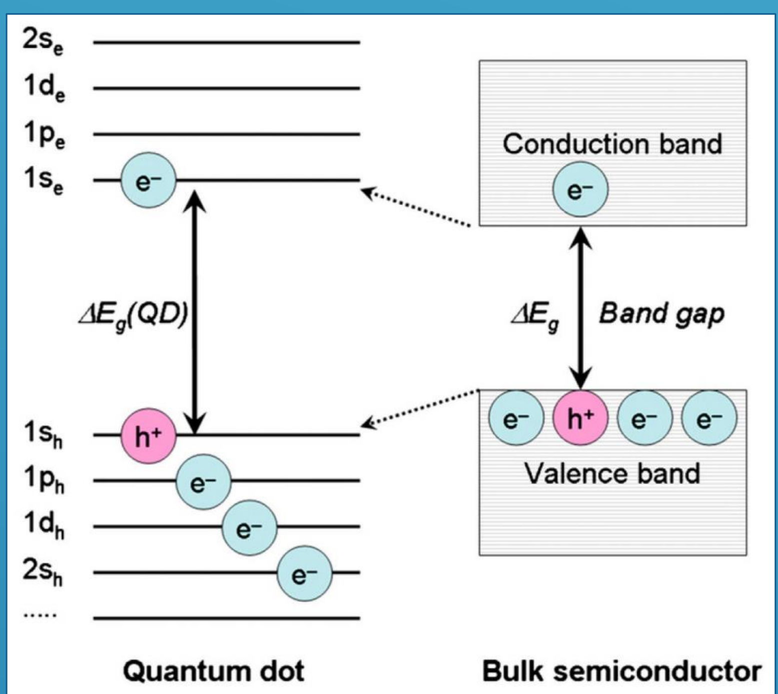

Figure1 [2]

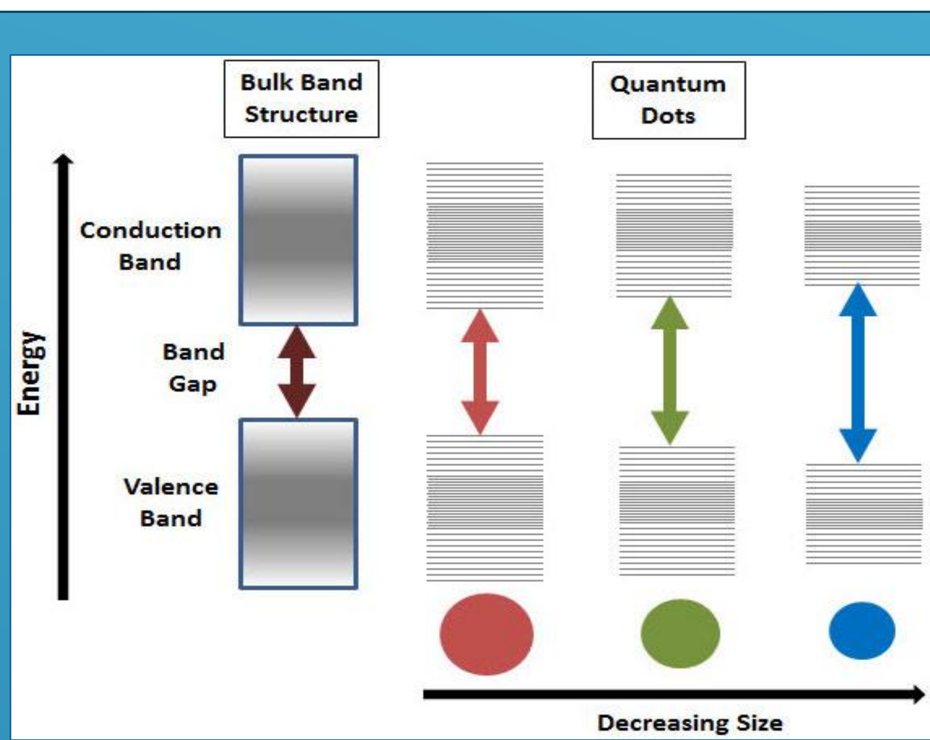

Figure 2 [3]

Quantum confinement effect:

Once the diameter of the quantum dot is of the same order as the exciton Bohr radius, the energy gap increases and the bands separate (see figure 2)[3].

Using Schrodinger's equation, its possible to model the quantum dot as an infinite potential well, but in 3 dimensions – a particle in a box. Decreasing the radius of the quantum dot, reduces the length of the of the box and therefore the smallest wavelength that can fit inside. So the relationship between the radius and the band gap is given by[4]:

$$E_g = \frac{\hbar^2 \pi^2}{2R^2 m} \rightarrow E_g \propto \frac{1}{R^2}$$

Properties of Quantum dots:

- Wide absorption spectra (see Figure 4) and narrow emission spectra (see Figure 5)[5].
- High quantum yield (Number of converted photons out/number of photons that hit the quantum dot)[5].
- Large intensity of emission[1].
- High photostability – ability to withstand large number of absorption/emission cycles[5].
- Ability to control the absorption/emission spectra[1].

