

SYNTHESIS OF CARBON QUANTUM DOTS FROM MUSHROOMS AND THEIR USAGE IN ENERGY STORAGE DEVICES

Submitted in partial fulfillment of the requirements for the award of
Chemical Engineering.

By

VENKATA SUBRAMANIAN.S (40190028)
V.SUMANTH (40190032)



DEPARTMENT OF CHEMICAL ENGINEERING
SCHOOL OF BIO AND CHEMICAL ENGINEERING
SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(Deemed to be University)
Accredited with Grade "A++" by NAAC
JEPPIAAR NAGAR, RAJIV GANDHI SALAI,
CHENNAI – 600119, TAMILNADU

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SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
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DEPARTEMENT OF CHEMICAL ENGINEERING BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **VENKATA SUBRAMANIAN.S (40120028)** and **V. SUMANTH (40190032)** who carried out the project entitled "**SYNTHESIS OF CARBON QUANTUM DOTS FROM MUSHROOMS AND THEIR USAGE IN ENERGY STORAGE DEVICES**" under my supervision from December 2023 to April 2024.

Internal Guide

DR. S.SATHISH,M.E,Ph.D.,

Head of the Department

DR.S.SATHISH,M.E,Ph.D.,

HEAD OF THE DEPARTMENT
DEPARTMENT OF CHEMICAL ENGINEERING
SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Ippiaar Nagar, Rajiv Gandhi Salai
Chennai - 600 119

Submitted for Viva-voce Examination held on

6/4/24

Internal examiner

External Examiner

DECLARATION

We, VENKATA SUBRAMANIAN.S AND V. SUMANTH hereby declare that the Project Report entitled "SYNTHESIS OF CARBON QUANTUM DOTS FROM MUSHROOMS AND THEIR USAGE IN ENERGY STORAGE DEVICES." done by me under the guidance of DR.S.SATHISH,M.E,Ph.D.,is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Chemical engineering.

DATE: 03/04/24
PLACE: CHENNAI

V. Sumanth
S. Venkata Subramanian

SIGNATURE OF THE CANDIDATES

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VENKATA SUBRAMANIAN.S (40190028)

V.SUMANTH (40190032)

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ABSTRACT

This abstract explores the synthesis of carbon quantum dots (CQDs) from mushrooms and their potential utilization in supercapacitors, energy storage devices and energy production and conversion devices. Carbon quantum dots, a class of nanoscale carbon materials, have garnered considerable attention due to their unique properties and versatile applications. The process of deriving CQDs from mushrooms involves a carbonization process that transforms mushroom-derived precursors into nanoscale carbon structures. These CQDs exhibit remarkable optical, electronic, and electrochemical properties, making them suitable candidates for energy storage applications. In this particular study, fluorescent CQDs were successfully synthesized from edible mushrooms using a simple one-step hydrothermal process, assisted by diluted sulfuric acid. These spherical carbon quantum dots, with a mean diameter range of 4-5 nm, shows blue photoluminescence. They were further tested in FTIR Spectroscopy, XRD (X-Ray diffraction) and SEM images. Our results demonstrated that edible mushroom can be used to produce multi-faceted carbon quantum dots with diverse applications.

The integration of CQDs into supercapacitors and energy storage devices capitalizes on their high surface area, tuneable bandgap, and excellent charge transport characteristics. This allows for enhanced energy storage and rapid charge-discharge cycles, crucial for efficient supercapacitor performance. Moreover, the abundance of precursor sources, such as agricultural waste from mushrooms, adds to the environmental appeal of this synthesis approach. By utilizing mushroom-derived CQDs in energy storage devices, a sustainable and efficient route to advancing energy storage technologies can be achieved, contributing to the development of more reliable and environmentally friendly energy solutions.

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CHAPTER - 1

INTRODUCTION

Utilizing Carbon Quantum Dots (CQDs) derived from mushrooms presents an innovative avenue in the development of supercapacitor technology. These naturally sourced CQDs offer remarkable charge storage capabilities, owing to their unique structural and compositional properties. By harnessing the renewable potential of mushroom based CQDs, supercapacitors can achieve sustainable energy storage solutions. The compatibility of these biogenic materials with existing electrode systems fosters the creation of efficient and eco-friendly energy storage devices. As we explore the diverse applications of mushroom derived CQDs in supercapacitors, a greener and more efficient energy landscape comes into focus.

1.1 PURPOSE OF THE PROJECT

The purpose of this project is to explore the utilization of Carbon Quantum Dots (CQDs) extracted from mushrooms as a novel and sustainable material for enhancing supercapacitor performance. By investigating the unique properties of mushroom based CQDs, the project aims to unlock their potential in advancing energy storage technologies. Through comprehensive analysis and experimentation, the project seeks to contribute to the development of efficient, eco-friendly, and cost-effective supercapacitors for diverse applications.

1.2 OVERVIEW ON CARBON QUANTUM DOTS (CQDs)

Carbon Quantum Dots (CQDs) sourced from mushrooms are nanoscale carbon particles with exceptional electrical properties. Extracted from natural biomass, these CQDs offer a sustainable and renewable material option. Their distinctive structure and composition make them suitable for energy storage applications like supercapacitors, due to their high surface area and conductivity. Harnessing these biogenic CQDs presents a promising avenue for greener and more efficient energy storage solutions.

1.3 BACKGROUND

Carbon quantum dots (CQDs) are small carbon nanoparticles with dimensions less than 10 nm. They have gained significant attention in the recent years due to their unique optical, electronic and chemical properties. The synthesis of CQDs from natural sources is a promising area of research as it is an eco-friendly and cost-effective alternative to synthetic methods.

CQDs have a range of fascinating properties that make them attractive for use in various applications. One of their most notable properties is their photoluminescence. CQDs emit bright and stable fluorescence, making them ideal for applications in areas such as bioimaging, biosensing, and optoelectronics. CQDs also possess excellent biocompatibility and low toxicity, making them suitable for use in biomedical applications. Furthermore, their small size allows for efficient cellular uptake, making them promising candidates for drug delivery systems.

Over the past few decades, CQDs have been extensively studied for their unique optical and electronic properties, which arise due to quantum confinement effects. These properties have led to their use in a wide range of applications such as solar cells, light-emitting diodes (LEDs), and bioimaging.

The development of CQDs has also played a significant role in the field of nanotechnology. Researchers have developed a range of synthetic methods for producing CQDs with precise control over size, shape, and composition. These developments have enabled the study of fundamental quantum phenomena and opened up new avenues for developing advanced materials with tailored properties. Overall, the study of CQDs continues to be an exciting area of research with promising prospects for future technological applications.

1.4 IMPORTANCE OF SUPERCAPACITORS IN ENERGY STORAGE

Supercapacitors play a vital role in energy storage by offering rapid energy discharge and high-power density. They bridge the gap between traditional batteries and capacitors, providing quick bursts of energy for applications like regenerative braking in vehicles and smoothing out power fluctuations in renewable energy systems. Their extended cycle life, rapid charging, and ability to store and release energy efficiently make them crucial for enhancing grid stability, extending battery life, and supporting emerging technologies such as electric vehicles and portable electronics.

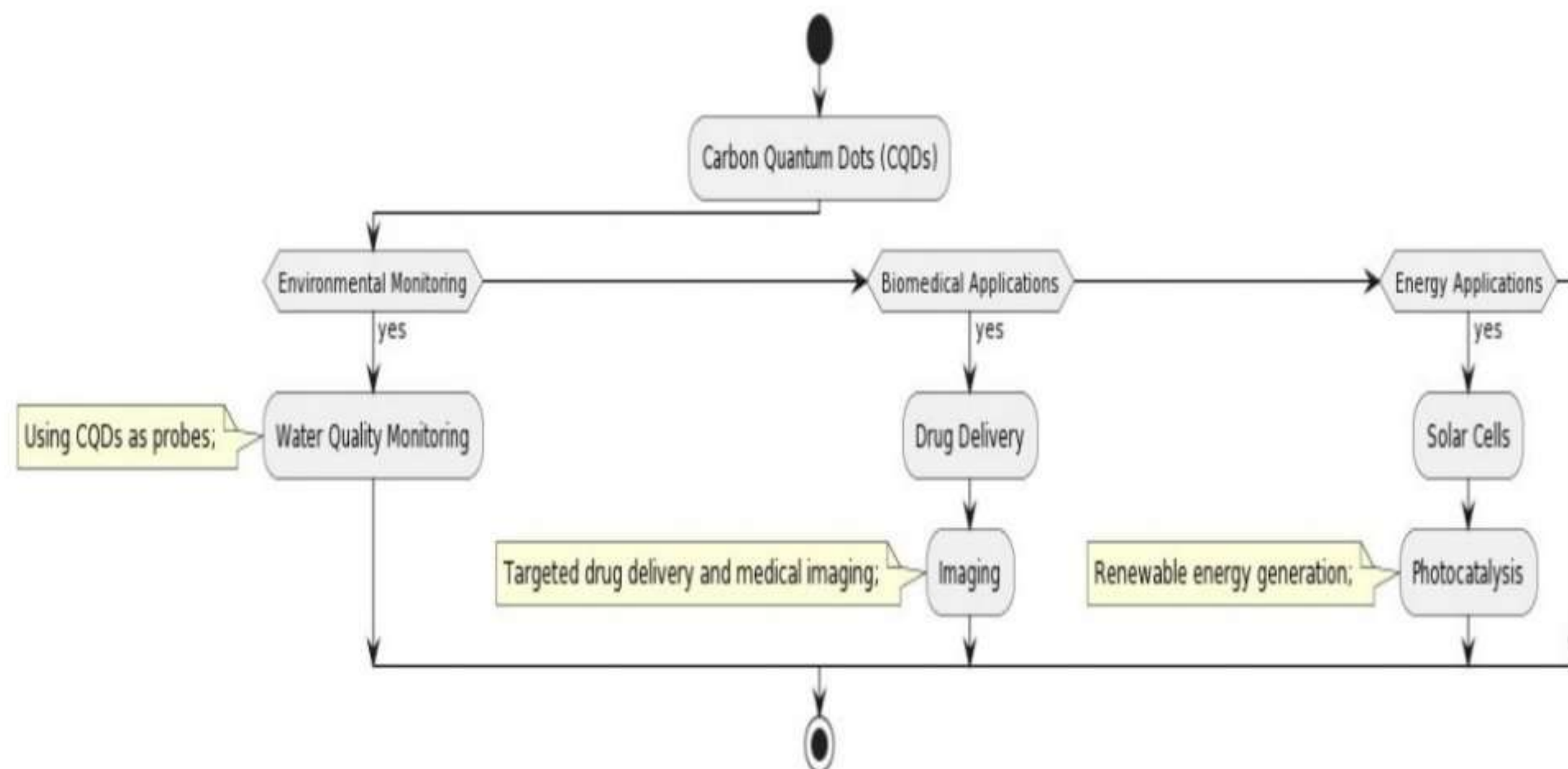


Fig:1.1 Different applications of CQDs

CHAPTER - 2

LITERATURE REVIEW

2.1 CARBON QUANTUM DOTS.

One of the most widely used top-down approaches for the synthesis of CQDs from mushrooms is the hydrothermal method. In this method, the mushroom-derived precursors are subjected to hydrothermal treatment in the presence of an acid or base catalyst. The hydrothermal treatment leads to the breakdown of the precursors into smaller CQDs. The size and properties of the CQDs can be controlled by varying the reaction parameters such as temperature, time, and precursor concentration

Another top-down approach for the synthesis of CQDs from mushrooms is the microwave-assisted method. In this method, the mushroom-derived precursors are subjected to microwave irradiation in the presence of a suitable solvent. The microwave irradiation leads to the formation of CQDs by the thermal decomposition of the precursors.

The bottom-up approach for the synthesis of CQDs from mushrooms involves the controlled assembly of smaller molecular units into larger nanoscale materials. One of the most widely used bottom-up approaches is the solvothermal method. In this method, the mushroom-derived precursors are dissolved in a suitable solvent, followed by the addition of a reducing agent and a stabilizing agent. The mixture is then subjected to solvothermal treatment, leading to the formation of CQDs by the controlled assembly of the precursor molecules.

2.2 SOURCES OF CARBON QUANTUM DOTS.

Carbon quantum dots (CQDs) can be derived from a variety of sources including:

- Carbon-rich materials such as graphite, carbon black, carbon nanotubes, and carbon fibers.
- Biomass waste such as fruit peels, vegetable waste, and eggshells.
- Organic molecules such as glucose, citric acid, and amino acids.
- Industrial waste such as fly ash, soot, and coal.
- Carbon dioxide (CO_2) through electrochemical or photocatalytic reduction.

The choice of source material depends on the desired properties of the CQDs and the specific application for which they will be used. For example, CQDs derived from biomass waste are considered eco-friendly and sustainable, while those derived from industrial waste may offer cost-effective solutions for large-scale production.

2.3 APPLICATIONS OF CARBON QUANTUM DOTS.

- **Bioimaging:** CQDs have excellent optical properties, including high fluorescence quantum yield, photo-stability, and biocompatibility. They can be used as imaging agents for bioimaging applications, such as fluorescent labeling of cells, tissues, and organs. CQDs can also be functionalized with targeting moieties, such as antibodies or peptides, to specifically bind to biomolecules of interest, making them an excellent tool for targeted imaging and disease diagnosis.
- **Sensing:** CQDs can be used as sensors for the detection of various analytes, such as metal ions, organic pollutants, and biological molecules. The sensing mechanism is based on the fluorescence quenching or enhancement of CQDs

in the presence of analytes. For example, CQDs functionalized with specific receptors can selectively detect target molecules through fluorescence quenching or enhancement, providing a sensitive and rapid detection method.

- **Energy conversion:** CQDs have shown potential applications in energy conversion, including solar cells and photocatalysis. In solar cells, CQDs can be used as sensitizers to convert light energy into electrical energy, while in photocatalysis, CQDs can be used as photocatalysts to accelerate chemical reactions under visible light irradiation. CQDs have also been used as electrocatalysts for fuel cells, showing excellent catalytic activity and stability.
- **Environmental remediation:** CQDs can be used for the removal of various pollutants, such as heavy metal ions, organic dyes, and antibiotics, from wastewater. The removal mechanism is based on the strong adsorption capacity of CQDs, which can efficiently remove pollutants from aqueous solutions. CQDs have also been used for the detection of environmental pollutants, providing a sensitive and selective detection method.
- **Biomedical applications:** CQDs have shown great potential in biomedical applications, including drug delivery, photodynamic therapy, and bioimaging. CQDs can be used as carriers for drug delivery, providing a controlled release of drugs with high efficacy and low toxicity. CQDs can also be used as photosensitizers for photodynamic therapy, which involves the use of light to activate photosensitizers to produce reactive oxygen species that can kill cancer cells.

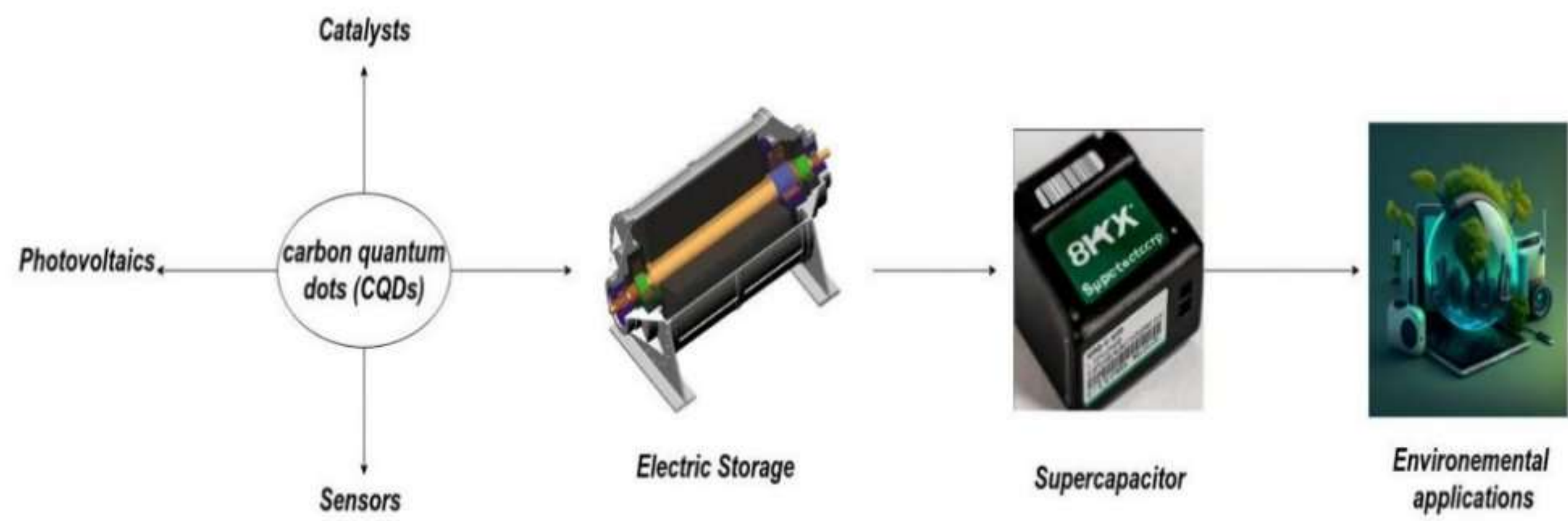


Fig:2.1 Scope for future in technical aspects

2.4 SYNTHESIS METHODS OF CARBON QUANTUM DOTS.

Carbon quantum dots (CQDs) can be synthesized through various methods, including top-down and bottom-up approaches. Here are some commonly used synthesis methods for CQDs.

- **Hydrothermal method:** This method involves the hydrothermal treatment of carbon sources, such as citric acid, glucose, or sucrose, in the presence of a strong acid or base at high temperature and pressure. The resulting CQDs are typically small in size and have a narrow size distribution.
- **Microwave-assisted synthesis:** This method involves the microwave-assisted pyrolysis of carbon sources, such as citric acid or glucose, in the presence of a surfactant or a stabilizer. The microwave irradiation leads to the rapid heating and decomposition of the carbon source, resulting in the formation of CQDs.
- **Electrochemical synthesis:** This method involves the electrochemical oxidation of carbon sources, such as graphite or carbon black, in the presence of a supporting electrolyte. The electrochemical process leads to the formation of CQDs on the surface of the electrode.
- **Laser ablation method:** This method involves the laser ablation of carbon targets, such as graphite or carbon nanotubes, in a liquid medium. The laser irradiation leads to the fragmentation of the carbon targets, resulting in the formation of CQDs.
- **Solvothermal method:** This method involves the solvothermal treatment of carbon sources, such as citric acid or glucose, in a polar solvent at high temperature and pressure. The resulting CQDs are typically small in size and have a narrow size distribution.

- **Template-assisted method:** This method involves the use of a template, such as a surfactant or a polymer, to control the size and morphology of the CQDs during synthesis. The template can also act as a stabilizer to prevent the aggregation of CQDs. In summary, there are several methods for synthesizing CQDs, each with its own advantages and disadvantages. The choice of method depends on the desired properties of the CQDs, such as size, morphology, and optical properties.

