Carbon Quantum Dots - Synthesis and Analysis

Khyati Jain

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Abstract: The aim of this work is to synthesize and analyse Carbon Quantum Dots. We have used gelatin to synthesize the Quantum Dots using hydrothermal method. The synthesized CQDs emit blue photo luminescence (PL). These CQDs have low toxic levels (due to organic base).

1 Introduction

1.1 What are Quantum Dots

Quantum dots are semiconductor nano crystals with sizes ranging from 2nm to 10nm, that is around 5 to 10 carbon atoms. They were discovered in 1980 and due to their property of florescence, they have found a wide variety of applications in the fields of chemical sensing, biosensing, bioimaging, nanomedicine, photocatalysis and electrocatalysis. The properties of quantum dots can be explained using confinement effect which is analogous to a particle in a box. The energy of the electron becomes more discontinuous, meaning that there are distinct states at which the electron can and cannot be. The quantum confinement effect is only applicable when the size of the particle is too small to be compared to de Broglie's wavelength.

1.2 Why Carbon Quantum Dots

CQDs do not compose of toxic compounds like CdSe and therefore are applicable to bio-imaging. Carbon is also an easily accessible material as it is an organic compound which makes its mass production cheap.

2 Theory

2.1 Properties of Quantum Dots

Due to their small size, their electrons are confined to very small closed spaces or quantum wells. As a result, electronic transitions caused due to external perturbations are quantized. Quantum dots have unique electronic properties, intermediate between those of single atoms and atoms in bulk. These properties are determined by the size of the crystals. When these crystals are subjected to some energy source, they get excited to the conduction bands, leaving behind a hole in the valence band. The gap between the conduction band minima and the valence band maxima increases with reduction in the size of these crystals. The size can be controlled by the temperature at which they are synthesised. Therefore, quantum dots with variable sizes, emitting photons of wavelengths varying from violet to red can be produced.

The wavelength of the colour produced is directly proportional to the size of the particle. Smaller particles emit shorter wavelengths and thus, produce a colour near the blue end of the spectrum. Inversely, as the radius of the particle expands to grow in size, it results in a longer wavelength and thus, radiates a colour near the red end of the spectrum.

2.2 Band Gap Energy

Once the wavelength corresponding to maximum absorbance is found out from the UV analysis the band gap energy can be calculated by using the relation $E = hc/\lambda$. There is an inverse relation between particle size and energy gap so when the particle size increase, the absorption peaks will shift towards longer wavelength, energy levels discretise and move higher up in the bands for stronger quantum confinement (smaller size).

3 Experimental Procedure

3.1 Materials Required

Knox gelatin, distilled water, silicon chip, acetone, iso-propanol.