Application to Medical Physics

Quantum dots have a wide range of uses within medical physics. Such as:

Imaging – Quantum dots can be tuned to specific wavelengths that are required. Due to narrow emission (Figure 5), the use of more than one type can be used simultaneously to detect different targets. High luminance and photostability are also very beneficial [5].

Drug delivery – Drugs can be attached to the quantum dots. Due to the luminescence properties, its possible to image quantum dots to determine their location, ensuring they have reached the targeted destination [1].

Photosensitizers - These convert high energy ionising radiation into a longer lower energy wavelength. Which can then be utilised to activate localised drug treatment [2].

Experiment

Aim:

To establish what effect x-rays have on quantum dots. Do quantum dots fluoresce under scintillation? If so can we get quantum dots to emit in the infrared wavelength?

The reason for this particular interest is due to infrared can be detected outside the body and some drug treatments require an activation wavelength in the infrared range[2].

Overview

Using an x-ray machine, we will irradiate a colloid solution of quantum dots, subjecting it to a range of energies ranging from 35-130kV$_p$; we will use an optical/near infrared camera to capture the result.

Current stage

Still in the process of acquiring quantum dots. However, we have gained backing and expertise from the x-ray technician, who will assist us in designing the beam.

Next stage

Once we have acquired the quantum dots, we can proceed with the experiment. Successful scintillation could possibly see the testing of different types of quantum dots, depending on time, funding and results.

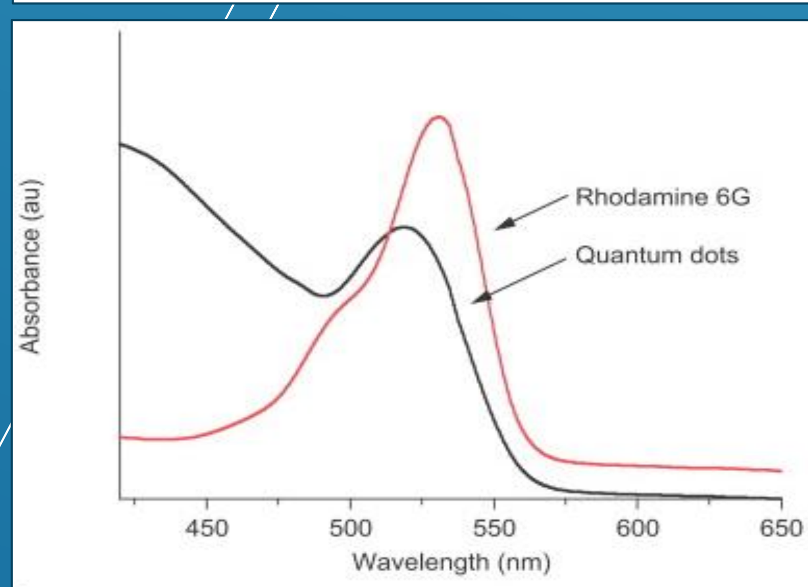

Figure 4 [5] - (Rhodamine 6G is a fluorescent dye)

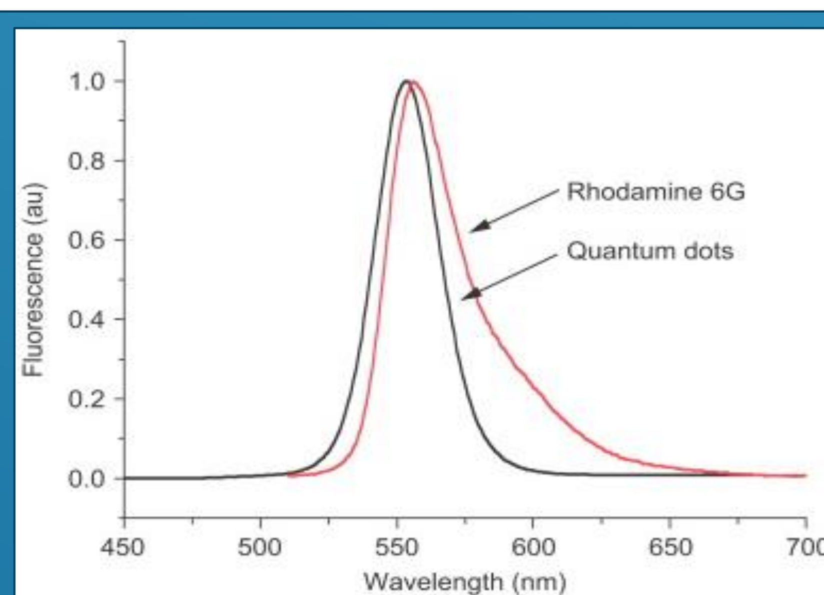

Figure 5 [5] - (Rhodamine 6G is a fluorescent dye)

References

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