2.5 PREVIOUS STUDIES ON CARBON QUANTUM DOTS FROM MUSHROOMS.

- **CQDs from *Lentinula edodes*:** A study published in the journal Nanomaterials in 2020 reported the synthesis of CQDs from *Lentinula edodes* (shiitake mushrooms) using a hydrothermal method. The CQDs showed excellent photoluminescence properties and were found to have potential applications in bioimaging and drug delivery.
- **CQDs from *Pleurotus ostreatus*:** Another study published in the Journal of Nanoscience and Nanotechnology in 2020 reported the synthesis of CQDs from *Pleurotus ostreatus* (oyster mushrooms) using a hydrothermal method. The CQDs showed excellent fluorescent properties and were found to have potential applications in bioimaging and sensing.
- **CQDs from *Ganoderma lucidum*:** A study published in the Journal of Nanoparticle Research in 2018 reported the synthesis of CQDs from *Ganoderma lucidum* (lingzhi mushrooms) using a hydrothermal method. The CQDs showed excellent photoluminescence properties and were found to have potential applications in bioimaging and cancer therapy.

Overall, these studies highlight the potential of mushrooms as a source of CQDs with excellent properties for various applications in biomedicine, sensing, and imaging.

CHAPTER – 3

AIM AND SCOPE OF THE PROJECT

3.1 AIM OF THE PROJECT.

- To develop a sustainable and eco-friendly method for the synthesis of CQDs.
- To obtain CQDs with excellent photoluminescence properties, high stability, and low toxicity.
- To explore the potential of mushroom-derived CQDs for various applications such as electrochemical performance.
- To use CQDs in energy storage devices is to enhance their energy storage capacity and power density.
- To contribute to improved electrochemical performance, allowing for efficient charge storage and rapid energy release.

3.2 SCOPE

- **Lighting:** CQDs can be used in LED lighting technology to produce high- quality, energy-efficient lighting.
- **Solar cells:** CQDs have shown promise as materials for use in solar cells due to their ability to absorb light over a broad range of wavelengths.
- **Biomedical imaging:** CQDs can be used as contrast agents in biomedical imaging due to their unique optical properties.
- **Sensing:** CQDs can be used to develop sensors that are capable of detecting specific chemical or biological compounds.

- **Data storage:** CQDs can be used as materials for high-density data storage, as their small size allows for a larger amount of data to be stored in a smaller space.
- **Catalysis:** CQDs can be used as catalysts in chemical reactions due to their unique surface properties.
- **Quantum computing:** CQDs can be used as building blocks in the development of quantum computers, due to their ability to trap and manipulate individual electrons.
- **Water purification:** CQDs can be used in water purification technology to remove harmful contaminants from water.
- **Energy storage:** CQDs can be used as materials for high-performance energy storage devices such as batteries and supercapacitors.
- **Printable electronics:** CQDs can be used to develop printable electronics, which are flexible, lightweight, and low-cost electronic devices.

3.3 SUPERCAPACITORS: BASICS AND WORKING PRINCIPLE.

Supercapacitors store energy between two activated carbon electrodes in an electrolyte. Charge is stored through physical separation (double layer capacitance) and certain materials' reversible redox reactions (pseudo capacitance). This rapid energy exchange, distinct from batteries, suits high power demands in applications like electric vehicles and grid stabilization.

Supercapacitors, or ultracapacitors, are energy storage devices that store charge through reversible physical and electrochemical processes, distinct from batteries.

Classification of supercapacitors:

- Electrostatic Double Layer Capacitors (EDLCs)
- Pseudo capacitors
- Hybrid Supercapacitors

Supercapacitors Vs Batteries

- Supercapacitors store energy through physical separation and electrochemical processes, enabling rapid charge and discharge, whereas batteries rely on slower chemical reactions.
- Supercapacitors have shorter charge/discharge cycles, making them suitable for high power applications, while batteries offer higher energy density and longer cycle life.
- Supercapacitors excel in power delivery and energy capture during braking (regenerative braking) in vehicles, while batteries provide sustained energy over a longer period.
- Supercapacitors have lower energy density compared to batteries, but they can bridge the gap between batteries and conventional capacitors.

Supercapacitors vs. Normal Capacitors:

- Supercapacitors store much more energy than normal capacitors due to their higher surface area and specialized materials.
- Normal capacitors store energy through the electrostatic separation of charges without electrochemical reactions, resulting in much lower energy storage capacity.
- Supercapacitors are designed for higher energy and power densities, suitable for rapid energy exchange, while normal capacitors are mainly used for energy storage and discharge in simple electronic circuits.

3.4 WORKING OF SUPERCAPACITORS

Supercapacitors function by utilizing two key energy storage mechanisms: double layer capacitance and pseudo capacitance. In double layer capacitance, charges accumulate at the electrode electrolyte interface, creating a physical separation of charge. This process allows for rapid charge and discharge cycles, making supercapacitors adept at delivering high power bursts. Pseudo capacitance involves reversible redox reactions at the electrode surface, increasing energy storage capacity compared to conventional capacitors. When charging, ions from the electrolyte collect at the electrode surfaces, creating a potential difference. This stored energy is rapidly released during discharge, enabling supercapacitors to swiftly provide bursts of power for various applications.

CHAPTER – 4

MATERIALS AND METHODS

4.1 MATERIALS.

The following materials were used for the synthesis of CQDs:

- Fresh mushrooms (Agaricus biporous Or Button Mushrooms)
- blender
- sulfuric acid (H_2SO_4)
- Magnetic pellet.
- water
- Zinc Oxide (ZnO)

4.2 PREPARATION OF MUSHROOM EXTRACT

Select a mushroom species that contains high amounts of natural carbon, such as Shiitake mushrooms or button mushrooms. Wash the mushrooms thoroughly with water to remove any dirt or debris. Pat them dry with a clean towel. Cut the mushrooms into small pieces and put them into a blender. Blend the mushrooms in the blender until they are finely chopped.

Add enough water to the blender to cover the mushrooms completely. Blend the mixture for a few minutes until it becomes a smooth liquid. Pour the mushroom extract through a filter to remove any solid particles. Collect the filtered extract in a clean container. Boil the extract on low heat until it becomes concentrated. let the extract cool down to ambient room temperature. Store the mushroom extract in a clean and dry container until ready to use for CQDs synthesis. The concentration of the mushroom extract can be adjusted according to the desired concentration of the final CQDs solution.

4.3 SYNTHESIS OF MUSHROOM EXTRACT.

The synthesis of CQDs from mushrooms was carried out in two steps:

Step 1: Extraction of raw material.

The fresh mushrooms were washed thoroughly with water to remove any dirt or debris. The mushrooms were cut into small pieces and blended to form a fine paste. The paste was filtered using a muslin cloth to remove any solid particles. The filtrate was collected in a beaker and subjected to centrifugation at 10,000 rpm for 15 minutes. The supernatant was collected and stored in a refrigerator for further use.

Step 2: Synthesis of CQDs

To synthesize the carbon quantum dots (CQDs), a procedure was followed as described below: Initially, 5 mL of mushroom extract was combined with 5 mL of H_2SO_4 in a gradually added manner while maintaining continuous stirring until the pH of the solution reached 2. The resulting mixture was then heated at 100°C for a duration of 2 hours. Subsequently, the mixture was allowed to cool down to room temperature, followed by the addition of 5 mL of acid dropwise until the pH was adjusted to 1. The contents were then heated at 100°C for 1 hour. Afterward, the mixture was cooled to room temperature, and 5 mL of H_2SO_4 solution was gradually added dropwise until the pH reached 7. The contents were heated at 80°C for an additional hour. Upon cooling to room temperature. To collect the CQDs, the reaction mixture was subjected to centrifugation at 10,000 rpm for 15 minutes. The collected CQDs were then washed multiple times with water and ethanol to eliminate any impurities present.

METHODOLOGY:



Fig: 4.1 Methodology of synthesizing carbon quantum dots from Mushrooms

4.4 ACQUIRING MATERIALS AND BUILDING A CAPACITOR OUT OF THEM

MATERIALS REQUIRED: 2 copper mesh and 6 iron 3cm x 2cm, sulfuric acid (H_2SO_4) 30 ml, sodium sulfate (Na_2SO_4) 30ml, egg albumin, spatula, aluminum foil, hot air oven, adhesive glue, pH meter, activated char coal.

PROCEDURE:

1. Making of electrodes
2. Acquiring cell shells
3. Assembling
4. Testing

- Collect two copper mesh and six iron mesh of dimensions 3cm x 2cm.
- Make paste of activated char coal, quantum dots powder, egg albumin, and

synthetic glue.

- Now apply the paste over every mesh taken and leave them over for drying in hot air oven
- After drying, let the mesh cool and roll them up in an aluminum foil, now select the Empty cells for assembling the capacitors.
- Clean and dry the cells before assembling, pour in the electrolyte along with quantum dots centrifuge liquid in 5:0.5 ratio.
- Bring in the electrodes without disturbing their physical structure into the cell and insert the terminal points into the lid
- Now seal every leak found with the glue in the apparatus.

CHAPTER – 5

CHARATERISATION RESULT ON SYNTHESIS

5.1 CHARACTERISTICS OF CARBON QUANTUM DOTS (ANALYSIS).

Carbon quantum dots (CQDs) are semiconductor nanocrystals with unique optical and electronic properties. The characterization of CQDs is an important step towards understanding their physical properties and potential applications.

One of the key characteristics of CQDs is their size-dependent optical properties. As the size of the CQD decreases, the bandgap energy increases, leading to a blue-shift in the absorption and emission spectra. This tunability in the absorption and emission spectra makes CQDs useful for various applications, including photovoltaics, light-emitting diodes, and sensors.

Another important characteristic of CQDs is their surface chemistry. The surface of CQDs is usually passivated with ligands, which can influence the electronic properties of the CQDs. The type of ligand used and the ligand-to-CQD ratio can affect the stability and optical properties of CQDs.

Additionally, the morphology and crystal structure of CQDs can also influence their properties. For example, the shape of CQDs can affect their electronic and optical properties, and the crystal structure can determine the exciton lifetime and carrier transport properties.

Overall, the characterization of CQDs is crucial for understanding their properties and potential applications. Techniques such as absorption and photoluminescence spectroscopy, transmission electron microscopy, and X-ray diffraction can provide valuable information about the size, morphology, and crystal structure of CQDs.

FTIR Spectroscopy results for carbon quantum from mushrooms

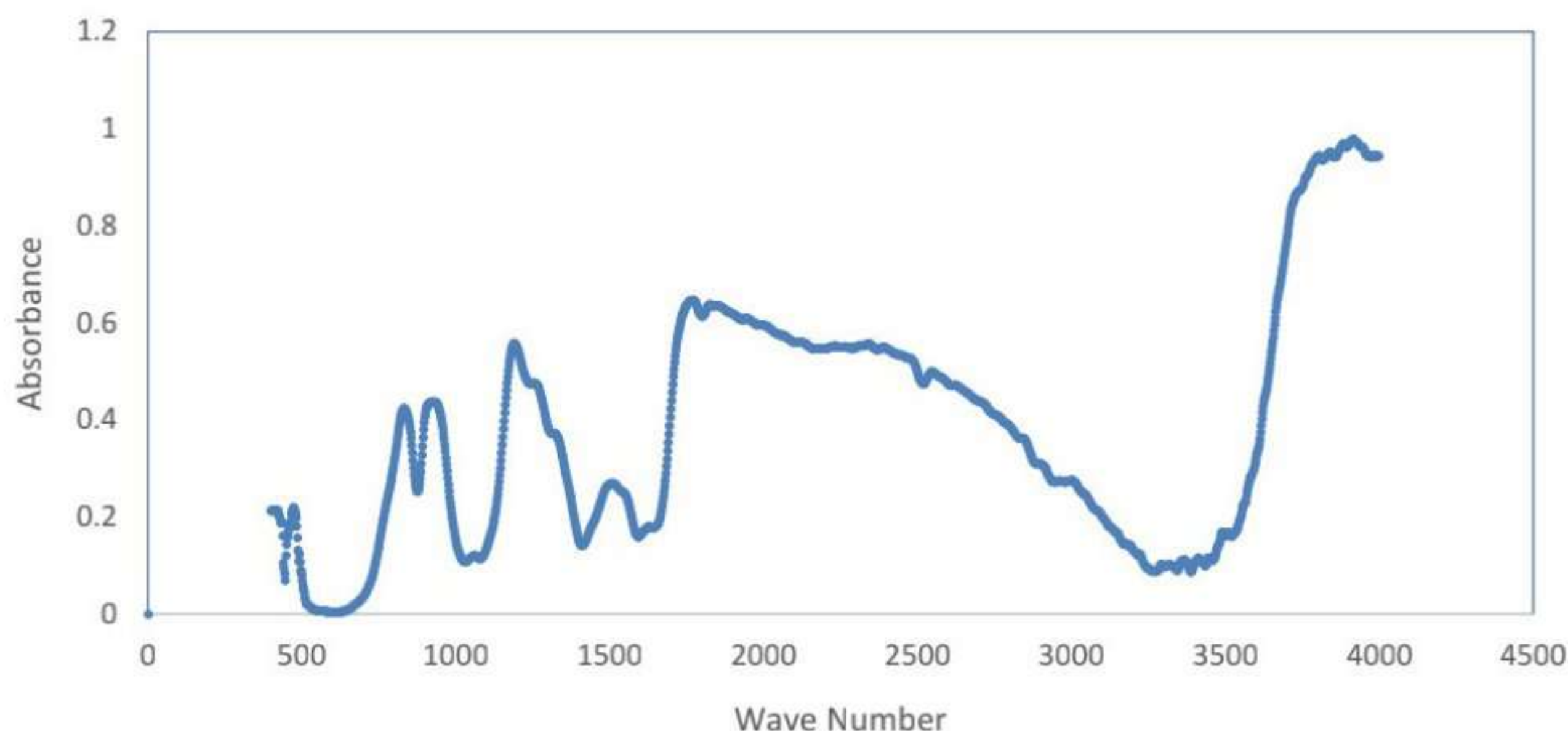


Fig:5.1 FTIR (blue at 3500in X-axis line represents carbon)

Peaks in the FTIR spectrum can be assigned to specific chemical bonds, allowing researchers to identify the types of functional groups present on the surface of the CQDs. For example, peaks in the region between 1200 and 1800 cm^{-1} can indicate the presence of carbonyl or carboxyl groups.

1. Broad Peak around 3400-3300 cm^{-1} : This peak corresponds to the O-H stretching vibration, indicating the presence of hydroxyl (OH) groups on the CQD surface. These groups may be responsible for CQDs' hydrophilic nature and potential applications in biological systems.

2. Peak at 1620-1680 cm^{-1} : This region typically represents the C=O stretching vibration, indicating the presence of carbonyl groups (C=O) on the CQD surface. These groups can be associated with functionalization and reactivity of CQDs.

3. Peak around 1400-1600 cm^{-1} : This region corresponds to the C=C stretching vibration, suggesting the presence of sp^2 -hybridized carbon atoms, which are typical in the graphene-like structure of CQDs.

4. Peak at approximately 1100 cm⁻¹: This peak is often associated with C-O-C stretching vibrations, indicating the presence of ether or epoxy groups, which can affect CQDs' stability and chemical reactivity.

5. Absence of Peaks in the 2800-3000 cm⁻¹ Range: The absence of peaks in this range suggests the low presence of aliphatic C-H stretching vibrations, indicating that CQDs are less likely to contain significant amounts of aliphatic carbon chains.

By analyzing the FTIR spectrum, researchers can gain insights into the chemical composition and structure of the CQD surface, as well as any functionalization or modification that may have occurred. This information can be valuable in understanding the properties of CQDs and optimizing their performance in various applications

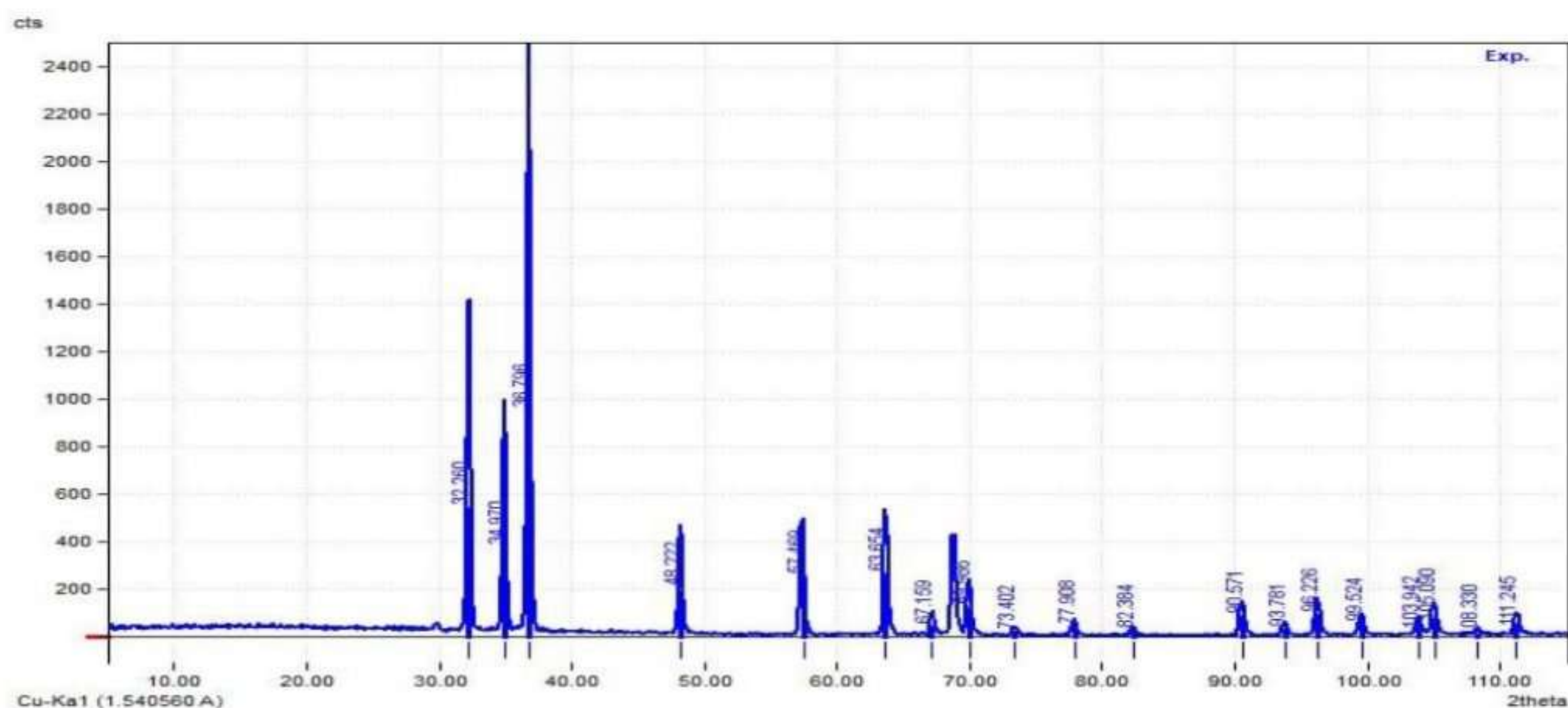


Fig:5.2 X-Ray diffraction spectroscopy

At wave length below 200 and angle (theta) below 50 carbon quantum dots are found. More precisely the CQDs are found at wavelength under 50 and angle up to 30 in our XRD results.