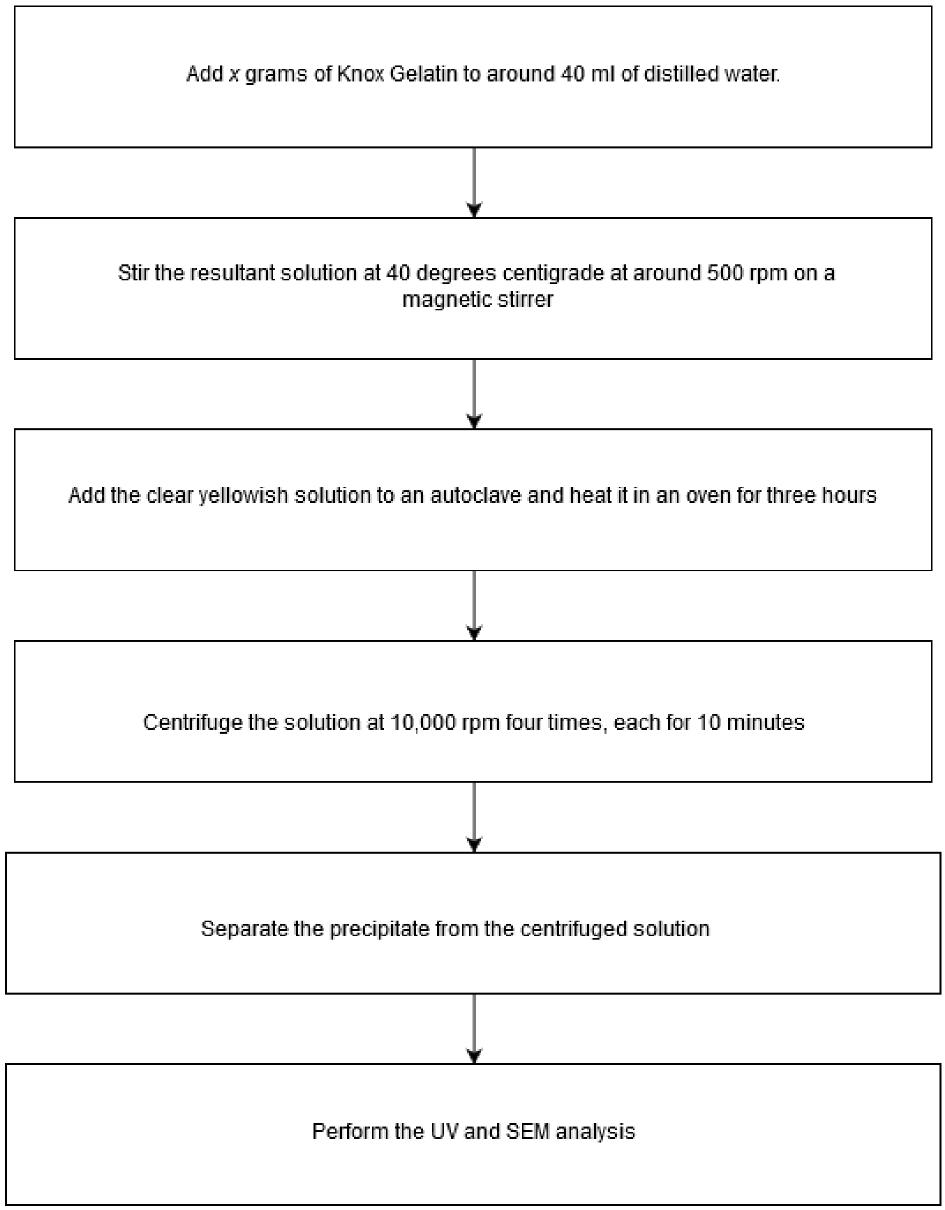
3.2 Apparatus Required

Weighing apparatus, magnetic stirrer, hot plate, thermometer, autoclave, oven, fume hood, ultra-sound equipment, dropper, beaker, thermometer, UV spectrometer, scanning electron microscope, UV cabinet

3.3 Procedure

The quantum dots are produced using hydrothermal method. Crystals are synthesized under high temperatures and pressures the colour emitted can be adjusted by manipulating the size of the particle with the addition or absence of heat.

Figure 1: Flowchart of experimental procedure



4 Observation

A summary of the samples produced					
Label	Mass	Water	Temperature	rpm	Wavelength
Sample A	0.8	40ml	160	10000	390nm
Discarded	1.0	40ml	200	10000	NA
Sample B	0.8	40ml	240	10000	410nm
Sample C	0.8	40ml	200	10000	467nm

4.1 Florescence in UV

The samples when viewed in the UV Cabinet showed florescence of blue color. A highly florescent blue is seen for the smallest quantum dot (Sample A)

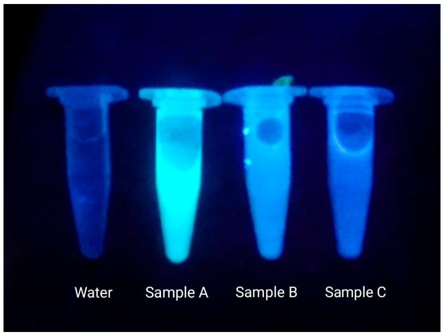


Figure 2: Florescence under UV light

4.2 UV Analysis

- Water was used as the base line correction. At first, a sample of distilled water was used to produce the absorbance curve and the corresponding data was stored.
- The sample was then subjected to UV rays and absorbance of solution was analysed. The absorbance values of the solvent (here, distilled water) was subtracted from the corresponding values of the solution.
- From the resultant absorbance curve, the wavelength of the of the absorbed light was obtained which in turn can be used to calculate the band gap.

