QUANTUM DOTS(QDs) SENSORS FOR DETECTION OF METALS IN WATER

A literature review submitted in partial fulfilment of the requirements for the degree of

Masters of science in chemistry.

By

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DECLARATION

I hereby declare that the literature review titled "**Quantum dots (QDs) sensors for the detection of metals in water"** has been carried out by me in the School of Chemical Science, Goa University, Goa under the supervision of Dr. Diptesh G. Naik and the same has not been submitted elsewhere for the award of a degree or diploma.

Gulzar Ahmad Bhat

20P0490037

CERTIFICATE

This is to certify that the dissertation entitled,” **Quantum dots (QDs) sensors for the detection of metals in water”** submitted by Mr. Gulzar Ahmad Bhat For the partial fulfilment of the degree of masters of science in chemistry (physical chemistry) during the period of January 2022-April 2022 in the school of chemical science, Goa University, is a record of authentic work carried out by him under my supervision. To the best of my knowledge, the matter embodied in the dissertation has not previously submitted for any degree in this/any other institute.

DATE:

Dr. Diptesh G. Naik

AKNOWLEDGMENT

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CONTENTS

INTRODUCTION

Quantum dots are a new class of nanomaterials with sizes in the nanometer range (<10nm). QDs are nanometer-scale semiconductor crystals made up of elements from groups II to VI or III to V, having physical dimensions smaller than the exciton Bohr radius. Wide and continuous absorption spectra, limited emission spectra, and great light stability are just a few of the remarkable luminescence and electronic properties of QDs. They absorb white light and, depending on the material's bandgap, re-emit a specific colour a few nanoseconds later.[1]

The detection and measurement of ions in various samples, such as environmental or biological samples, has long been a challenge. For the scientific community, it has been crucial. in reality, the development of innovative nanoparticle-based approaches the use of nanoparticles (NPs) for ion sensing has grown significantly. Heavy metal ions, such as lead, cadmium, and mercury, have gotten a lot of attention because of their severe toxicity as well as negative health consequences. Even relatively low levels of It are well recognised that significant concentration of lead, cadmium, and mercury ions create health problems. cardiovascular disease, cancer mortality, liver, kidney, and central nervous system damage, neurological, and reproductive disorders, as well as developmental abnormalities, which are more serious issues Especially for children. As a result, significant efforts have been made. committed to the research and development of the selective and sensitive methods of detection. [2]

A traditional analytical approach for identifying heavy metals includes atomic absorption spectroscopy, atomic absorption spectroscopy, and atomic absorption spectroscopy. Fluorescence spectroscopy (FL) and inductively coupled plasma mass spectrometry, which is time-consuming, expensive, and difficult to operate, bulky Optical sensing is a viable alternative to traditional sensing technologies. Due to its elevated sensitivity, simple hardware design, and ease of use, sensing and electrochemical sensing technologies have gotten a lot of attention. and usefulness. Various materials (such as) have been used in recent years. In optical applications, metal nanoparticles, semiconductor oxides. composite materials, polymers, and metal-organic frameworks (MOFs) have all been used. and electrochemical sensors to enhance sensor performance.[3]

Quantum dots (QDs) are one of them, and they're commonly used in heavy metal due to their superior performance, such as light stability, detection, Surface modification is simple, optical tuning is simple, and the environment is friendly. Since 2002, quantum dots (QDs) have been utilised to detect metal ions spectroscopically, and a wide spectrum of ions have been studied—both transition metals and heavy metals. The development of QD-based sensors for the most relevant harmful heavy metal ions, Cd2, Pb2, and Hg2, is the subject of this paper. Although a number of original publications have been published in the literature employing the unique features of QDs for sensing heavy metal ions, no thorough assessment of the many QD-based techniques for this particular range of target analytes has yet been published. We begin by outlining several ways for obtaining ion selectivity when designing chemo sensors for metal ion.[4]

The toxic industrial effluents are extensively causing harm to the aquatic organisms. These effluents, such as Cr(VI), Fe(III), Pb(II), etc. are mostly carcinogenic and mutagenic in nature . Such toxins are not only polluting water and aquatic organisms but also cause critical harm to the environment and thus need proper detection and removal. Chromium (Cr) is a common metal element used in the manufacturing of stainless-steel production and industrial applications. The chromium element has two stable ion forms in nature, trivalent chromium (Cr(III)) and hexavalent chromium (Cr(VI)). Cr(III) is a trace element, that is necessary for human metabolism. Cr(VI) is toxic and a recognized carcinogen, and extended period of time of exposure to the Cr(VI) ions will pose a risk of cancer.[5]

Table no.1

Summary of CPDs-based sensors for metal ion detection.