1. Broad Diffraction Peak at Low Angles (around 22-26 degrees 2θ): This peak indicates the presence of amorphous or disordered carbon structures within the CQDs. The broadness suggests that CQDs may lack long-range crystallinity, which is typical of graphene.

2. Graphitic Carbon Peak (around 42-44 degrees 2θ): A small, intense peak in this range indicates the presence of graphitic carbon structures within the CQDs. It suggests the existence of graphene-like domains in the CQD structure.

3. Lack of Sharp Crystalline Peaks: Unlike traditional crystalline materials, CQDs typically lack sharp and well-defined XRD peaks, reinforcing their amorphous or quasi-amorphous nature. This amorphous character is due to their small size and disordered structure.

4. No Presence of Other Crystalline Phases: The absence of peaks corresponding to other crystalline phases (e.g., metal oxides or impurities) indicates the purity of the CQD sample and suggests that they consist primarily of carbon-based materials.

5. Peak Shifts and Broadening: The positions and broadening of XRD peaks can provide information about the size and strain within CQDs. Peaks that are shifted or broadened compared to bulk carbon materials can be indicative of the quantum confinement effect due to CQDs' nanoscale size.

At 70 wavelength and angle 110, SO_3 is found in the test sample. At 600 wavelength and angle 65 ZnO is seen.

FESEM Images of Sample

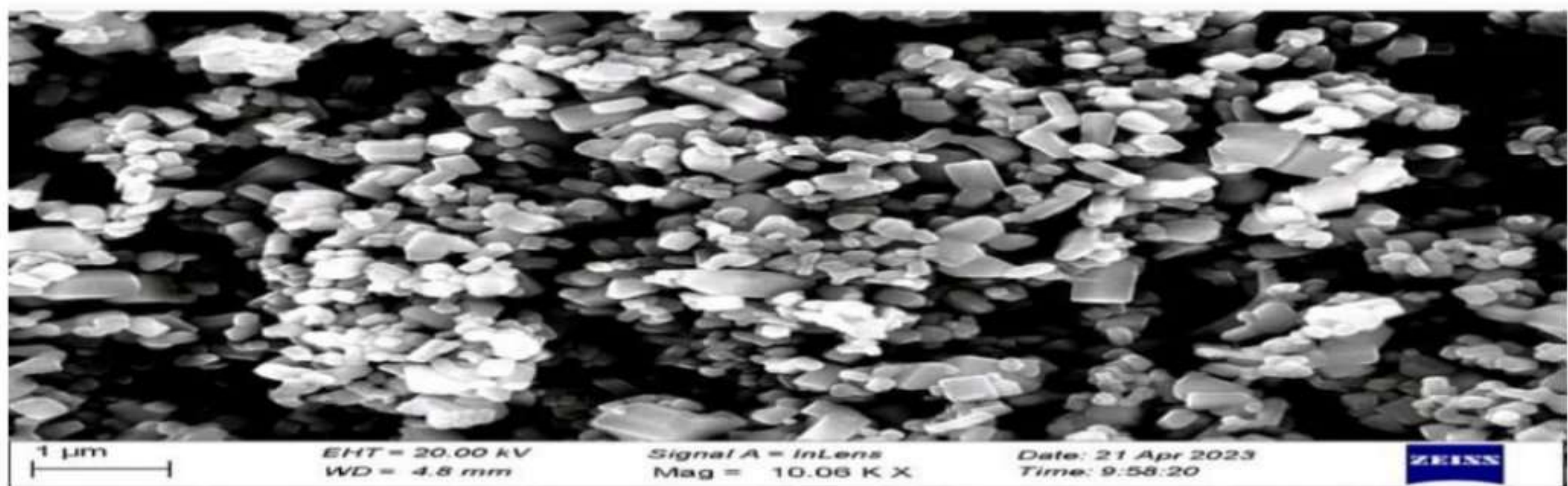


Fig:5.3 SEM Image under 10.05 KX magnification

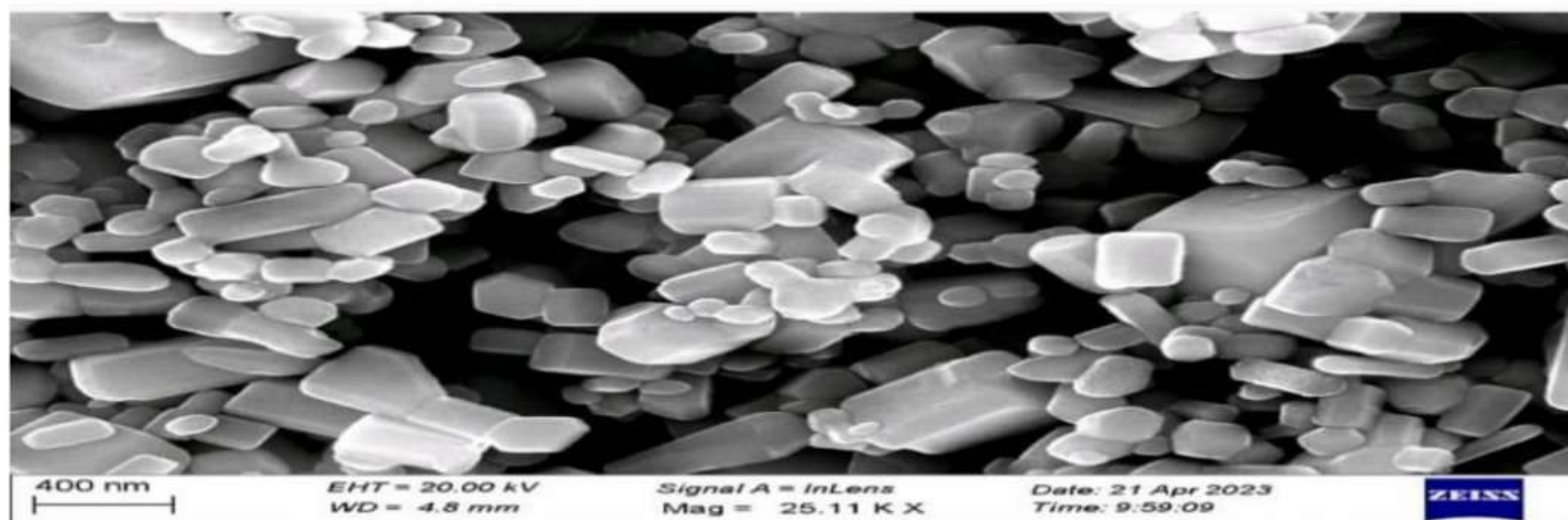


Fig:5.4 SEM Image under 25.11 KX magnification

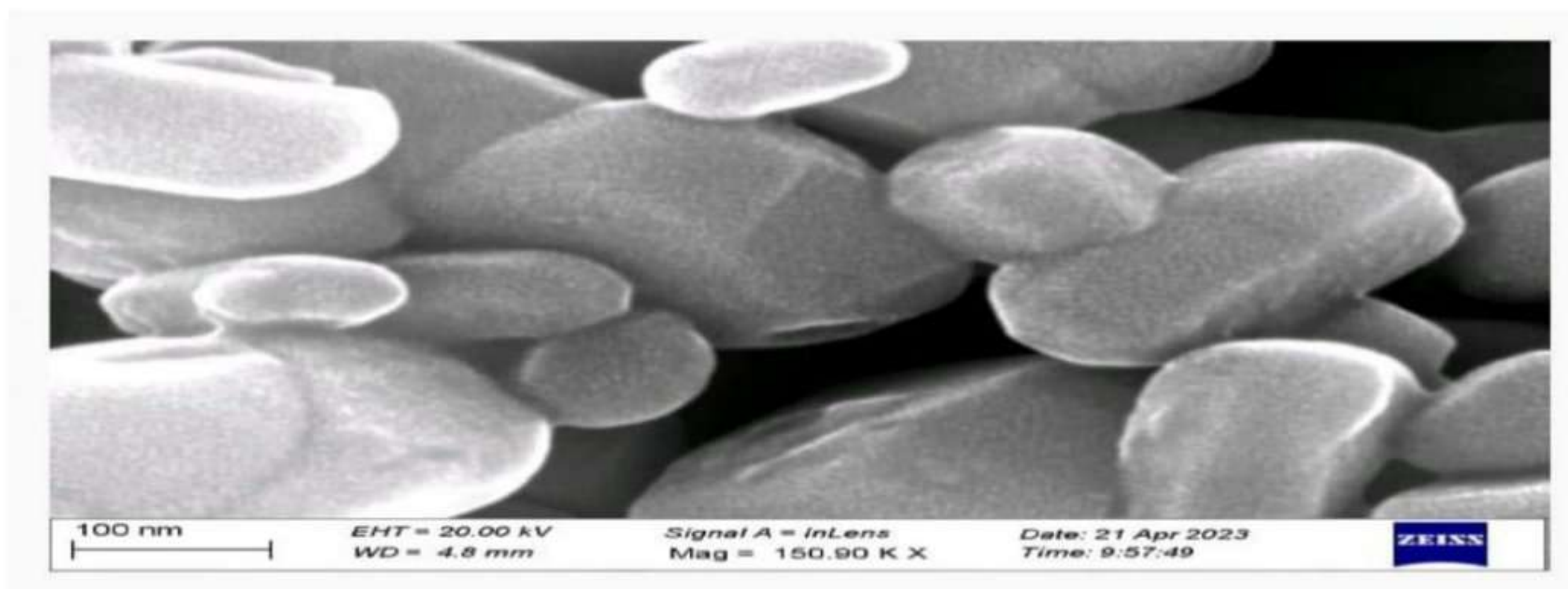


Fig: 5.5 SEM Image under 150.90 KX magnification

HRTEM RESULTS

Black color blemishes show the presence of CQDs in the below image.