4.3 SEM Analysis

- Silicon chip was cleaned using acetone, iso-propanol and subjected to ultra sound waves.
- The solution was drop casted on the silicon chip and dried at 60 degrees for an hour.

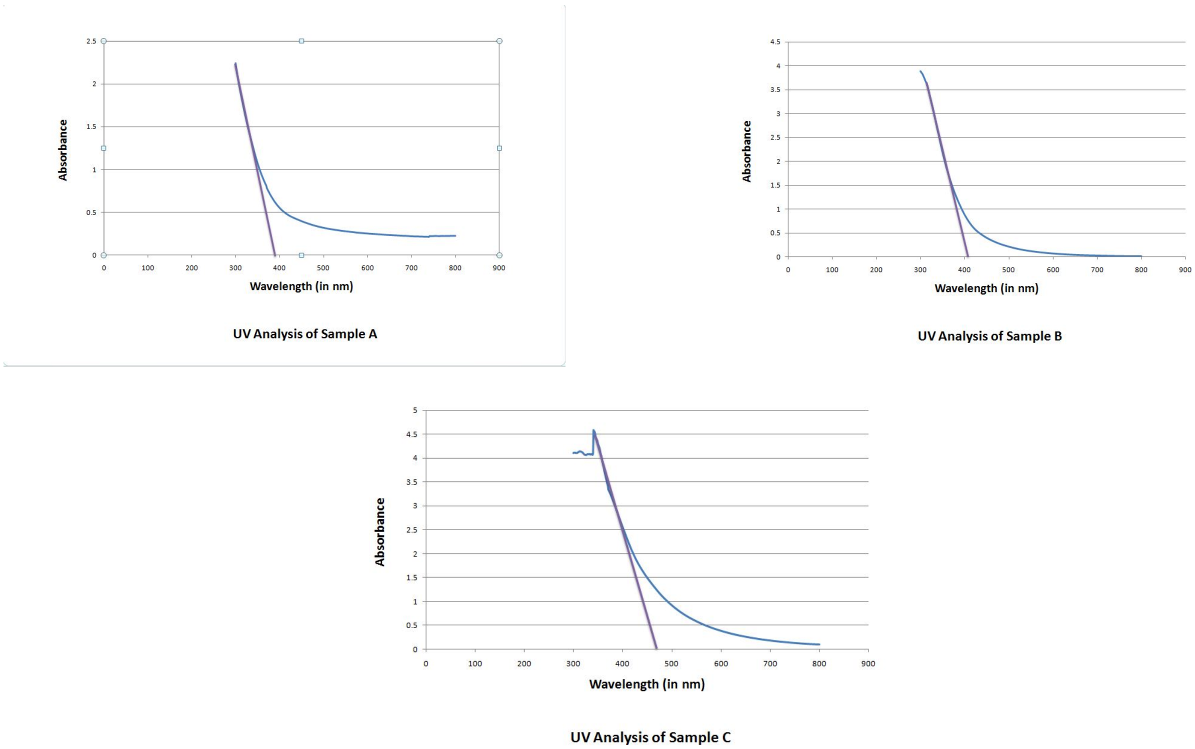


Figure 3: UV analysis Results

- Gold and palladium was sputtered on the silicon chip before imaging under SEM at 5kV.
- We have been able to see nano-structures of the diameter of the range 20nm - 30nm in the SEM image of sample C (synthesized at 240 degrees).
- We have been able to see nano-structures of the diameter of about 70nm- 75 nm in the SEM image of sample B (synthesized at 200 degrees).