Analyte	Classification	Limit of detection	Linear range
Cr(vi)	N-CPDs	0.28μM	0.1μm-430μM
Cr(vi)	N,S-co-doped CPDs	0.52μM	1.40 μM
Hg^{2+}	N,S-co-doped CPDs	180nM	0-20mM
Hg^{2+}	Amino-modified CPDs	20nM	0.1-1.2mM
Hg^{2+}	N-CPDs	0.23nM	0.25nM
Fe^{3+}	CPDs	0.7 μM	5-80mM
Fe^{3+}	n-Doped CPDs	2.5nm	0.01-500mm
Cu^{2+}	CPDs	2nM	0-0.5mM
Cu^{2+}	N,S-co-doped CPDs	5nM	1-200nM

Based on the aforementioned research and the published results of heavy metal sensors constructed of CPDs (Table 1), we created a rapid, easy-to-use, portable, and reusable sensor by integrating specifically produced CPDs onto PVA-co-PE nanofibrous membranes for detection of Cr(VI) ions.[5]

LITERATURE REVIEW

2. Classification of Quantum dots

Excitation is made up of an electron and a hole, and the difference in energy between them is known as excitation Bohr's energy. When the semiconductor crystal is substantially larger than the excitation Bohr's radius of the material, the energy levels are considered as when the crystal size of the semiconductor gets smaller in comparison to excitation The energy levels appear to be discrete with a finite radius according to Bohr's radius. Quantum confinement is the outcome of the preceding condition, and it occurs when the Quantum dots are semiconductor materials that differ from their bulk characteristics. (QDs) are classified into three types based on the type of electron confinement. classes as described further down.[1][6]

2.1 Planer Quantum Dots

Metal gates are fabricated on the surface of a 2D electron gas heterostructure in this type of quantum dots (2DGH). The 2DGH is created by the flow of 2D electron gas on GaAs/AlsGaAs heterostructures. By supplying a voltage to the electrostatic potential, it may be increased. Negative gate bias is a term used to describe a bias in the 2DGH splits under the right biassing conditions, generating a tiny ring.[19] Planer area with a dot in the middle. The gate voltage affects the planer dots. external disturbance, form, and height the following are the primary characteristics of PQDs:

i) the flow of current in the 2DGH plane.

ii) adjustable tunnel barrier height.

2.2 Vertical Quantum Dots

Vertical QDs are made up of a GaAs disc (zero dimensional) sandwiched between two AlGaAs. The surrounding gate electrode in vertical QDs is negatively biased. The depletion of electrons from the pillar's outer area occurs when the pillars are negatively biased. as a result of which the disc shrinks. This finding suggests that the confinement of electron in a relatively small area near the pillar's core. There are fewer vertical QDs. Because of the huge band gap material and high tunnelling, it is vulnerable to external disturbances. Current flow is perpendicular to 2DGH in these obstructions.[7]

2.3 Self-assembled Quantum Dots

Self-assembled Quantum dots are formed in heterogeneous systems, when one kind of semiconductor material is deposited by chemical vapour deposition onto the surface of another semiconductor with different lattice spacing, e.g. Indium Gallium Arsenide deposited onto Indium Gallium Phosphide. The difference in the lattice spacing means that it is energetically favourable for the secondary crystal to form localised structures, rather than a flat layer. This is closely analogous to the way mercury droplets do not disperse when placed on a surface. When several monolayers of InAs are developed on a GaAs substrate, the heterogeneity in the materials results in a random distribution of self-assembled QDs due to the split of a 2D-layered structure. SAQDs have a significantly stronger confinement than PQDs and VQDs. This results in lens-shaped and pyramidal structures with a size of around 100A.[8]

3. Synthesis of quantum dots

Many ways have been used to make quantum dots, and these methods may be divided into two categories, as illustrated in Fig. 1, "Bottom-up" and "Top-down." Small materials are employed as a precursor to manufacturing quantum dots in the bottom-up technique.

In the top-down approach, the size of the materials must be reduced in order to generate quantum dots . Modifications are sometimes necessary to improve the characteristics and applications of quantum dots-based materials . Carbonaceous aggregation, size control, homogeneity, and surface characteristics are the key challenges confronted by researchers in the synthesis of QDs. Post-treatments such as dialysis, gel electrophoresis, and centrifugation can be used to improve the size and homogeneity of the samples. Electrochemical synthesis, solution chemistry, and proven pyrolysis methods can be used to solve the aggregation problem. The production of carbon-based quantum dots (CQDs) is discussed in depth in this section. Top down processing methods include Molecular beam epitaxy (MBE), ion implantation, and e-beam lithography are examples of processing techniques, as well as X-ray lithography.

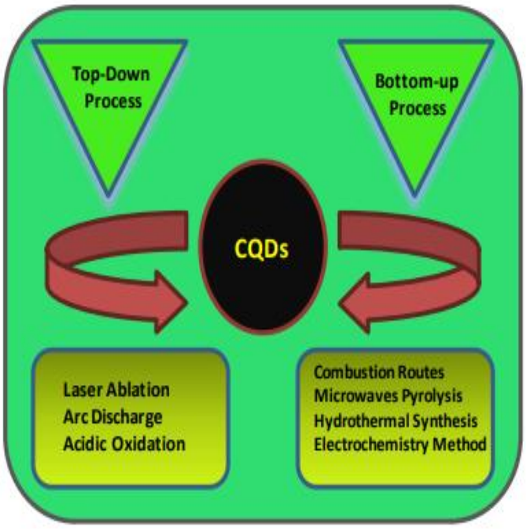


Fig.1 The typical approaches for the synthesis of CQDs

The QDs have been synthesised using a variety of self-assembly processes (bottom-up), which may be generally classified into wet-chemical and vapor-phase approaches: (a) Wet-chemical procedures primarily follow traditional precipitation methods, with appropriate parameter control for a single solution or mixture of solutions. Nucleation and limited growth are generally involved in the precipitation processes. Below in the figure is a chart form how the process 0f both approaches bottom down and top up methods are working.[9]