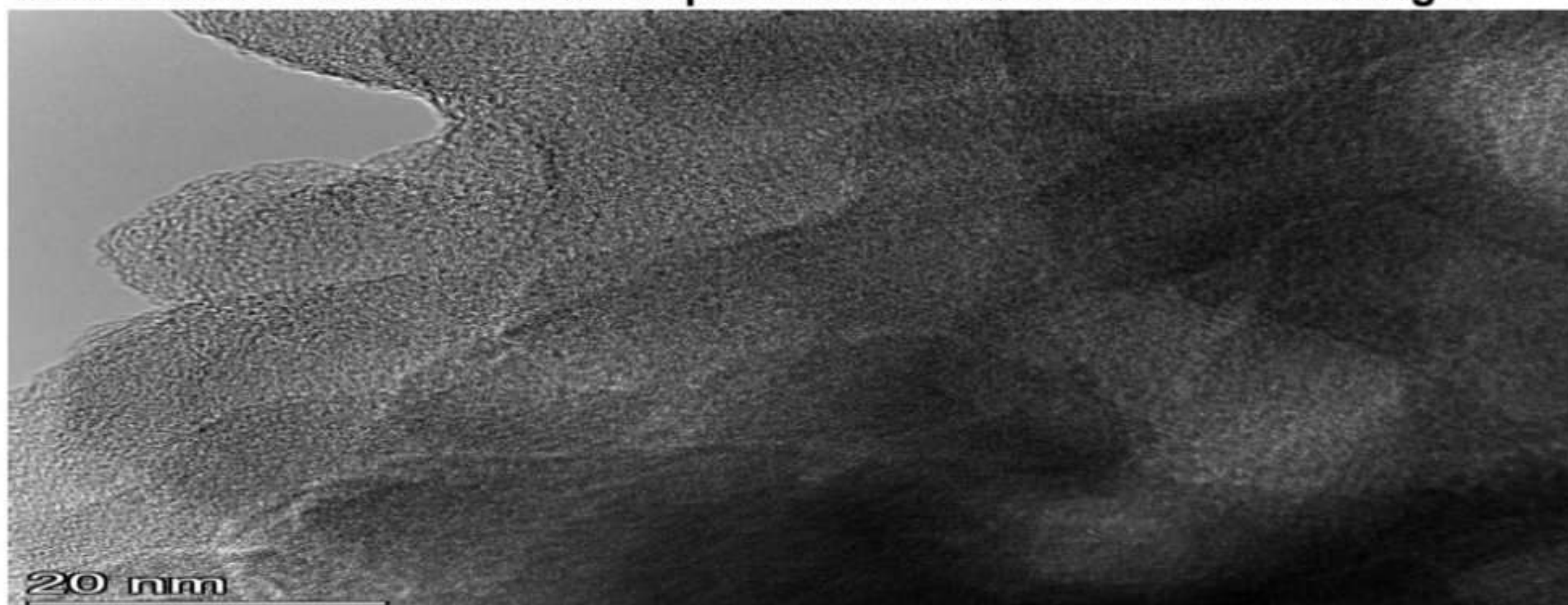


Fig: 5.6 TEM Image of the sample at 20nm shows the CQDs presence

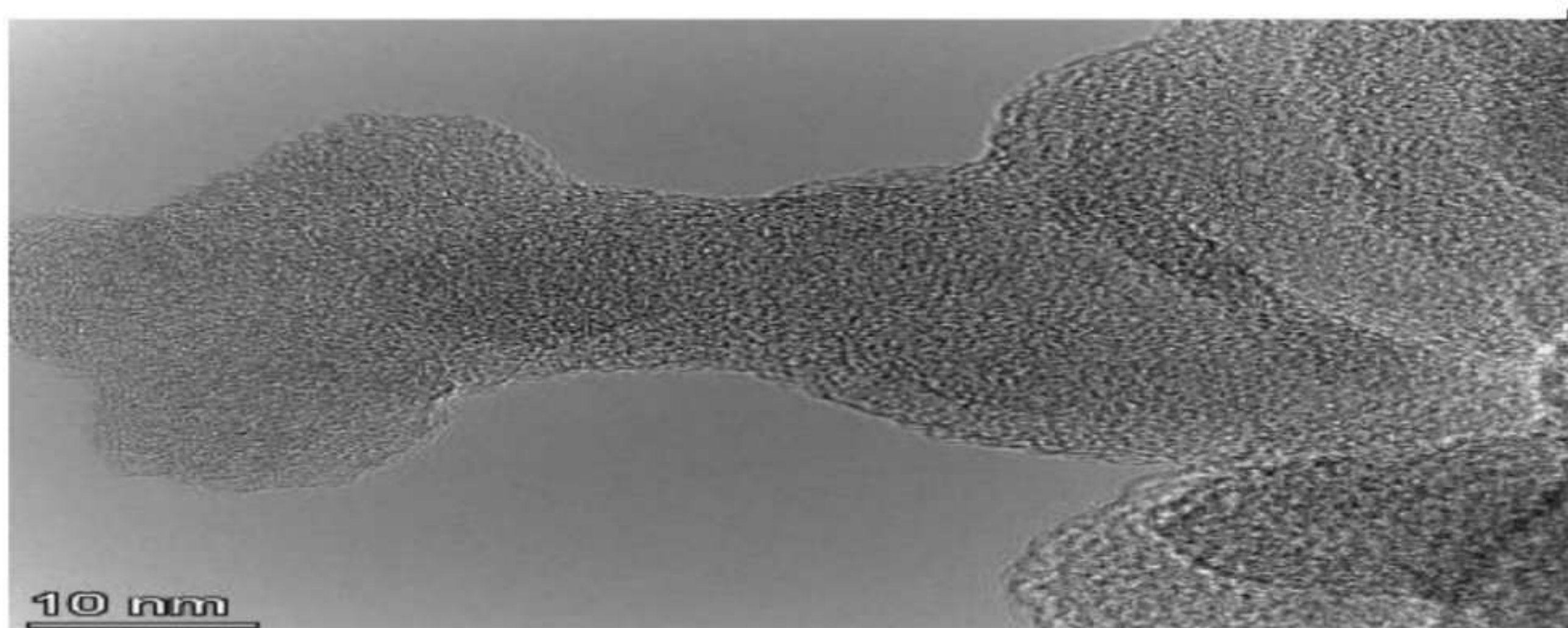


Fig: 5.7 TEM Image of the sample at 10nm shows the CQDs presence

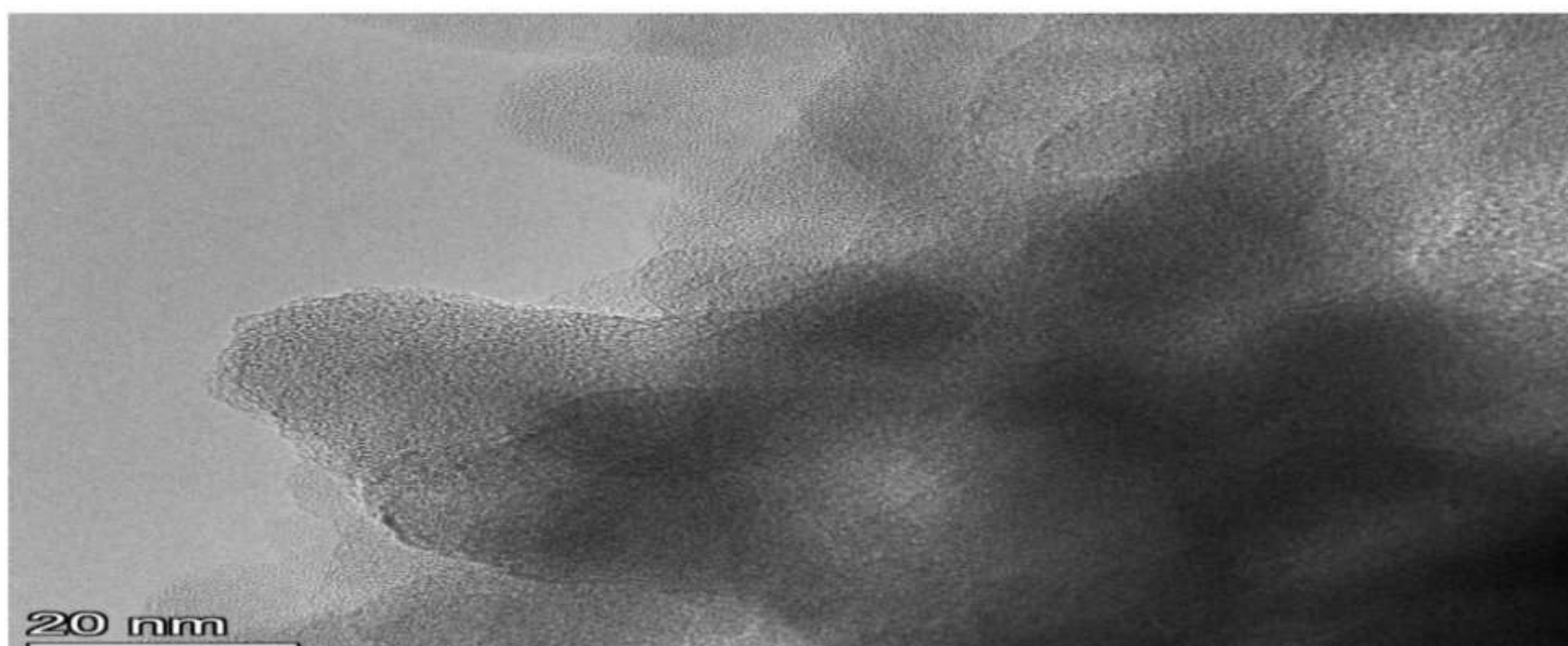


Fig: 5.8 TEM Image of the sample at 20nm shows the CQDs presence

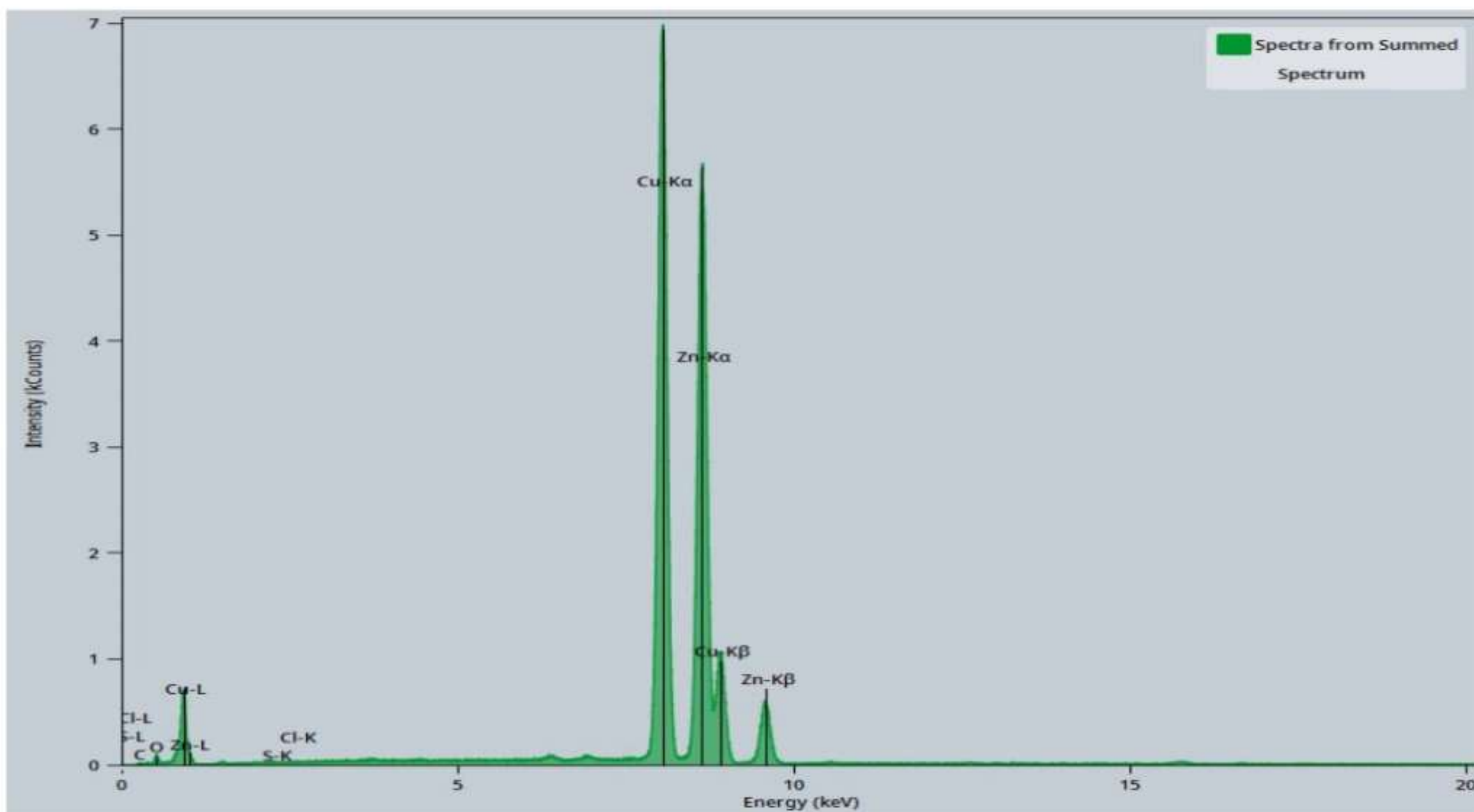


Fig: 5.9 EDAX peaks of Cu, Zn, S, Cl, C.

The presence of copper (Cu), zinc (Zn), chlorine (Cl), oxygen (O), and sulfur (S) at different peaks in an EDAX analysis of carbon quantum dots (CQDs) synthesized from mushroom precursors can be attributed to various factors:

5.2 COMPARISON WITH PREVIOUS STUDIES.

Carbon quantum dots (CQDs) are a class of carbon-based nanomaterials that have garnered much attention in recent years due to their unique optical and electronic properties. The differences are mostly with the dealing of availing the CQDs more in number since we are following the most efforting way of synthesizing CQDs by the hydrothermal process it can be achieved

It maximizes the biological response of the CQDs in the process of adding the H₂So₄ and ZnO in the mixture heating it at optimized temperatures gives the spectroscopic results more accurately because it will not kill the size and shape of

CQDs. Compared to other synthesis of CQDs in other ways maybe not this much positive in terms of size and shape and sensitive to electric potential.

Overall, previous studies have demonstrated the potential of mushrooms as a promising source for the synthesis of CQDs with various properties and applications. However, further research is needed to optimize the synthesis conditions and explore the full range of their potential applications.

5.3 ANALYSIS OF RESULTS.

Firstly, the studies have demonstrated the potential of mushroom-derived CQDs as an alternative to traditional synthetic CQDs due to their low toxicity and biocompatibility. This makes them a promising option for applications in biomedicine and environmental monitoring. However, the studies have also shown that the synthesis and characterization of mushroom-derived CQDs can be challenging due to the variability of the mushroom species, the extraction method used, and the purification techniques employed.

Secondly, the studies have shown that the properties of CQDs can be optimized through varying the synthesis parameters, such as temperature, reaction time, and precursor concentration. For example, CQDs derived from mushrooms have been shown to exhibit strong fluorescence at an optimum temperature of 150 °C. Furthermore, surface modification of the CQDs can enhance their stability and solubility, making them more suitable for various applications.

5.4 DISCUSSION OF FINDINGS ON SYNTHESIZING CQDs.

CQDs, or carbon quantum dots, are nanoscale carbon-based materials that have attracted significant interest in recent years due to their unique optical and electronic properties. These materials have a wide range of potential applications, including in areas such as bioimaging, sensing, and energy conversion.

The researchers found that the CQDs extracted from the mushrooms had a number of interesting properties. For example, they were fluorescent, meaning that they could emit light when excited by certain wavelengths of light. This makes them potentially useful for bioimaging applications, as they could be used to visualize biological structures in living cells or tissues.

The CQDs also had good biocompatibility, meaning that they were not toxic to living cells. This is an important property for any material that is intended for use in biological systems.

The findings on CQDs from mushrooms are promising and suggest that these materials could be a valuable source of nanoscale carbon-based materials for a range of applications. Further research will be needed to fully understand the properties and potential applications of these materials, but the initial results are encouraging.

CHAPTER-6

CQDs IN SUPERCAPACITORS

6.1 PERFORMANCE ENHANCEMENTS ACHIEVED WITH CQDS

Carbon Quantum Dots (CQDs) have significantly elevated supercapacitor performance through key enhancements. Their high surface area facilitates greater energy storage by maximizing charge adsorption. This, combined with rapid charge discharge capabilities, boosts power density, enabling swift energy release. Moreover, CQDs' enhanced electrochemical stability contributes to prolonged cycle life, ensuring sustained performance over repeated use. The pseudo capacitance behavior exhibited by certain CQDs further amplifies capacitance. Additionally, CQDs' compatibility with eco-friendly design and their ability to reduce internal resistance offer a holistic approach to improving overall supercapacitor efficiency and effectiveness.

Performance enhancements achieved with Carbon Quantum Dots (CQDs) in supercapacitors include:

1. *Improved Energy Storage:* CQDs' high surface area and unique properties enable enhanced charge adsorption, increasing energy storage capacity compared to conventional materials.

2. *Enhanced Power Density:* CQDs' rapid charge discharge capabilities contribute to higher power density, enabling quick bursts of energy delivery.

3. Longer Cycle Life: CQDs exhibit better electrochemical stability, leading to reduced electrode degradation and prolonged cycle life, ensuring sustained performance over multiple charge discharge cycles.

4. Pseudo capacitance Contribution: Some CQDs exhibit Pseudo capacitance behavior, adding reversible redox reactions to charge storage mechanisms, further boosting overall capacitance and performance.

5. Compatibility with Eco Friendly Design: CQDs, often derived from biomass sources, align with sustainability goals, offering a greener approach to energy storage technology.

6. Customizable Electrode Materials: can be combined with various electrode materials, allowing customization for specific applications and optimizing performance characteristics.

7. Reduced Internal Resistance: CQDs' efficient ion transport properties can reduce internal resistance, leading to improved charge discharge efficiency and overall device performance

6.2 ENERGY DENSITY AND POWER DENSITY LIMITATIONS

Energy Density Limitations in Supercapacitor Technology:

- Supercapacitors' energy density is limited by the physical separation of charges and electrode materials, resulting in lower energy storage capacity compared to batteries.
- Electrode materials with high surface area for charge adsorption are essential, but achieving high energy density without sacrificing power density remains challenging.

- Pseudocapacitive materials can enhance energy density, but tradeoffs between energy and power density persist due to material characteristics and electrode design.

Power Density Limitations in Supercapacitor Technology

Supercapacitors offer high power density due to rapid charge discharge cycles, but their power density is still lower than conventional capacitors.

- The need for thick electrode layers for energy storage can restrict ion diffusion, limiting the device's ability to provide rapid bursts of power.
- Achieving high power density while maintaining electrode stability and preventing electrical breakdown requires advanced electrode materials and precise engineering of device components.

CQDs can store charge through various mechanisms, including double layer capacitance and Pseudo capacitance. In the case of double layer capacitance, charges accumulate at the interface between the CQDs and the electrolyte, relying on the electrostatic interaction. Pseudo capacitance involves redox reactions at the CQD surface, contributing to additional charge storage capacity. Many CQDs exhibit redox properties, allowing them to undergo reversible electron transfer reactions. This redox activity is often associated with the presence of specific surface functional groups on the CQDs, enabling them to participate in electrochemical processes and contribute to the overall capacitance of the system

The electrochemical behaviour of CQDs is influenced by the accessibility of ions to the CQD surface. A high surface area and porous structure of CQDs facilitate efficient ion diffusion and adsorption/desorption processes, leading to improved charge storage performance. The kinetics of electron transfer at the CQD electrolyte interface play a crucial role in determining the charge discharge rates of supercapacitors. Fast and efficient electron transfer is desirable for achieving high power density. CQDs can enhance the electron transfer kinetics, contributing to the supercapacitor's overall performance.

The electrochemical behaviour of CQDs can be pH sensitive. Changes in the pH of the electrolyte may affect the surface charge and chemical state of CQDs, influencing their electrochemical properties. This pH sensitivity can be harnessed for specific applications or tailored through surface modifications. The electrochemical stability of CQDs is crucial for the long-term performance of energy storage devices. CQDs need to withstand repeated charge discharge cycles without significant degradation. Understanding and improving the electrochemical stability of CQDs are essential for the practical application of these materials.

6.3 ELECTROCHEMICAL PERFORMANCE OF CQDs

Cyclic voltammetry (CV) is a common electrochemical technique used to study the redox properties and electrochemical behaviour of materials, including quantum dots (QDs) derived from mushrooms. Here's an outline of how CV can be applied to study the electrochemical performance of carbon quantum dots (CQDs) from mushrooms:

1. Preparation of Electrochemical Setup:

Prepare a three-electrode electrochemical cell comprising a working electrode (e.g., glassy carbon electrode), a reference electrode (e.g., Ag/AgCl electrode), and a counter electrode (e.g., platinum wire). Ensure the proper connection of electrodes to the potentiostat for controlled potential measurements.

2. Preparation of CQD Suspension:

Disperse the CQDs derived from mushrooms in a suitable electrolyte solution or solvent (e.g., phosphate-buffered saline, PBS, or a non-aqueous solvent like acetonitrile). Sonicate the CQD suspension to ensure uniform dispersion and minimize aggregation.

3. Baseline Measurement:

Perform a baseline CV scan in the absence of CQDs to record the electrochemical behaviour of the solvent or electrolyte solution. This provides a reference for subsequent measurements with CQDs.

4. Cyclic Voltammetry with CQDs:

Apply cyclic voltammetry to the CQD suspension by sweeping the potential between appropriate limits (typically -1.0 V to 1.0 V vs. reference electrode) at a suitable scan rate (e.g., 50 mV/s). Record the current response as a function of the applied potential. Repeat the CV measurements at different CQD concentrations or under varying experimental conditions to explore the effects of CQD concentration, scan rate, pH, and temperature on the electrochemical behaviour.

5. Data Analysis:

Analyse the CV curves obtained from the CQD suspension to identify redox peaks corresponding to the oxidation or reduction of CQDs. Determine the peak potentials, peak currents, and peak shapes to extract information about the electrochemical activity and kinetics of CQDs. Calculate parameters such as the anodic/cathodic peak potential separation, peak current density, and peak area to quantify the electrochemical performance of CQDs.

6. Interpretation and Discussion:

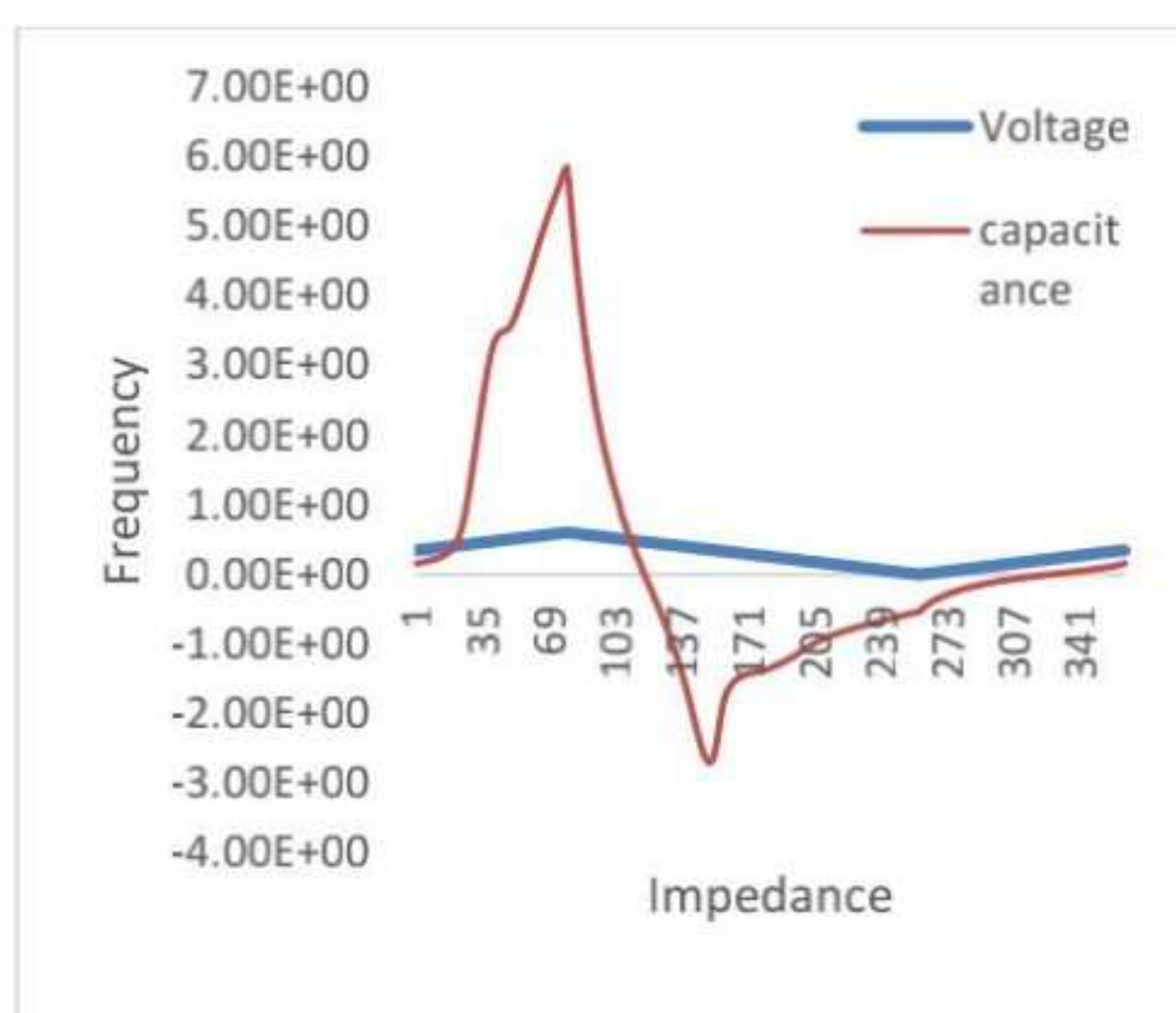
Interpret the CV results in the context of the electrochemical properties of CQDs, such as their electron transfer mechanisms, electrochemical stability, and redox chemistry. Discuss the implications of the observed electrochemical behaviour for potential applications of CQDs in energy storage, catalysis, sensing, or other electrochemical devices.

7. Comparison and Validation:

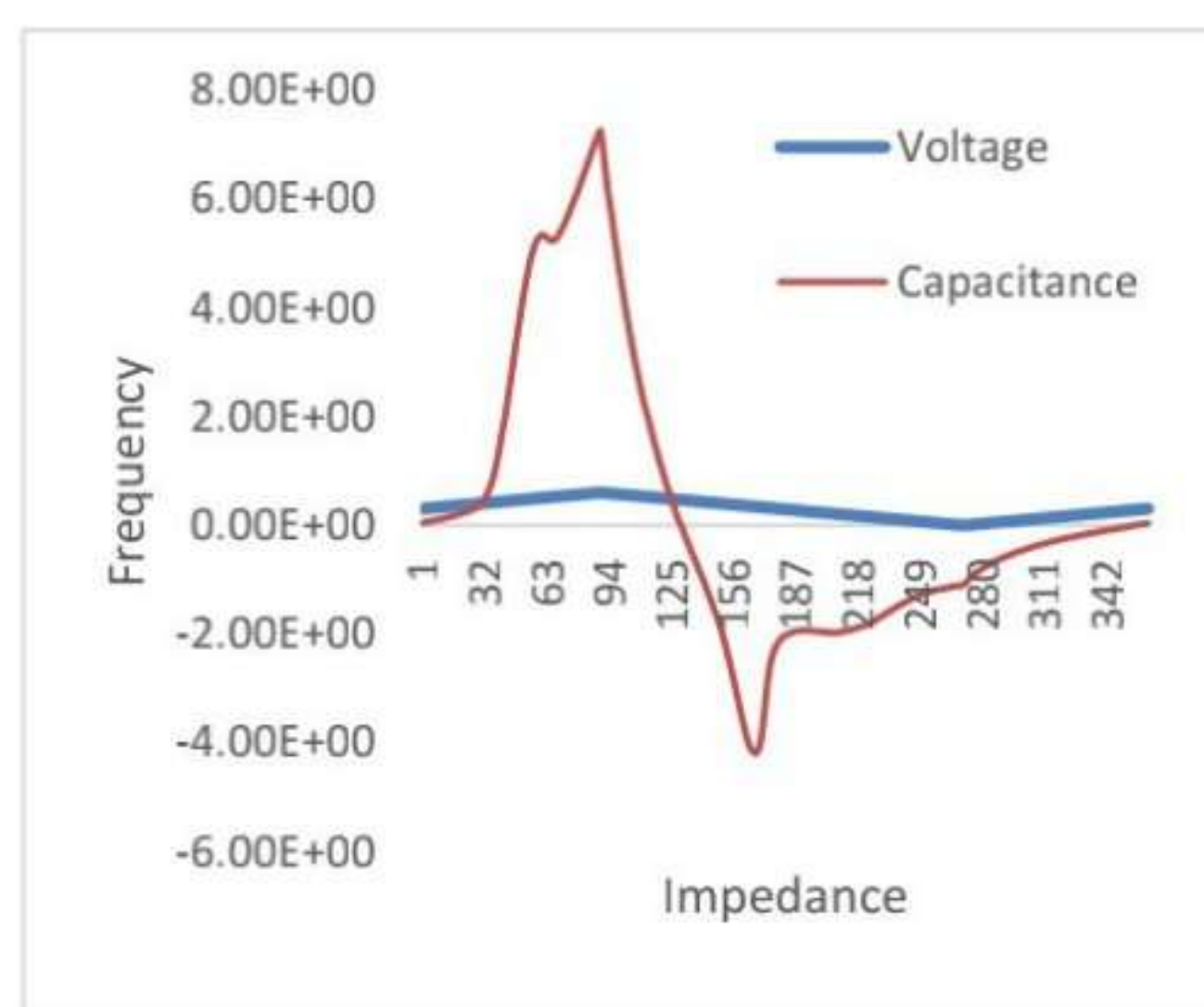
Compare the CV results obtained for CQDs from mushrooms with those of other carbon-based materials or QDs synthesized using different methods to validate the uniqueness and advantages of mushroom-derived CQDs.