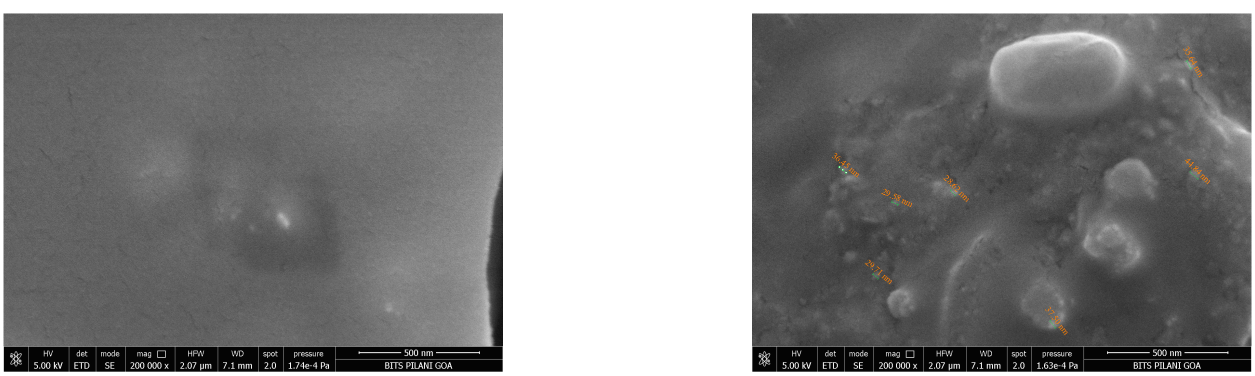


Figure 4: SEM image of sample B and sample C

5 Sources of Error

- The concentration of the solution used for the SEM was very high. This caused the SEM images to be flaky. And it made the quantum dots difficult to observe due to the large concentration.

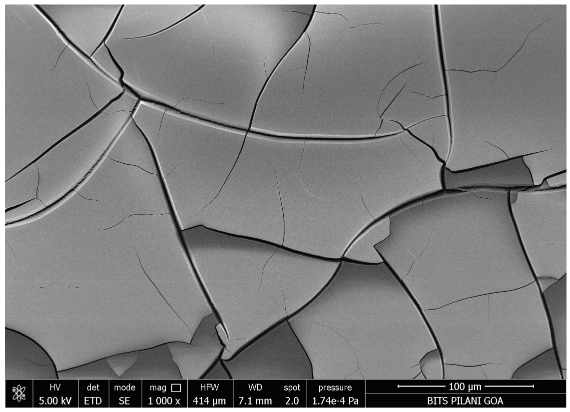


Figure 5: SEM Image of the sample showing flakes

- The relative composition of the particles present shown by EDAX showed the presence of other element in high concentration. The solution needs to be purified before observation.

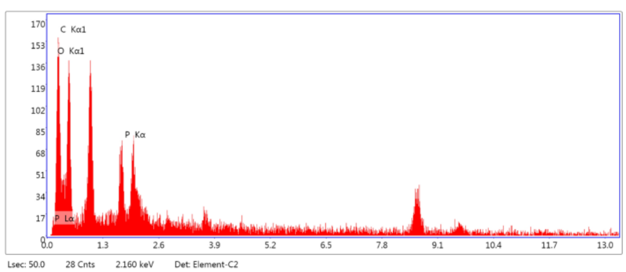


Figure 6: EDAX Result for sample B

- For sample C, the autoclave we used was not clean. The residual compounds cause a clear error in the UV and EDAX results.

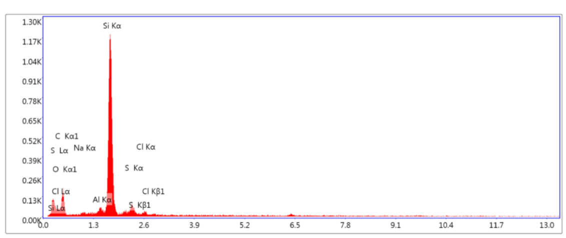


Figure 7: EDAX Result for sample C

- The SEM analysis of Sample A did not show Quantum dots, due to the delay in the time of preparation of the Quantum dots and SEM analysis. An agglomeration causing a thick white mass was seen in the solution.

6 Conclusion

- Three samples of quantum dots were synthesised, at different temperatures, corresponding to different wavelength of lights absorption when they were subjected to UV source.
- The fluorescence under UV light, and the characteristic UV absorption curve are an indication of successful preparation of fluorescent quantum dots.
- From the UV plot, it can be inferred that the wavelength increases with increase in temperature, implying the bandgap decreases with increase in the temperature at which the quantum dots are synthesised.
- The bandgap obtained from the UV analysis is around 3eV.

7 Acknowledgement

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