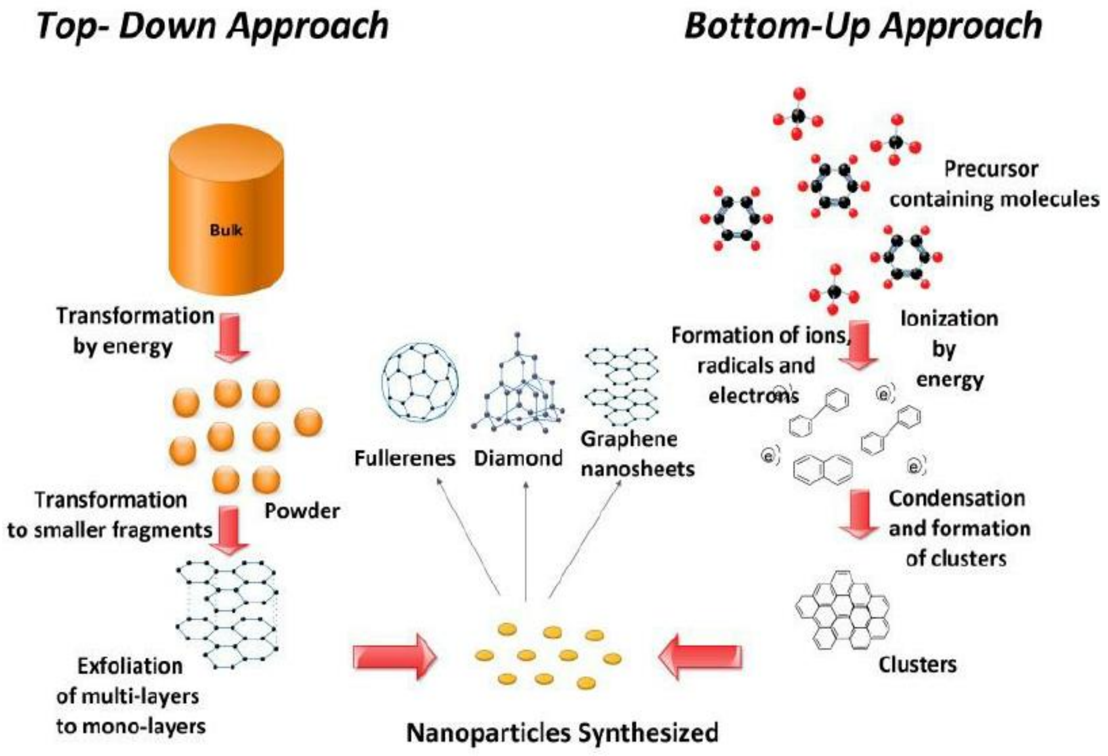


Fig.2 Synthesis of quantum dots: Top-Down approach; Bottom-Up approach

3.1 Top-Down Approach

3.1.1 Laser Ablation

Quantum dots are created in the laser ablation procedure by the nucleation of precursors and the development of vaporised molecules in the background gases. The rapid vapour reduction resulted in the formation of very pure quantum dots with a diameter of less than 10 nm. These nanoparticles have features that are not seen in bulk materials. The size distributions of such nanoparticles influence their most essential characteristics (electrical, magnetic, optical, and so on). The laser ablation method involves bombarding a laser beam on the surface of a solid target material in a gas or liquid media, causing the temperature of this region to quickly rise, causing the substance to vaporise in the form of atoms and clusters.[10]