By conducting cyclic voltammetry of CQDs from mushrooms and analysing the resulting electrochemical data, researchers can gain insights into the redox properties and electrochemical performance of these materials, contributing to their further development and applications.

CYCLIC VOLTAMMETRY



**Fig: 6.1 Cyclic voltammetry
5 mV s 0 06V**



**Fig: 6.2 Cyclic voltammetry
10 mV s 0 06V**

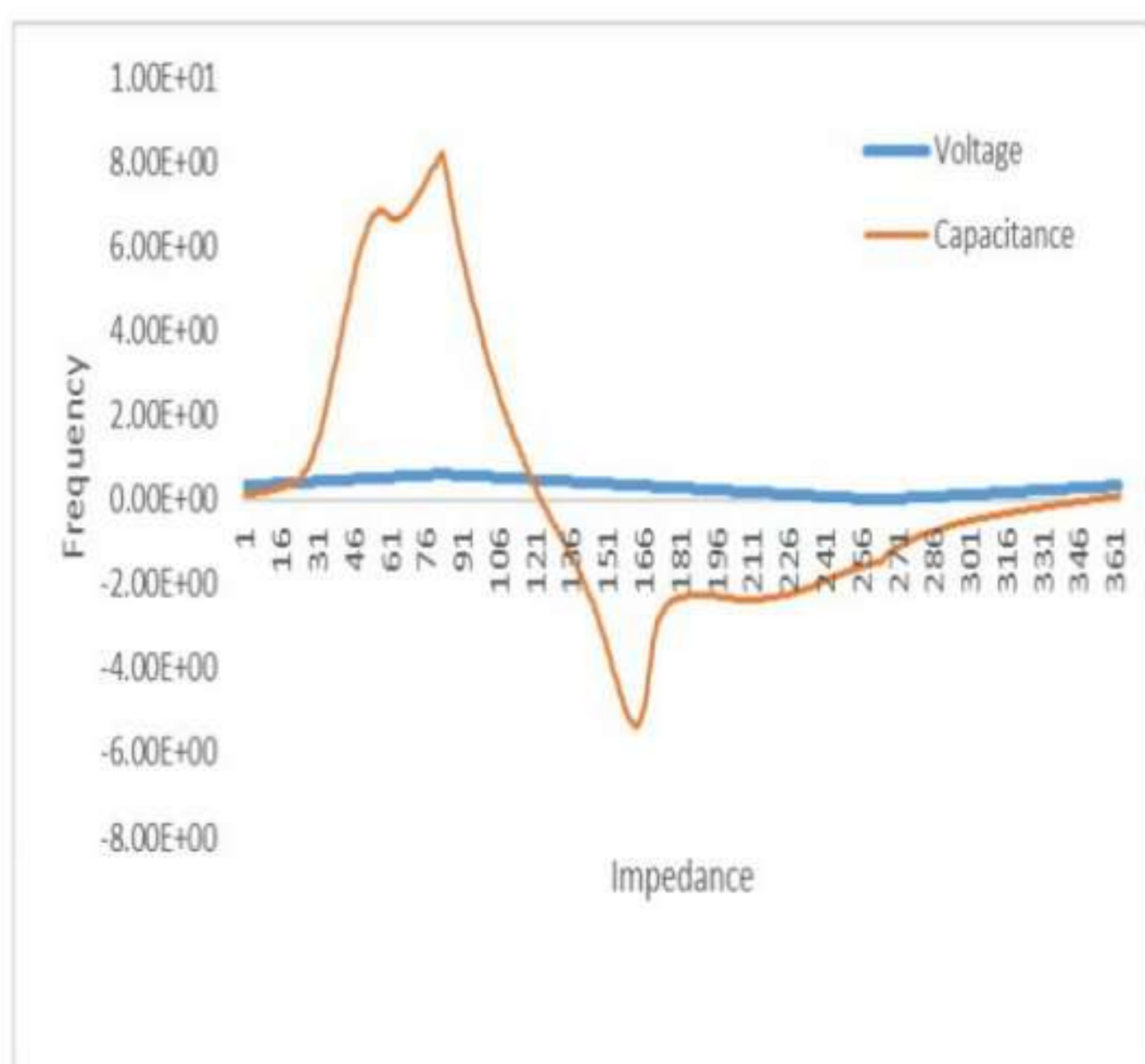


Fig: 6.3 Cyclic voltammetry
15 mV s⁻¹ 0.06V

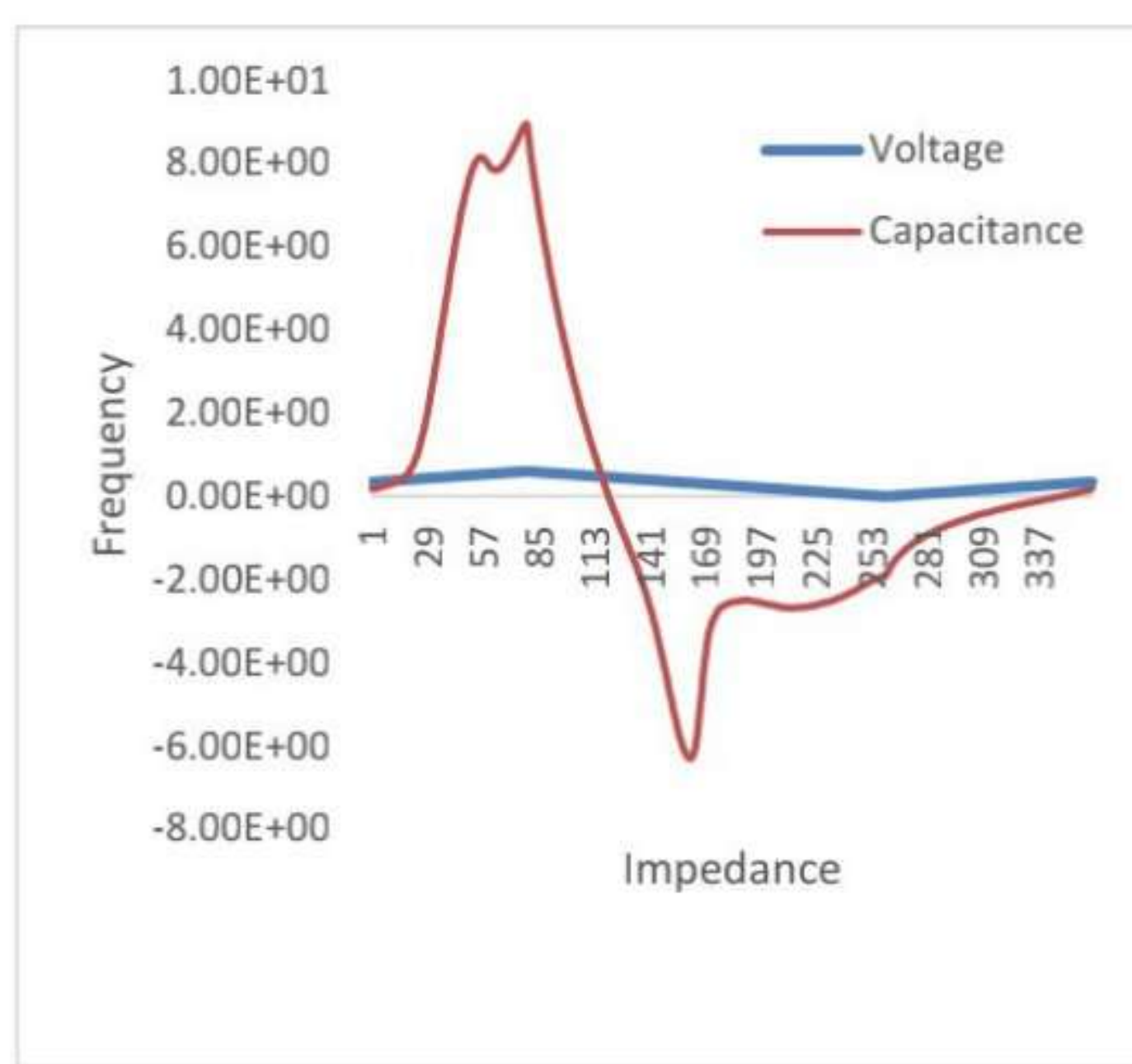


Fig: 6.4 Cyclic voltammetry
20 mV s⁻¹ 0.06V

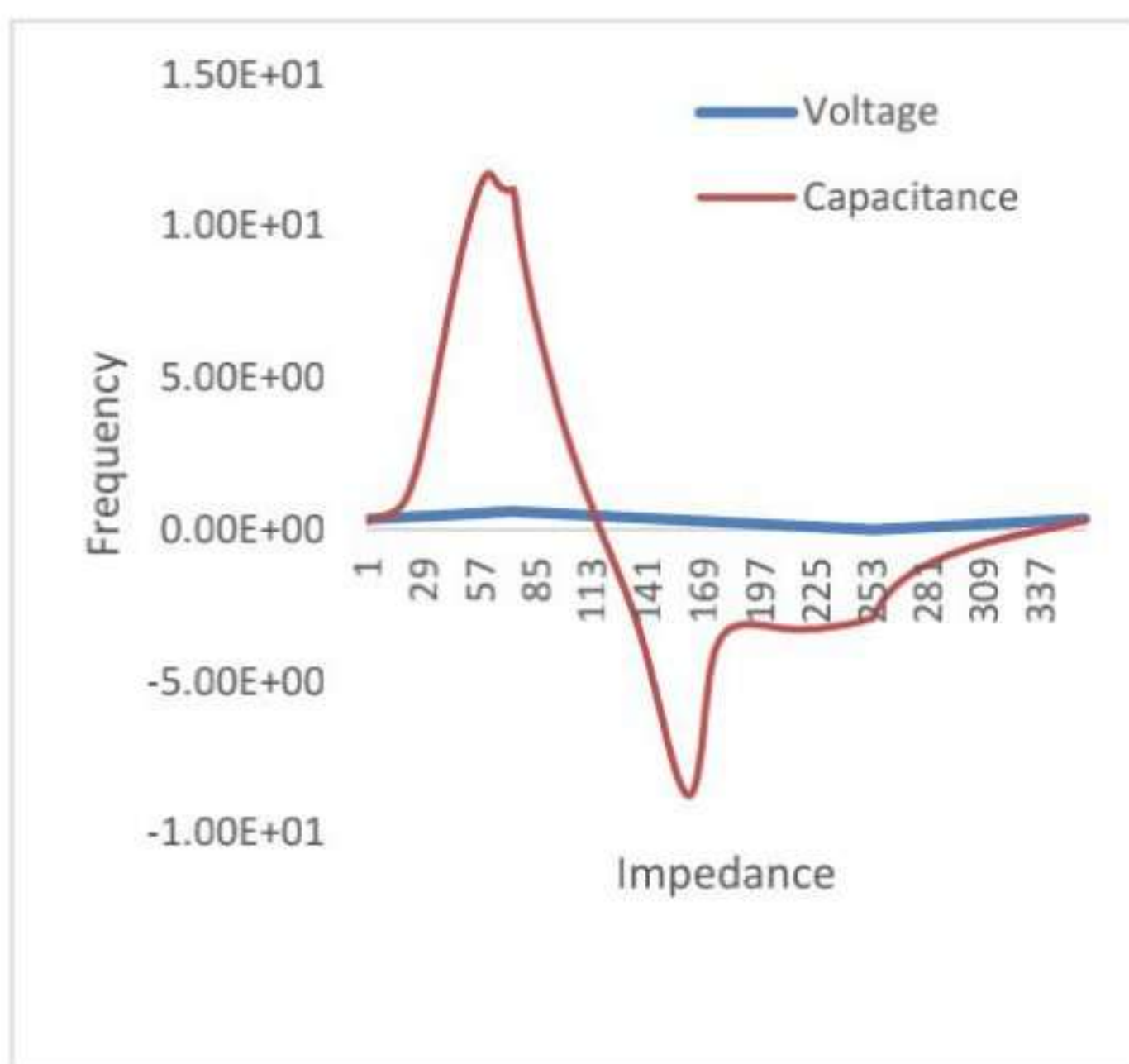


Fig: 6.5 Cyclic voltammetry
40 mV s⁻¹ 0.06V

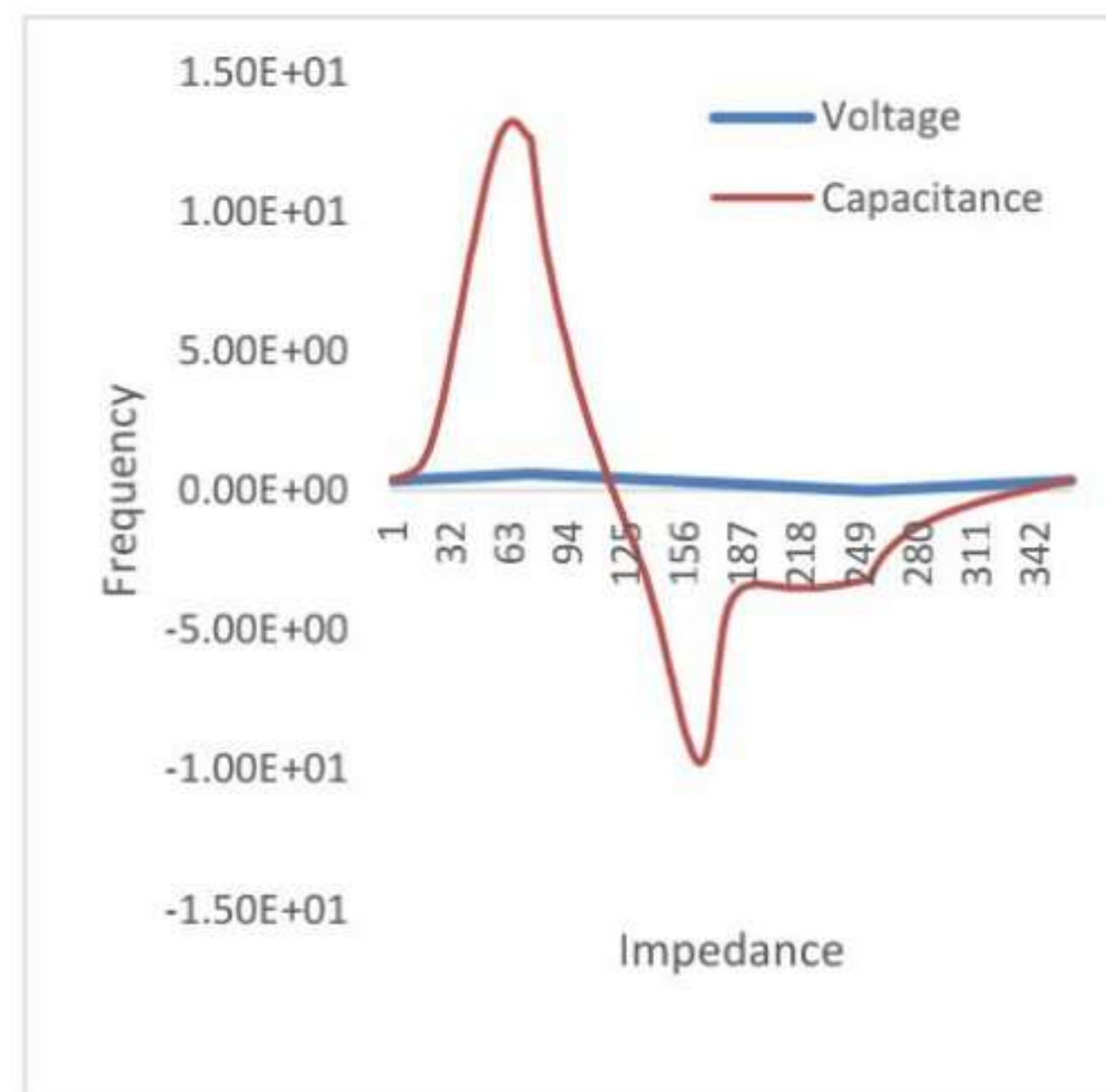


Fig: 6.6 Cyclic voltammetry
50 mV s⁻¹ 0.06V

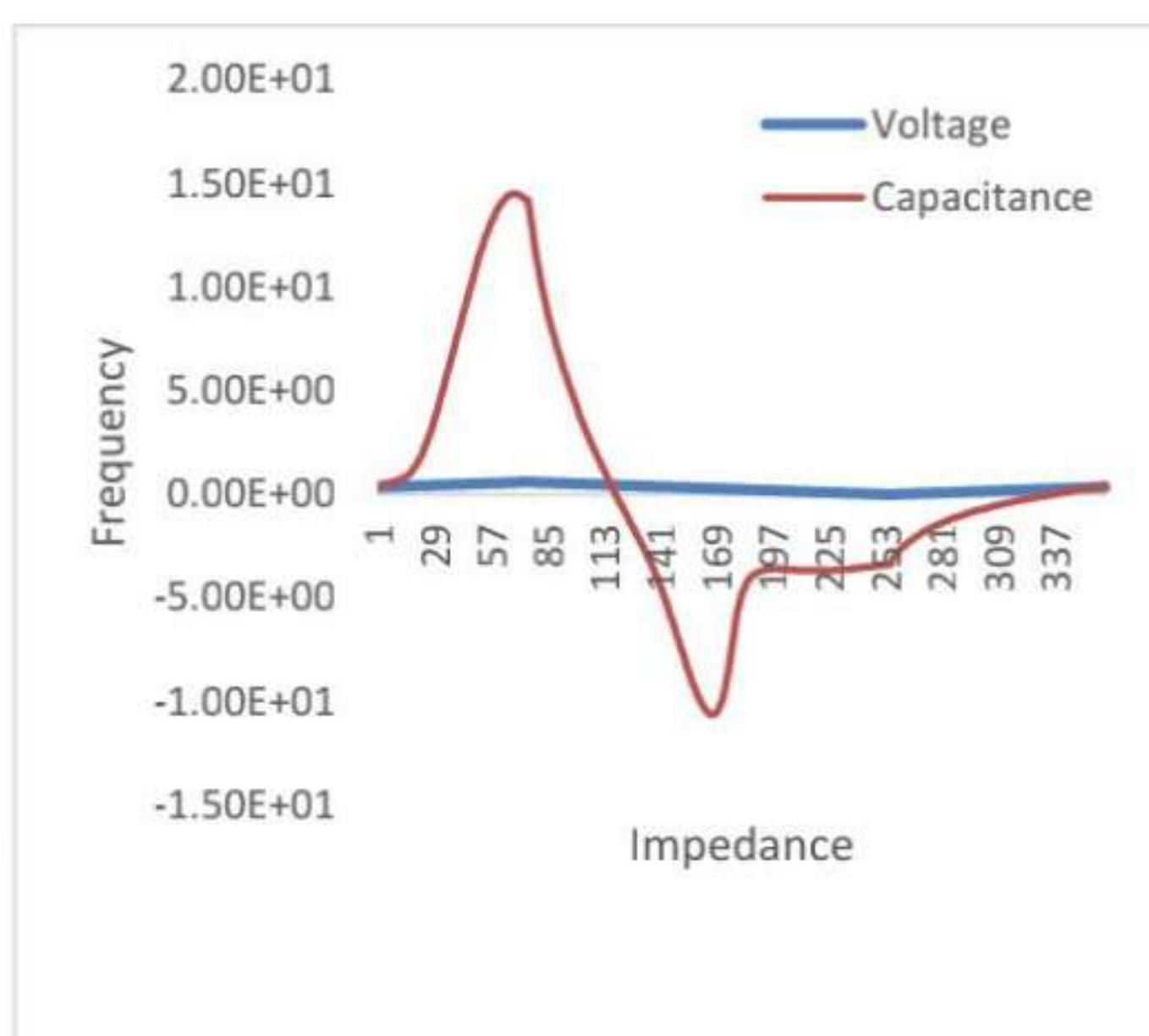


Fig: 6.7 Cyclic voltammetry 60 mV s⁻¹ 0.06V

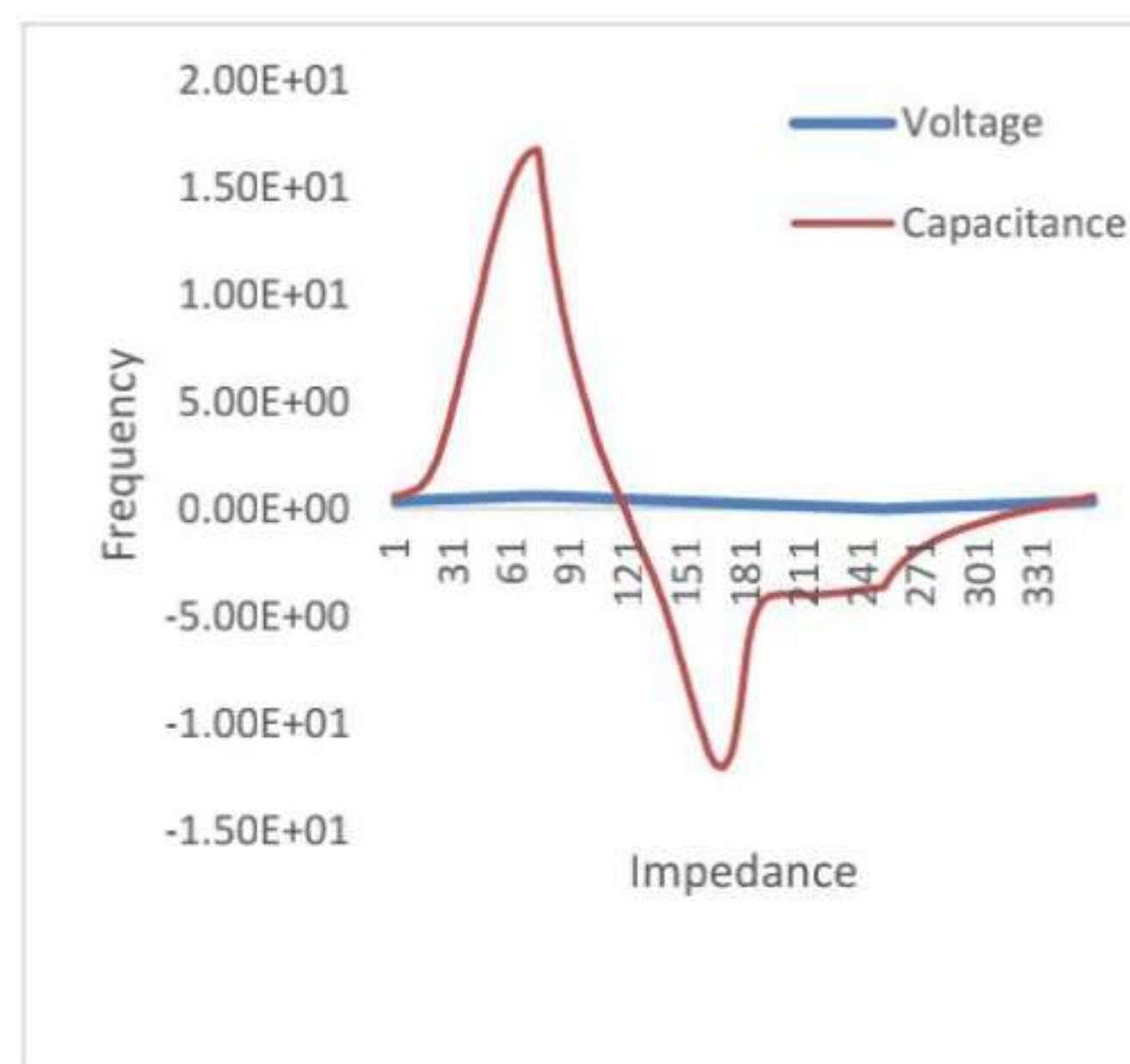


Fig: 6.8 Cyclic voltammetry 80 mV s⁻¹ 0.06V

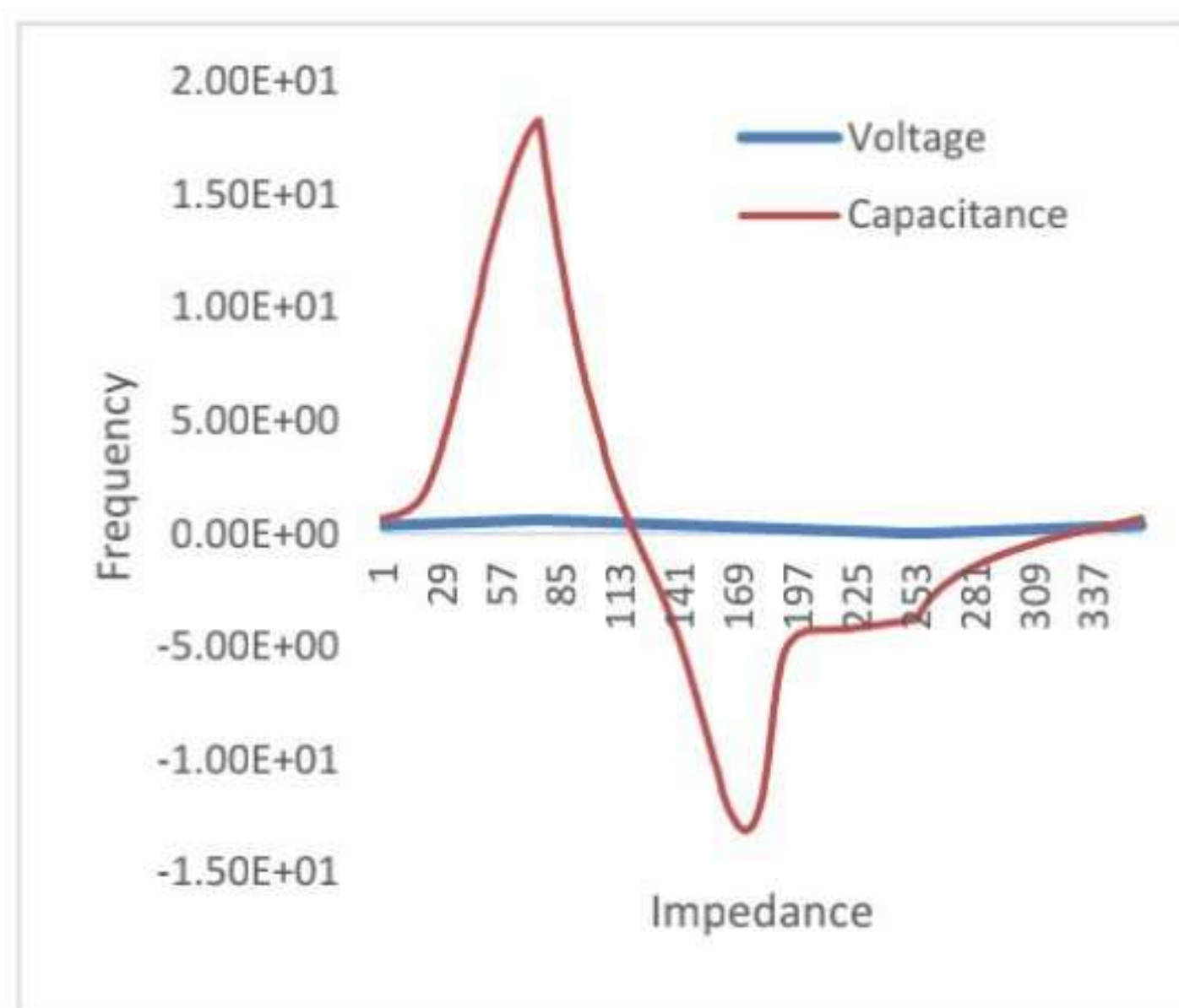


Fig: 6.9 Cyclic voltammetry 100 mV s⁻¹ 0.06V

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY (EIS)

Electrochemical impedance spectroscopy (EIS) is a powerful technique used to analyze the electrical properties of materials and interfaces in electrochemical systems. When applied to carbon quantum dots (CQDs) derived from mushrooms, EIS can provide valuable information about their charge transfer kinetics, surface properties, and electrochemical behavior. Here's how EIS can be utilized to study CQDs from mushrooms:

1. Experimental Setup:

Set up an EIS system comprising a potentiostat, a three-electrode electrochemical cell (similar to the setup used for cyclic voltammetry), and appropriate software for data acquisition and analysis. The working electrode can be a conductive substrate coated with CQDs or a CQD-modified electrode, while the counter and reference electrodes remain the same as in cyclic voltammetry.

2. Sample Preparation:

Prepare the CQD suspension or electrode surface by depositing a layer of CQDs derived from mushrooms onto the working electrode. Ensure uniform coverage and good adhesion of CQDs to the electrode surface. Optionally, perform surface functionalization or modification of CQDs to tailor their electrochemical properties or enhance their stability.

3. EIS Measurement:

Apply a small sinusoidal perturbation potential (typically a few millivolts) to the working electrode over a range of frequencies (typically from millihertz to megahertz). Measure the resulting impedance response, which includes both the real (resistive) and imaginary (capacitive) components of impedance, as a function of frequency. Record the impedance spectra, which typically consist of Nyquist plots (plots of imaginary impedance vs. real impedance) and Bode plots (plots of impedance magnitude and phase angle vs. frequency).

4. Data Analysis:

Analyze the EIS data to extract parameters such as charge transfer resistance (R_{ct}), double-layer capacitance (C_{dl}), and Warburg impedance (Z_w), which provide insights into the electrochemical kinetics and processes occurring at the CQD-electrolyte interface. Fit the experimental impedance spectra to appropriate equivalent circuit models, such as the Randles circuit or modified Randles circuit, to quantitatively interpret the observed impedance behavior and extract relevant electrochemical parameters. Compare the impedance spectra obtained for CQDs from mushrooms under different conditions (e.g., varying concentration, surface functionalization) to evaluate the effects of these factors on their electrochemical performance.

5. Interpretation and Discussion:

Interpret the EIS results in the context of the electrochemical properties and behavior of CQDs, including their charge storage capacity, electron transfer kinetics, and interfacial interactions with the electrolyte. Discuss the implications of the observed impedance behavior for the performance of CQDs in various electrochemical applications, such as energy storage devices, sensors, and electrocatalysts.

6. Validation and Further Studies:

Validate the findings from EIS measurements through complementary techniques, such as cyclic voltammetry, X-ray photoelectron spectroscopy, or transmission electron microscopy. Conduct additional studies to explore the effect of external factors (e.g., temperature, pH, solvent composition) on the electrochemical behavior of CQDs from mushrooms and optimize their performance for specific applications.

By performing electrochemical impedance spectroscopy on CQDs derived from mushrooms and analyzing the resulting impedance data, researchers can gain valuable insights into their electrochemical properties and behavior, facilitating their further development and application in diverse fields.

Galvanostatic charge-discharge (GCD) measurements are another important electrochemical technique used to characterize the energy storage properties of materials, including carbon quantum dots (CQDs) derived from mushrooms. Here's how GCD can be applied to study CQDs:

1. Experimental Setup:

Prepare a three-electrode electrochemical cell with a working electrode (e.g., glassy carbon electrode coated with CQDs), a counter electrode (e.g., platinum wire), and a reference electrode (e.g., Ag/AgCl electrode). Connect the electrodes to a potentiostat capable of delivering constant current for charge-discharge measurements.

2. Sample Preparation:

Prepare the CQD-coated working electrode by depositing a uniform layer of CQDs onto the substrate surface. Ensure good adhesion and electrical contact between the CQDs and the electrode surface.

3. Charge-Discharge Measurement:

Start the experiment by applying a constant current to the working electrode for the charge process. The current density can be chosen based on the specific application or desired charge/discharge rate. Monitor the potential across the working electrode as a function of time during the charge process. Once the desired charge capacity is reached, switch the current direction to discharge the electrode. Record the discharge curve, which shows the variation of potential with time as the electrode releases stored charge.

4. Data Analysis:

Analyze the charge-discharge curves to extract important parameters such as specific capacitance, energy density, power density, and cycling stability.

5. Interpretation and Discussion:

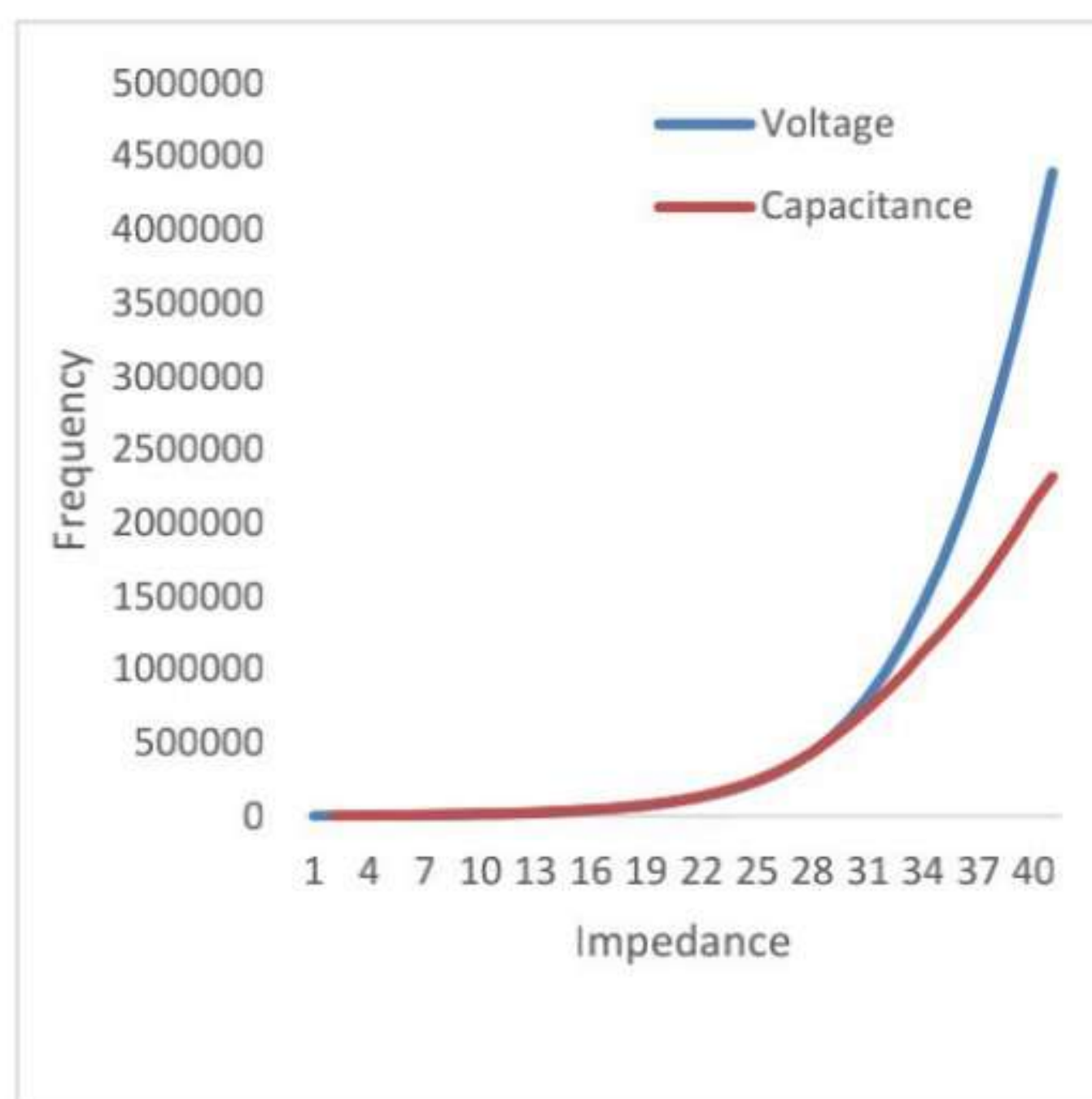
Interpret the GCD results in terms of the energy storage performance of CQDs derived from mushrooms.

Discuss the factors influencing the charge storage mechanism, such as the surface area, pore structure, and conductivity of CQDs, as well as the electrolyte composition and electrode morphology. Compare the GCD results obtained for CQDs under different experimental conditions (e.g., electrolyte composition, electrode configuration) to evaluate their performance and identify optimization strategies.