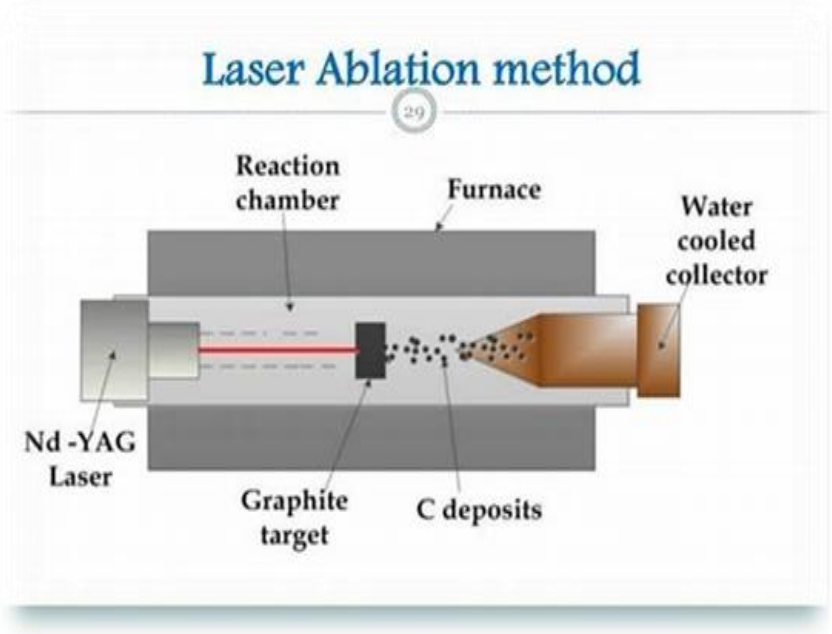
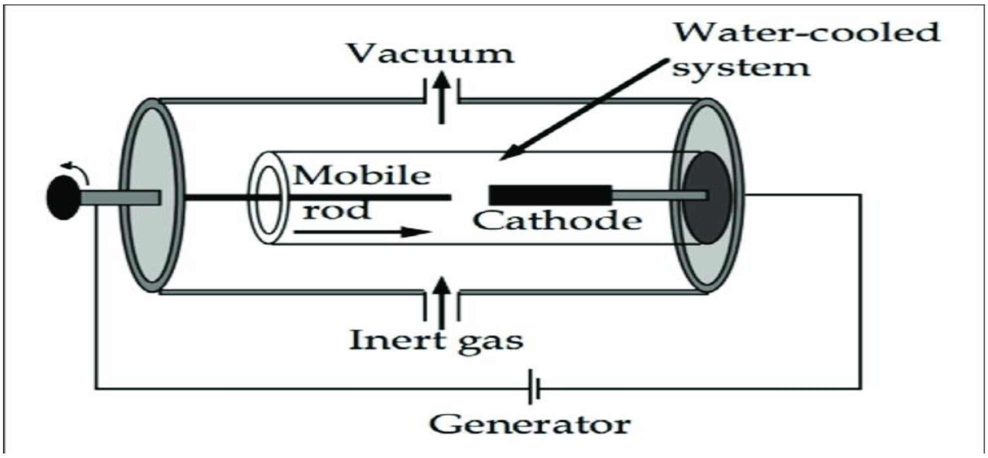


Fig.3 Laser ablation method

3.1.2 Arc Discharge

The quantum dots are generated through the breakdown of the bulk carbon precursor in arc discharge, which is a top-down technique. Carbon atoms are degraded in an acidic environment and electrode driven by gas plasma produced in a sealed reactor system in this process. Under electric current, the temperature of the reactor may reach 3727°C, allowing high-energy plasma to develop and carbon vapours to assemble at the cathode to generate CQDs.[11][12]



3.1.3 Acidic Oxidation

To breakdown bulk carbon sources and generate quantum dots, an acid oxidation technique is performed. During exfoliation and breakdown, hydrophilic groups (hydroxyl group, carboxyl group) are introduced into the material, enhancing the water solubility and fluorescence characteristics of the QDs. This broadens the scope of material synthesis in the subject of biological sciences. This approach requires strong oxidising acids for the carbonization of tiny organic molecules to carbonaceous material, and the resulting material may then be converted to quantum dots by controlled oxidation.

Tang et al. published a large-scale synthesis of CQDs with heteroatom doping utilising acid oxidation and hydrothermal reduction in 2014. Carbon nanoparticles were produced from Chinese ink and oxidised using a solution of HNO3, H2SO4, and NaClO3 in this process. The nitrogen, sulphur, and selenium were then doped using DMF, NaHS, and NaHSe as nitrogen, sulphur, and selenium sources in hydrothermal treatment. Doped quantum dots outperformed pure CQDs in terms of quantum yield, controllable PL performance, and fluorescence lifespan.[13]

On the other hand, multiple publications have shown that doped-CQDs have the capacity to interact with transition metal ions. Other metal ions, such as Co2+, Fe3+, and Ni2+, may be absorbed by the N-CQDs, S-CQDs, and Se-CQDs to form single-atom catalysts (SAC).

3.2 Bottom-up Approach

3.2.1 Combustion /thermal routes

The most advantageous technique in solution combustion for the creation of smaller nanoparticles (10nm). It has been reported that using a bottom-up strategy, high-surface-area nanoparticles may be made in a single step. The approach has a variety of benefits over traditional methods, including synthesis time, cost, and energy use. The in-situ oxides doping approach is also available, with the essential features being molecular level homogenous mixing, high-purity and highly crystalline end products creation due to the high reaction temperature, as well as growth that is hampered by the short reaction time. Solution combustion is the best method for making smaller nanoparticles (less than 10 nm).

An elegantly simple source of C-dots is the soot derived from the combustion of unscented candles or natural gas burners. Mao et al. produced water soluble multicolor fluorescent c-dots (< 2 nm) from the combustion soot of candles through oxidative acid treatment, which introduced OH and COOH groups to the C-dot surfaces. They purified the particles by using polyacrylamide gel electrophoresis (PAGE) fraction. Surface passivated C-dots were produced using one-step thermal decomposition of low-temperature-melting molecular precursors. Careful selection of the carbon source and surface modifier resulted better control over the geometry and physical properties of the C-dots. Highly blue luminescent C-dots with PL QY of 31.6–40.6% were prepared by a one-step pyrolytic route from ethylenediamine–tetra acetic acid salts. Also chemical oxidation of carbohydrates (glycerol, glycol, glucose, sucrose, citric acid, etc.) was another important approach to obtain C-dots. However, most of these synthesis methods need several steps and strong acid, and further treatment with other compounds to improve the water solubility and PL properties. Wu et al. exploited a high-yield synthesis of hydrophilic C-dots by controlled carbonization of sucrose. They effectively separated green luminescent C-dots and non-luminous C-dots, which on functionalization with PEG emitted blue fluorescence. Other groups also exploited hydrothermal technique for produce C-dots with high quantum yield taking different molecular precursor such as glucose, fructose sucrose, and ascorbic acid etc. Recently,in our laboratory, large scale synthesis of highly photoluminescent C-dots was achieved by hydrothermal treatment of cheap and readily available orange juice. Due to high photostability and low toxicity these C-dots are demonstrated as excellent probes in cellular imaging. Zhu et al. also produced bifunctional florescent C-dots by hydrothermal treatment of soya milk, which exhibited good electrocatalytic activity towards oxygen reduction.