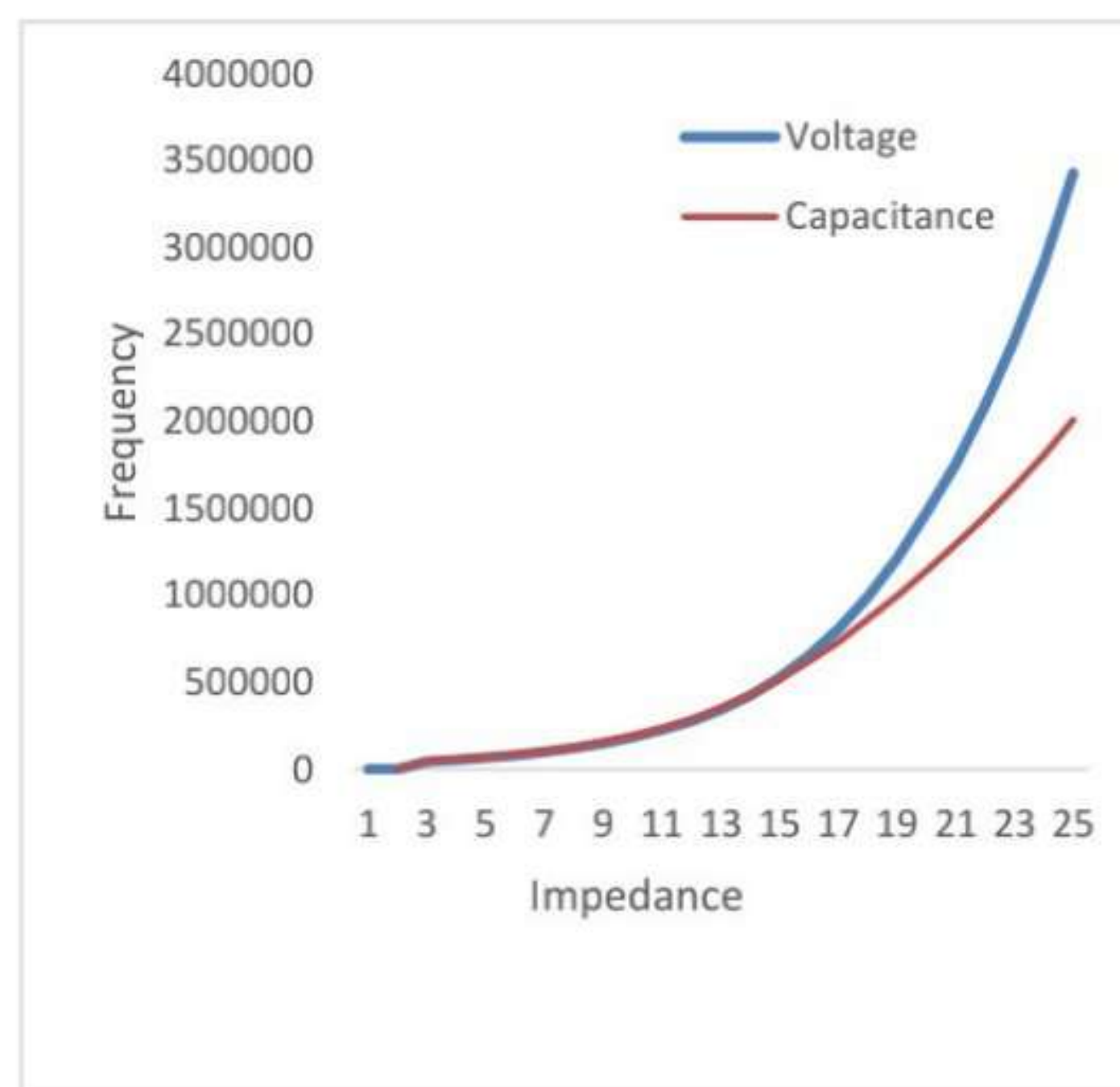
6. Validation and Further Studies:

Validate the GCD results through complementary electrochemical techniques, such as cyclic voltammetry and electrochemical impedance spectroscopy. Conduct further studies to explore the effect of parameters like temperature, electrolyte concentration, and cycling stability on the charge-discharge behavior of CQDs and optimize their performance for specific energy storage applications.