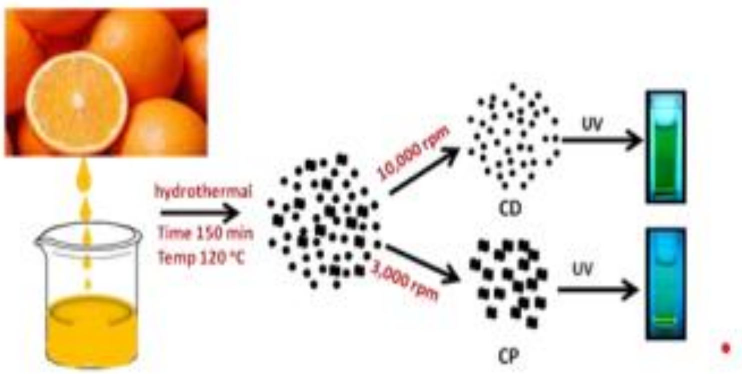


Fig.3.2 Illustration of formation of CDs from hydrodermal treatment

3.2.2 Microwave Pyrolysis

Microwave irradiation of CQDs with hydrophilic groups is a fast, environmentally friendly, and cost-effective method of synthesis . H. Zhu et al. [30] prepared a clear solution of poly (ethylene glycol) and a saccharide (glucose, fructose, etc.) in water and stored it in a microwave oven to make CQDs. Excitation-dependent PL characteristics were observed in the obtained CQDs. Microwave-mediated pyrolysis was used by Chen et al. to produce extremely luminous quantum dots. They did this by combining citric acid with different amine compounds as a carbon source. The amine molecules served as passivating agents as well as a nitrogen doping source, enhancing the quantum dots photoluminescence capabilities.

3.2.3 Hydrothermal /Solvothermal synthesis

The hydrothermal method for synthesis of quantum dots is widely used due to the size homogeneity of the final product and ease of setup [32, 33]. Using citric acid and amine, S. Zhu et al. [34] recorded the greatest quantum yield, which was virtually equivalent to fluorescent dye, i.e.,80 percent (ethylene diamine). The reaction precursor was created using this method by dissolving small molecules (organic and/or polymers) in a solvent, such as water or any other organic solvent. The reaction precursor was placed in a stainless-steel autoclave coated with Teflon. The organic molecules fused together under the influence of high temperatures to generate quantum dots of carbon-based materials. The size of these particles is less than 10nm. This technique is particularly useful in designing and fabricating new electro-catalysts because of the controlled doping and convenience of the synthesis process. The nitrogen doped QDs were synthesised by Niu et al. [35] using a hydrothermal approach, and the TEM picture of the obtained QDs in Fig. 2 [35] shows that the size of the QDs is less than 10 nm.[14]

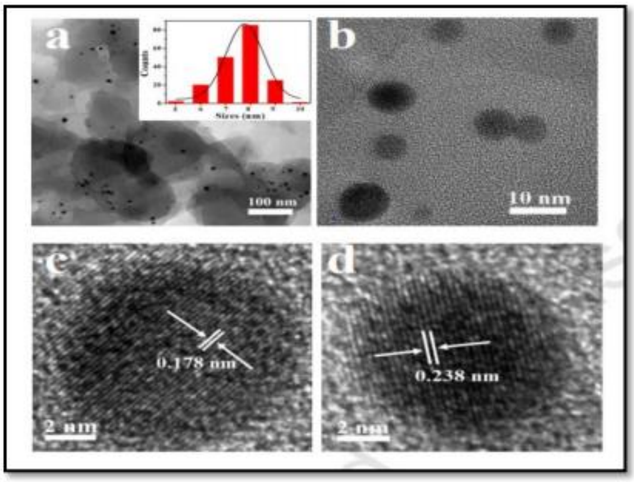


Fig. 2 LR- (a) and HR-TEM TEM (b, c, d) images of the as-synthesized N-doped carbon quantum dots (N-CQDs). The inset of (a) shows the particle size distribution histogram. Adapted with permission from Niu et al. [35]

3.2.4 Electrochemistry methods

This process is simple and convenient to use, and it may be done in normal pressure and temperature parameters. The electrochemical approach is widely used in the synthesis of CQDS in order to get a fast PL performance of CQDS [36-38]. Luo et al. [39] analyzed the emission of blue CQDs with a particle size of 2.4nm in deionized (DI) water by carbonization of urea and sodium citrate, which functions as a sensitive pathfinder for Hg2+ in waste water.

Although electrochemical synthesis is a capable and efficient approach for fabricating an electro catalyst, CQD synthesis for the electro catalyst is rarely documented. As a result, the combination of CQD synthesis and electro catalyst development in a single pot electrochemical method is intriguing. Using various bulk carbon components as precursors, electrochemical soaking might be used to build CQDs [40-46]. However, electrochemical carbonization of small substances has only been documented in a few cases. For the synthesis of CQDs, Zang et al. [47] developed the carbonization of low molecular weight alcohols. The experiment was carried out with a calomel electrode set on a fully adjustable stand and two Pt sheets functioning as auxiliary electrodes. The

Luggin capillary was employed as a reference electrode. Under normal conditions, this carbonization resulted in the transition of alcohols into CQDs. The size and degree of graphitization improved as the applied potential was increased. This amorphous core CQD exhibited excellent excitation and size-dependent PL characteristics and was as simple to make as a piece of low-hanging fruit [47]. Table 2 shows the merits and demerits of the different synthesis techniques mentioned previously.[15]

The merits and demerits of various synthesis approaches

S.NO.	Method	Merits	Demerits
1.	Laser ablation	Effective and fast process, tuneable surface states	It is difficult to control the size of obtained product. Modification is needed
2.	Arc discharge	Production of high quality CQDs	High temperature process, hard to control.
3.	Acidic Oxidation	Accessible	Harsh control, strong acid requirement, difficult to control the size
4.	Combustion routes	Single step process, less time required, cost effective	High temperature required
5.	Microwave	Irradiation eco-friendly, cost	It is difficult to control the size.

		effective, fast, process	
6.	Hydrothermal/solvothermal treatment	Cost effective, ecofriendly, non-toxic	It is difficult to control the size of obtained product.
7.	Electrochemical carbonization	Products are controllable (nanostructure and size), stable, single step process	Precursors are limited in numbers due to their smaller molecular size (limited precursor)

3.3 Additional synthesis

As shown in picture below core-shell structured CPDs were synthesised using a hydrothermal technique utilising citric acid as a carbon source and TAEA as a nitrogen source at 160°C for 4 hours. The mixed solution was dialyzed with a dialysis bag (3000 Da) for 48 hours, with the water outside the bag being replaced on a regular basis. The CPDs powder was produced after rotational evaporation and freeze-drying of the sample from the dialysis bag for further testing and use. Figure 3.3 shows a TEM picture of CPD morphology and the size distribution of CPDs. [5]

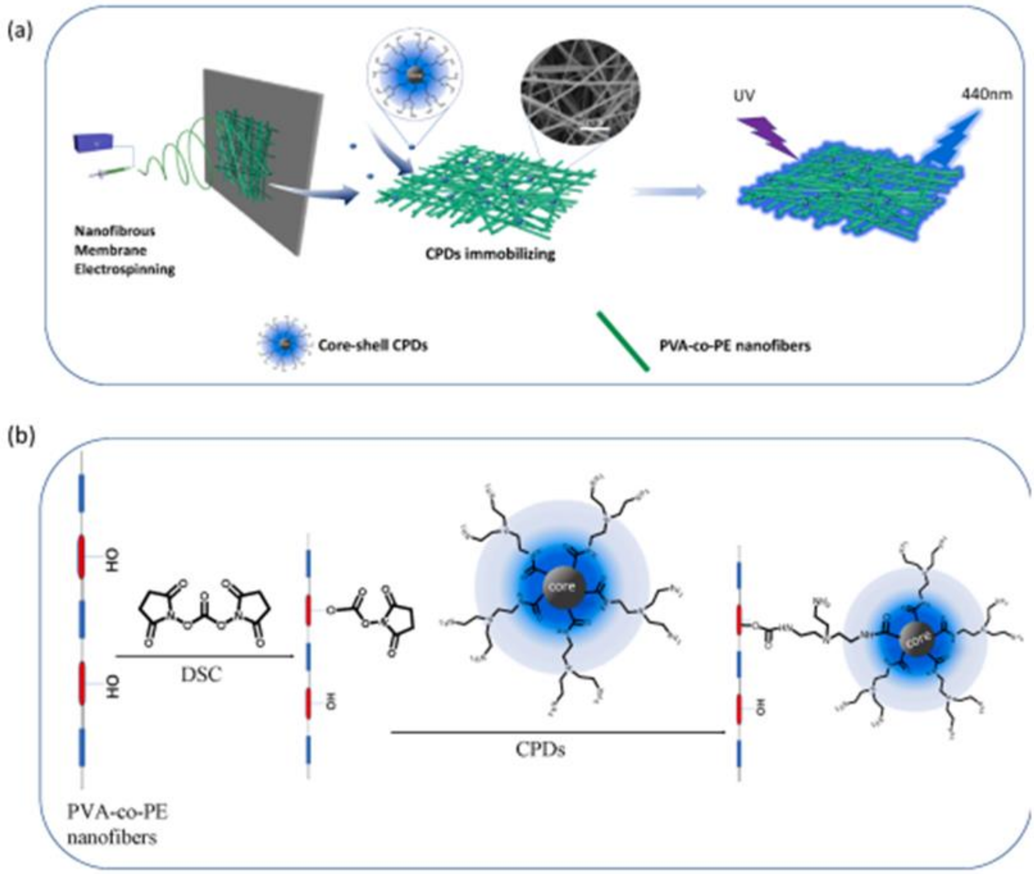


Fig. 3.3 TEM Picture of CPD morphology and size distribution.

4. Properties of carbon-based quantum dots

The nanocrystal's optical characteristics are determined by interactions between electrons and holes. When a beam of light is irradiated onto a material's surface, quanta are absorbed, and electrons move from the valence band to the conduction band. While a few electrons return to the valence band and produce photons, the majority of the electrons are trapped in the electron trap. As a result, quenching occurs in the form of a non-radiation transition. Only a few valence band photon electrons absorb energy before jumping back to the guidance belt. The luminous efficiency is reduced by using a deeper substance for the electron trap semiconductor. [16] The primary properties of any QD are the emission (photoluminescence) and absorption of different wavelengths of light, which combined give the optical behaviour of QDs. The absorbance of QDs has been shown to be in the UV-Visible region, with QDs fluorescing in response. The recombination of excited electrons with holes in their ground state is the core principle of lighting of various wavelength bands. In this type of recombination, a little quantity of symmetrical energy with a narrow wavelength inside the UV area is released, resulting in a colour shift from red to blue. Colour emission varies depending on the size of synthesised QDs, wavelength, and energy released intensity.[17] As the size of QDs grows larger, the spectrum shifts from blue to red, as seen in Fig. 5.[18]

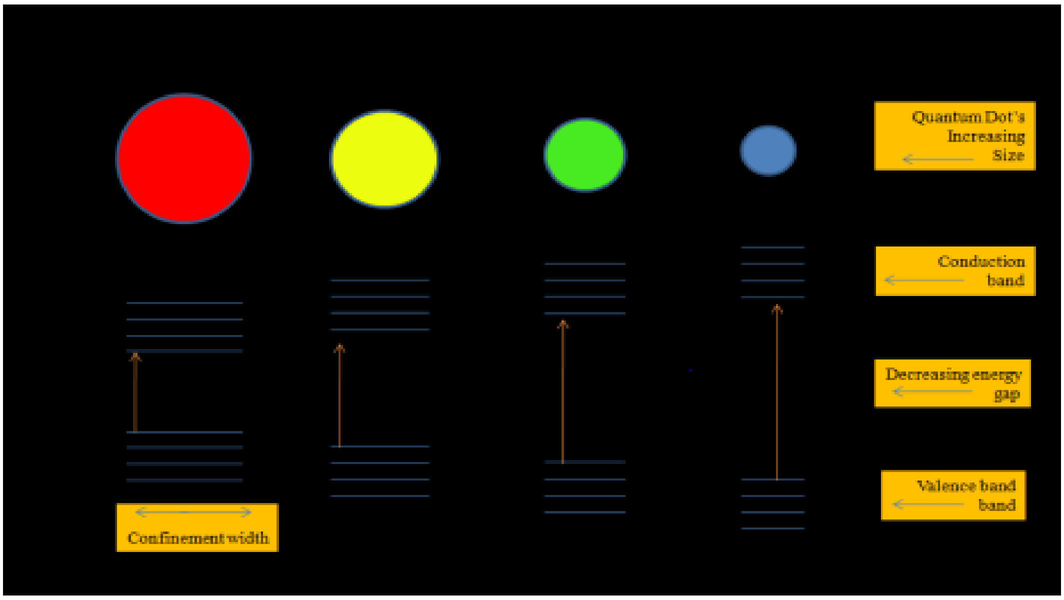


Fig.5 Decreasing size (left to right) and fluorescing under UV light

4.1 Photoluminescence

In both fundamental research and practical application, photoluminescence is the most fascinating feature of CQDs. The emission wavelength and intensity have an impact on the PL property of CQDs. This might be owing to differences in the size of emission traps on the surface. Pisanic et al. investigated the emission characteristics of dots with varying concentrations at 470 nm wavelength. As the concentration of CQDs was raised, the PL strength of the solution initially increased and subsequently declined.

Jaiswal et al. synthesised quantum dot impregnated-chitosan film for heavy metal ion detecting and removal.[7]

5. Detection of metals in water

Biomedical, energy, and water purification, as well as sensors for detecting toxins present in water samples, have all benefited from the massive industrial expansion and worldwide population explosion that has led to the populous manner of enrichment for nanotechnology based advancements.[17] Quantum dots, graphene, carbon nanotubes, and other nanomaterials have a vast potential for use in a variety of sectors. This section focuses on the use of carbon-based QDs in water treatment applications, such as heavy metal ion detection sensors, filter papers, and membrane improvements, among other things.[19] Water pollution is mostly caused by excessive water demand in numerous industries, including mining, organo chemical synthesis, energy-related applications, and biomedical. As a result, water becomes contaminated with heavy metals and their ions. Heavy metals can easily attach to any biological mechanism, resulting in serious consequences for everyone. Some metal ions, including as iron, copper, manganese, and nickel, play vital roles in a variety of biological processes, such as catalysis, biotechnology, haemoglobin production, and so on.[20]

Copper ions, too, play an important function in plants and animals. Each biological system requires a precise amount of these ions, as their excess might be harmful. As a result, selective concentrations of each heavy metal ion play an important role in human and animal health. The CQDs aligned organic metal based framework for the more accurate detection of Fe^{3+} and Cu^{2+} was reported by Fanet et al.. The organometallic CQDs were developed for their florescent sensing potential for Fe^{3+} and Cu^{2+} ions. By inserting and removing carbon quantum dots florescence from the system, the produced system was claimed to follow an on–off approach. This system served as a probe for detecting iron and copper in water, with LOD values of 1.3 and 2.3 ppb for sensing Cu^{2+} and Fe^{3+} ions, respectively, using the CQDs-based metal aligned organic framework. Summarily, Dong, and co-researchers described a GQDs-based monitoring system for detecting residual and free chlorine ions in drinking water, which relied on the quenching of graphene-based quantum dots, or GQDs. Because of its great reaction time, superior selectivity, and sensitivity, the created system for the detection of chlorine ions outperformed previous sensors. [21]The independent chlorine ions' response time range was determined to be about 0.05 to 10 Mm. The lower detection limit was lower than that of the commonly used N-N-diethylp-phenylenediamine colorimetric tests. The disclosed sensing apparatus was also employed to detect residual chlorine atoms and ions in tap water samples. The mentioned colorimetric methodology suggested to have excellent candidature along with huge potential for the application of water sensing and purification as it has the advantage of greener and environment facile pathway. The presence of distinct catechol groups beside the surface of QDs aided in the discovery of a particular response for the detection of iron ions. The generated QDs were said to have a good probe for labelling and detecting iron ions as well as dopamine, with detection limits of 0.32 nm for iron and 68 nm for dopamine.[22] The possible use of the synthesized QDs was also validated in water samples containing human urine. Carbon nanoparticles are made from carbon soot, which may be created by simply burning a candle. The most cost-effective way to make carbon nanoparticles was discovered to offer incredible detection and sensing abilities for silver ions. Silver ion detection limit was claimed to be as low as 500 pM with high specific selectivity. As a result, the produced nanoparticles were also applied for practical silver ion detection in a variety of applications. The use of CQD-based sensory platforms is a step toward resolving the drawbacks of traditional sensing technologies, such as bleaching, toxicity, inadequate sensitivity, complicated synthesis, and so on (e.g., colorimetric dyes and semiconductor quantum dots). Due to the better sensing characteristics of CQDs-sensory probes (e.g., fluorescence quenching, activation/enhancement, photo induced electron transfer (PET), phosphorescence, ratio metric dual emission, fluorescence resonance energy transfer (FRET), and surface enhanced Raman scattering (SERS)), practical applications for CQD-based heavy metal detection have been developed. The sensing performances for heavy metal ions using CQDs produced chemically and green synthesis techniques may be compared in terms of analytical properties (e.g., detection limit, linear range, and quantum yield). Nonetheless, the sensing technology based on chemically modified CQDs obviously yields higher sensitivity. The specialized interactions with heavy metals via strong interactions with ligands are a major advantage of sensory platforms based on chemically modified CQDs. In light of a growing demand for advanced monitoring systems for heavy metals, the visual sensors were recognized as emerging platforms due to their simplicity, cost-effectiveness, and eco- friendliness.[2][3][20]

6. CONCLUSION

In this review, we have reviewed the different types of quantum dots and their synthesis. For years, the use of QDs as metal sensors has gotten a lot of interest because of their unique properties. The QDs-based nano sensors for heavy metal ion detection have been discussed in this review. These sensors may be divided into two categories based on their sensing principles: optical and electrochemical sensors. Despite the remarkable development and innovation in QDs-based nano-sensors for heavy metal ion detection, there are still significant problems in terms of toxicity, selectivity, mobility, multi-metal co-detection, and degradation during detection. The initial focus should be the difficulty of synthesising high-quantum-yield QDs using easy and green synthesis techniques, as well as their simple and efficient coupling with other materials. QDs may now be utilised to detect heavy metals not just in water, but also in bodily fluids, food, soil, and other materials. However, due to in vivo toxicological effects, QDs cannot be safely employed as a probe in the body until the problem of QDs toxicity and green production is handled, which limits the development of QDs use. In conclusion, QDs-based nano sensors have several benefits and huge potential for detecting heavy metal ions. Corresponding antibodies and aptamers, among other things, have been added. Nano sensors based on QDs might be utilised to detect viruses, proteins, and nucleic acids. It might be used to detect potentially harmful pathogens. The purpose of this study is to describe the progress achieved in the development of CQD sensing systems by examining the current state, difficulties, and future prospects. and develop effective colour based visual sensing approaches to improve their performance, selectivity, and sensitivity, further design simplification and increase of specificity towards target metals should be considered. Sensors should be developed with the goal of making data processing and interpretation easier and faster. Finally, in order to broaden their usage in real-world sensing applications, the problems connected with CQD-based disposable sensors and user-friendly readout systems should be thoroughly addressed. The sensors' field use will make onsite metal detection possible and the task less stressful. It will also allow for continuous metal monitoring at the places chosen for observation.

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