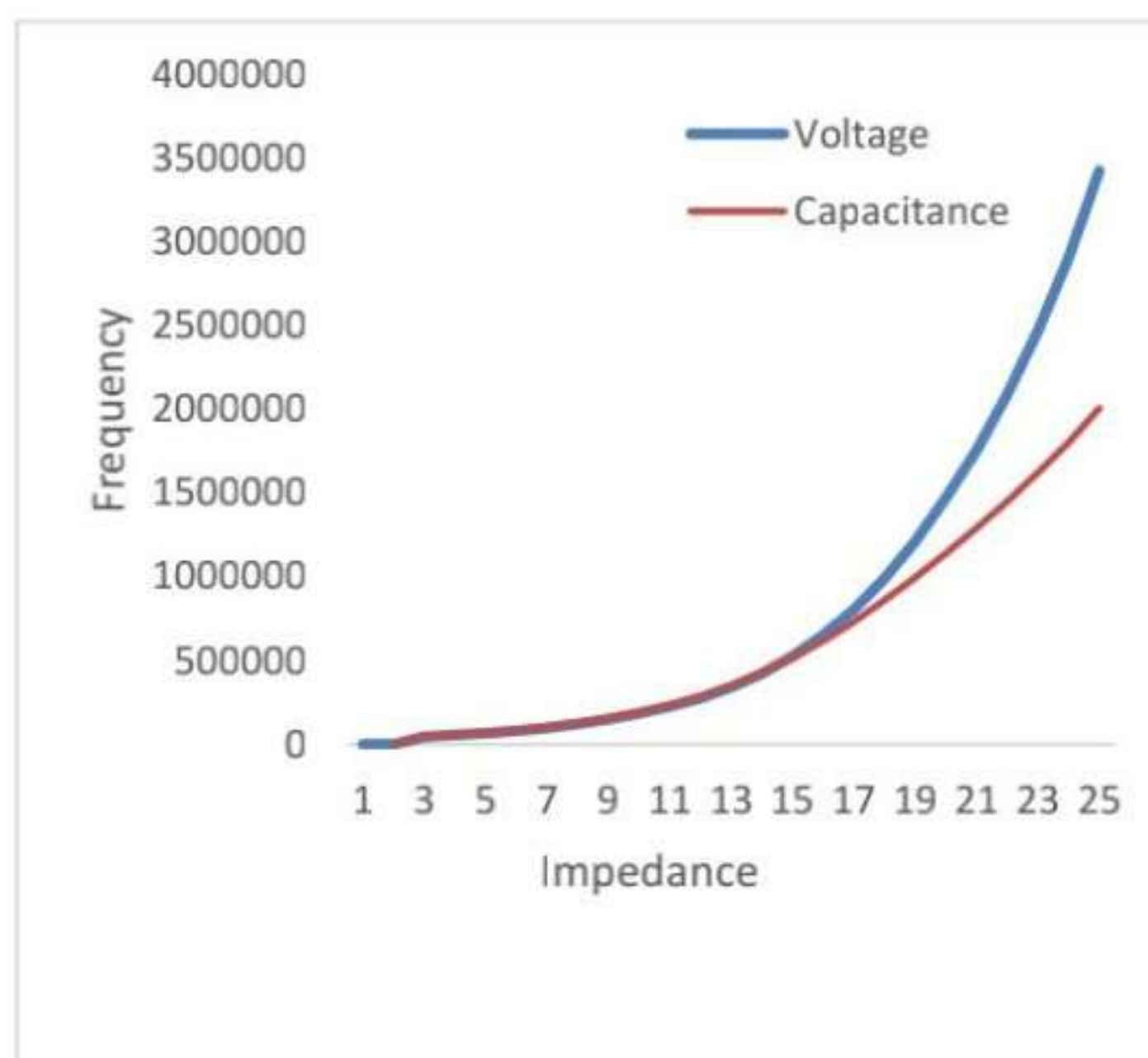
EIS after GCD



**Fig: 6.10 EIS after GCD 100 TO 0 01
PLOT 1**

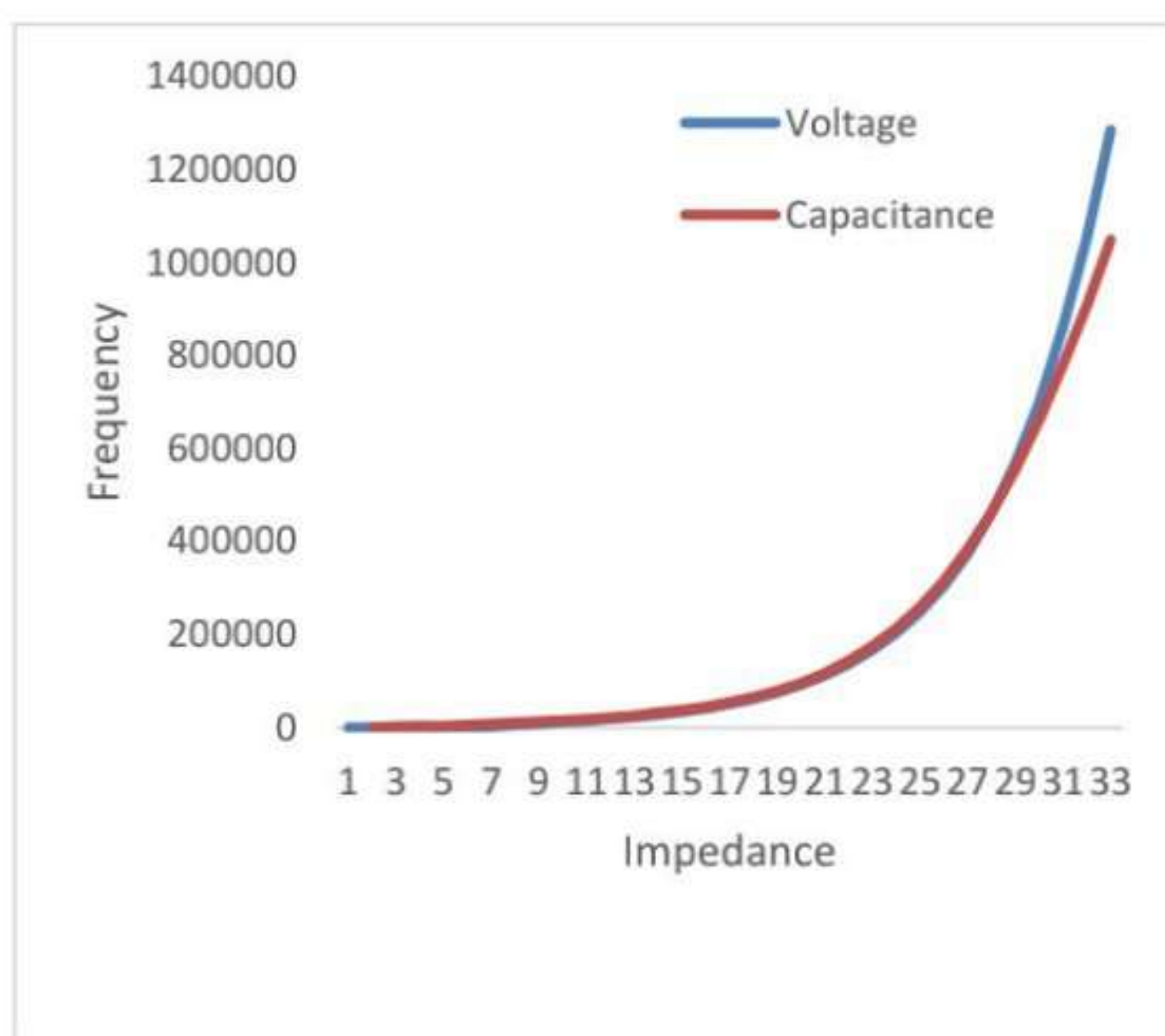


**Fig: 6.11 EIS after GCD 100 TO 0 01
PLOT 2**

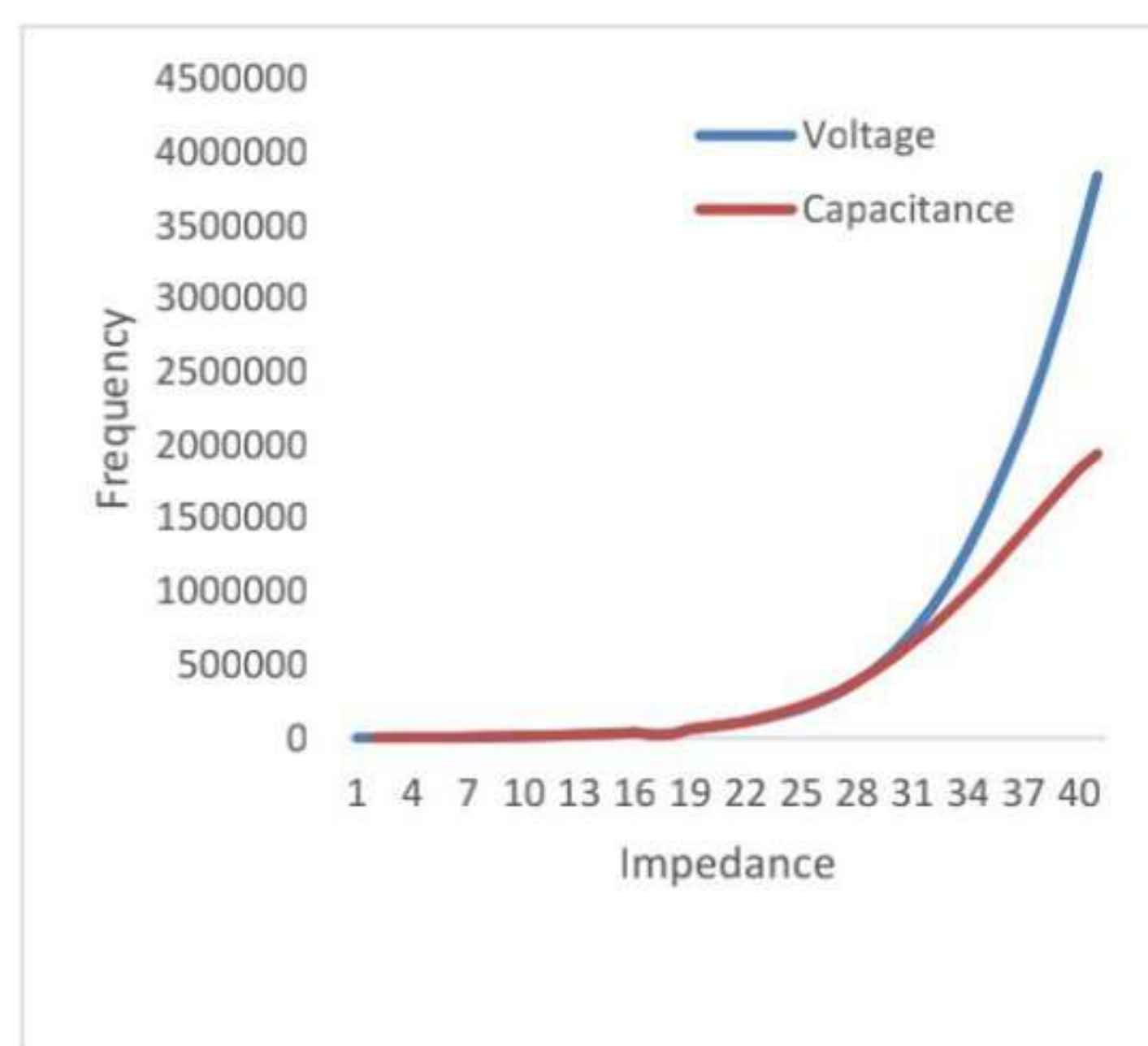


**Fig: 6.12 EIS after GCD 100 TO 0 01
PLOT 3**

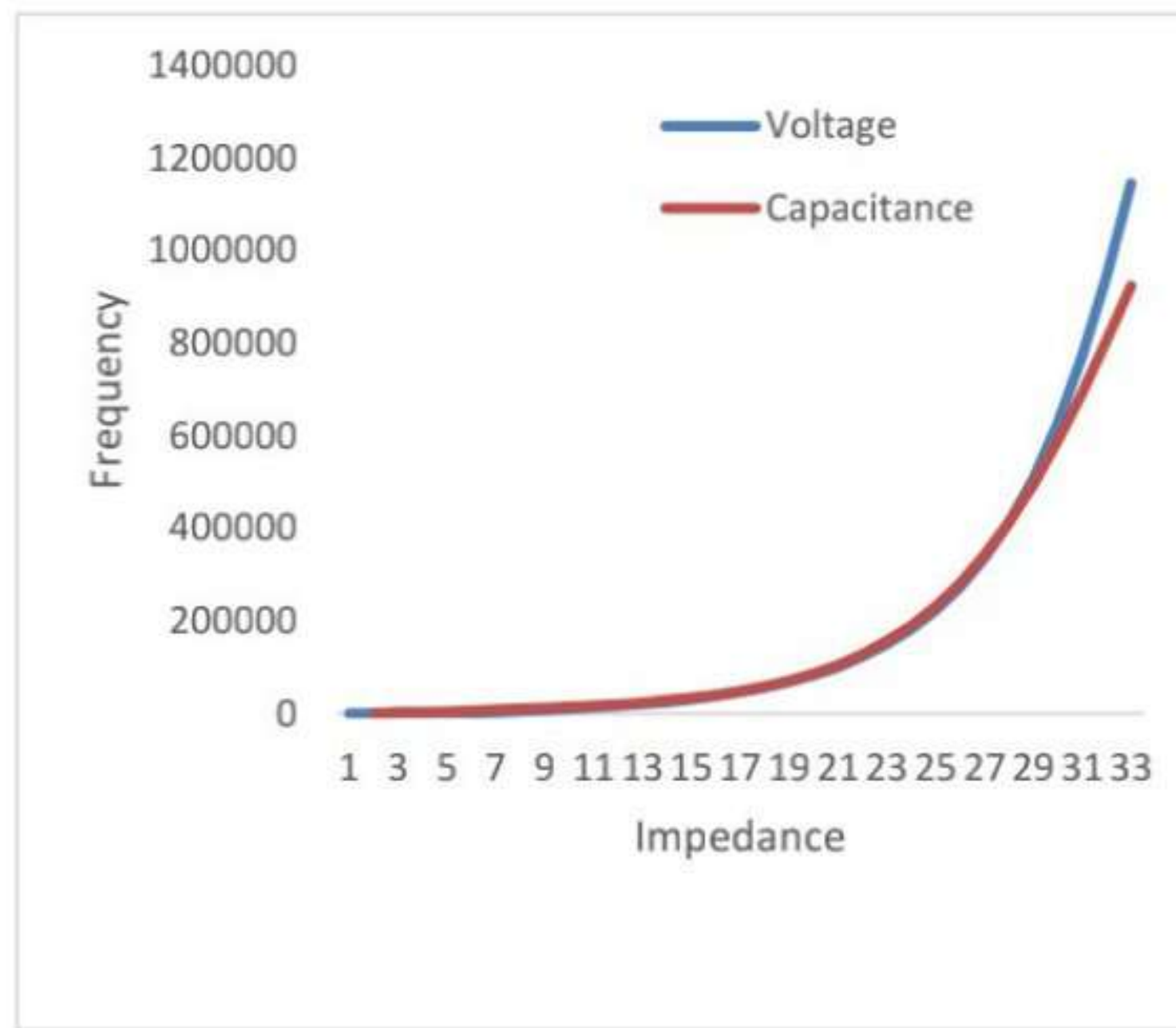
EIS after CV



**Fig: 6.13 EIS after CV 100 TO 0 01
PLOT 1**

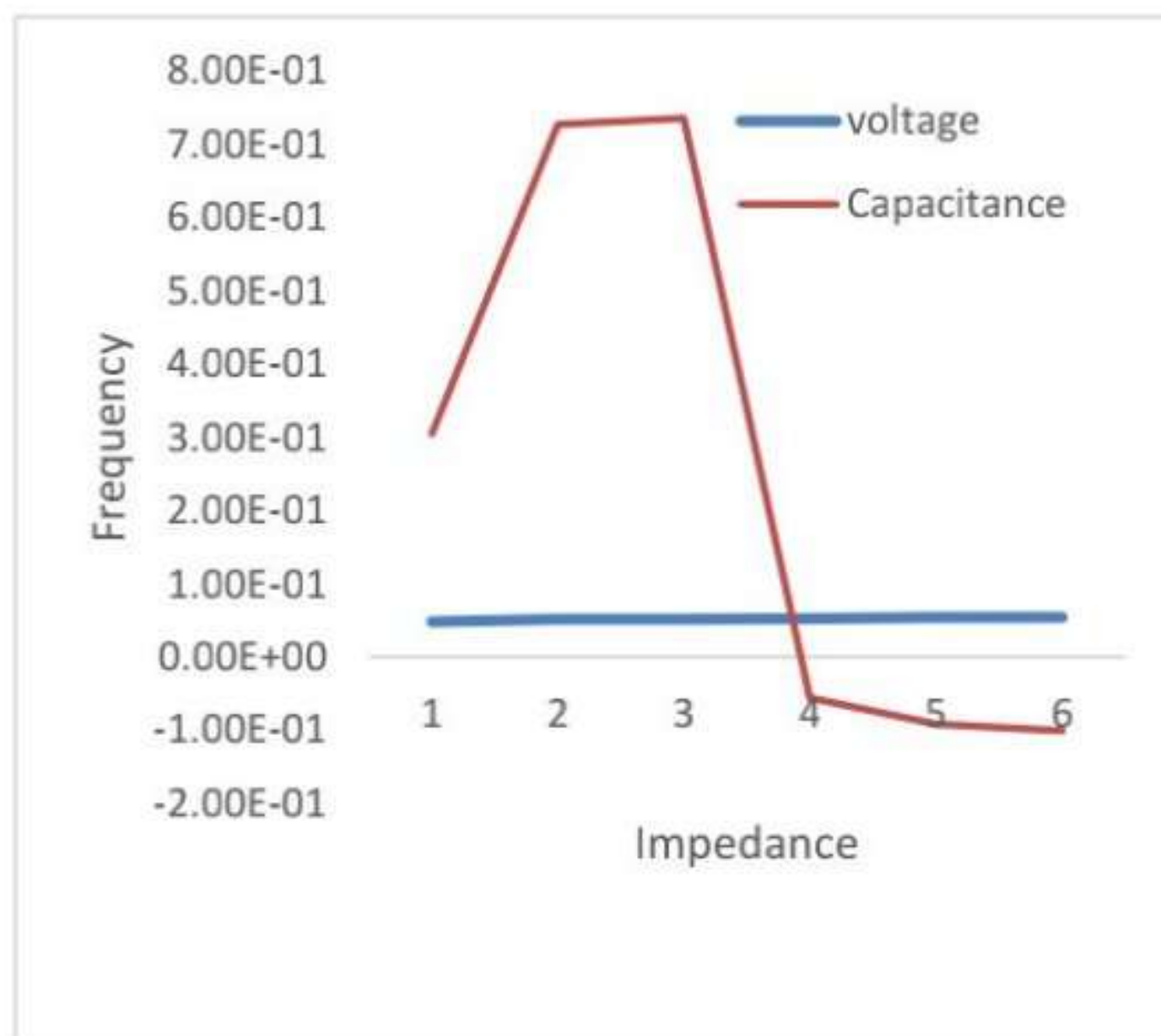


**Fig: 6.14 EIS after CV 100 TO 0 01
PLOT 2**

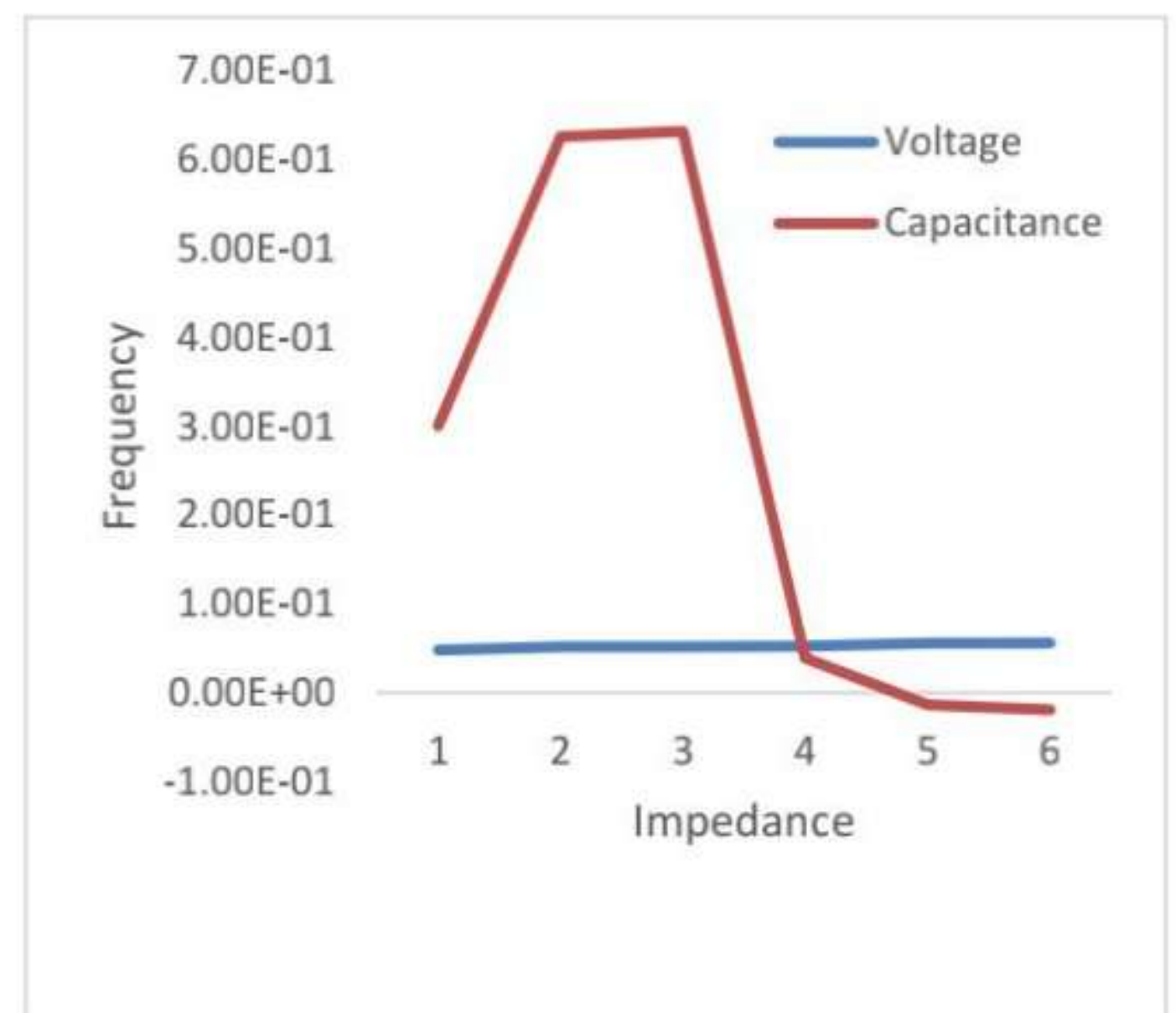


**Fig: 6.15 EIS after CV 100 TO 0.01
PLOT 3**

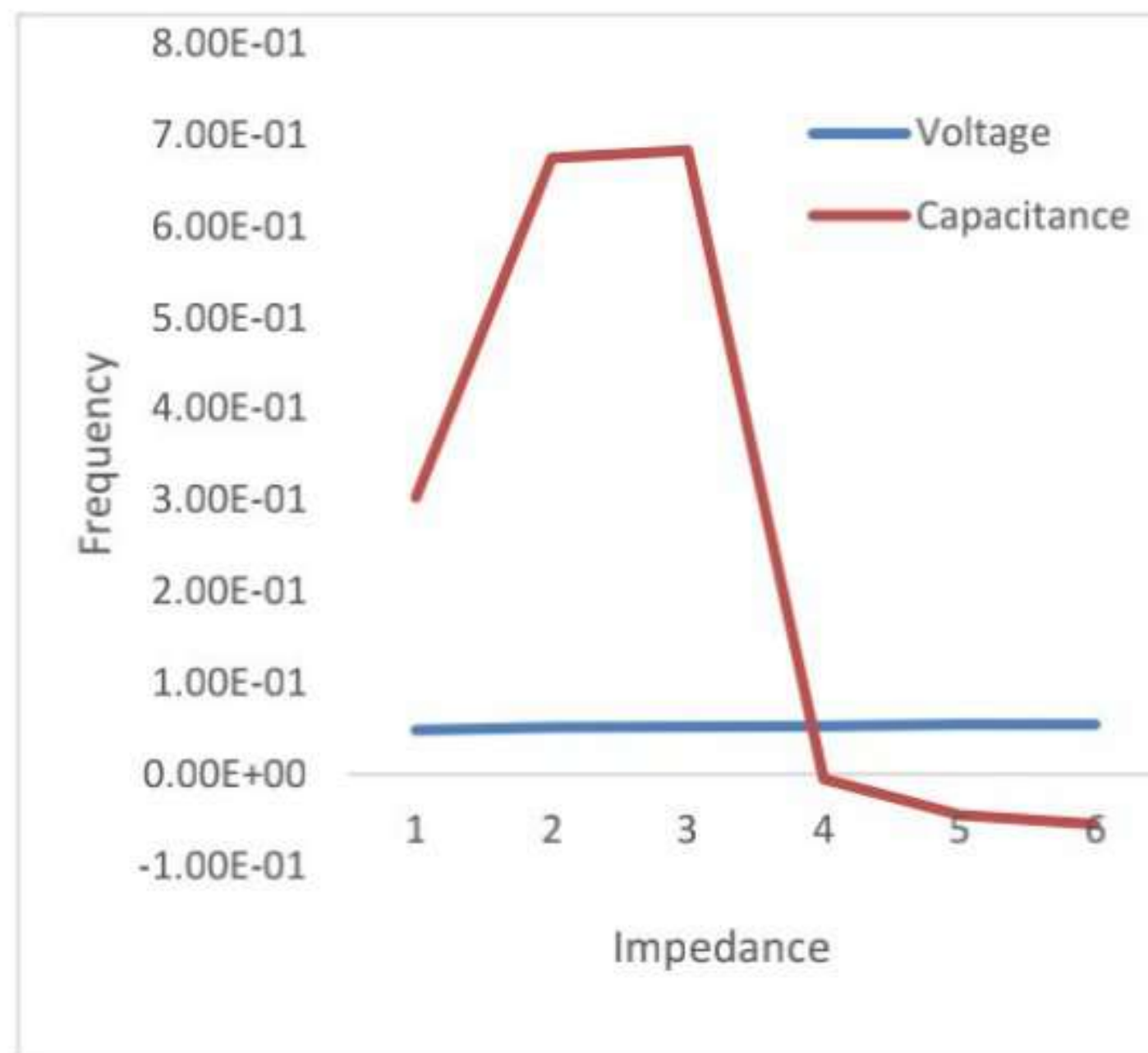
CHARGE DISCHARGE VOLTAGES



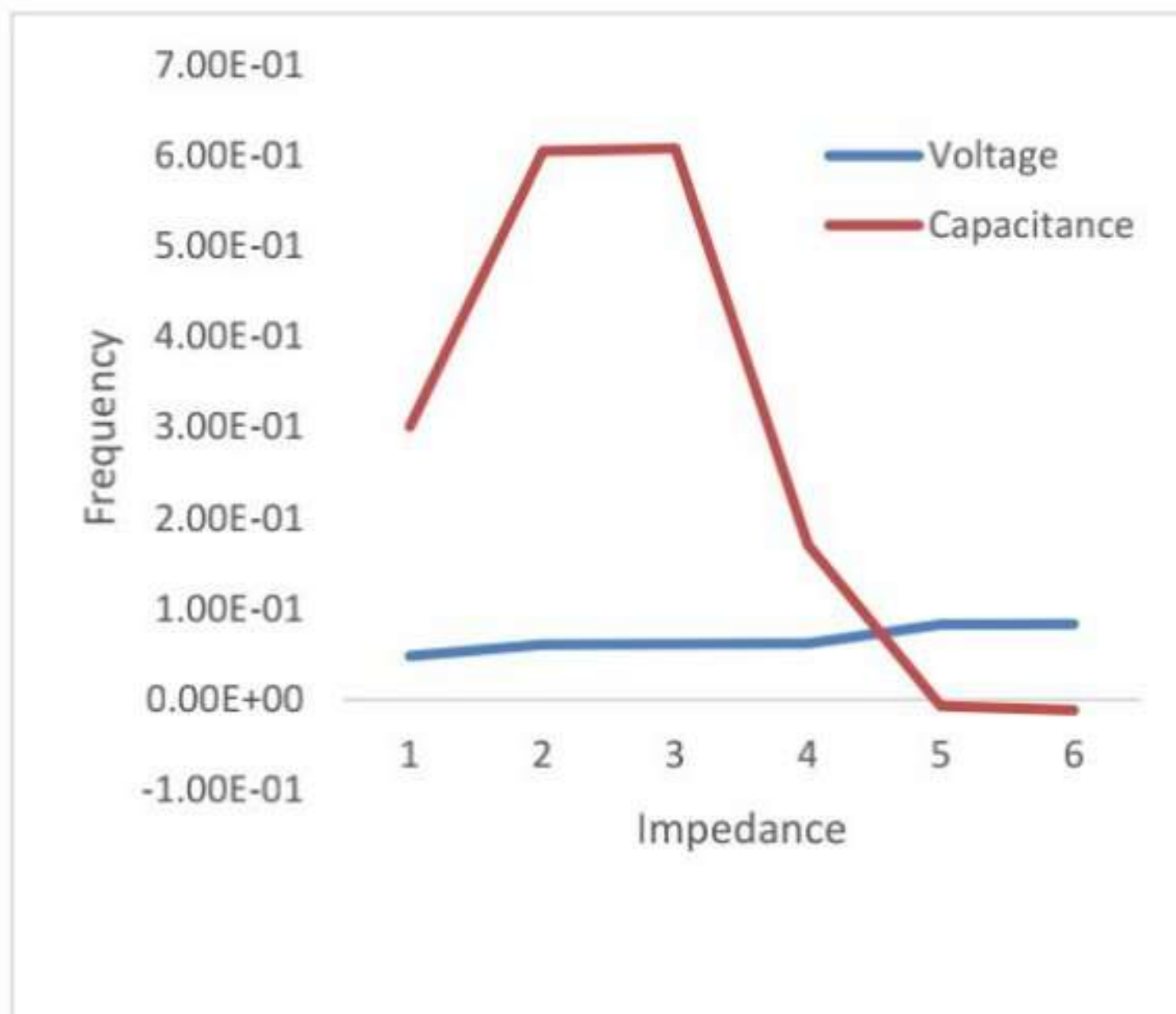
**Fig: 6.16 Discharge Voltage 20
mA 0 to 06 V**



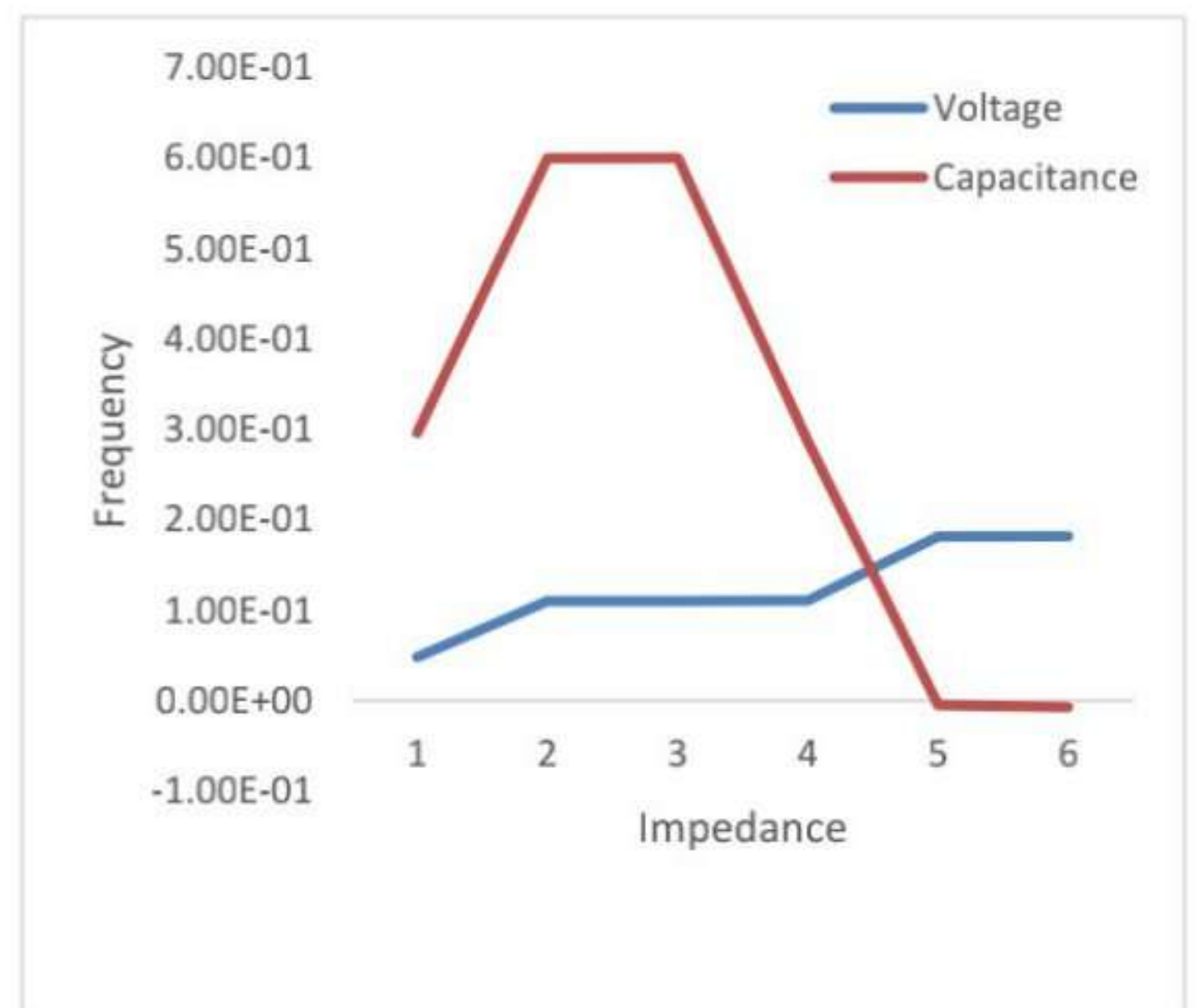
**Fig: 6.17 Discharge Voltage 16
mA 0 to 06 V**



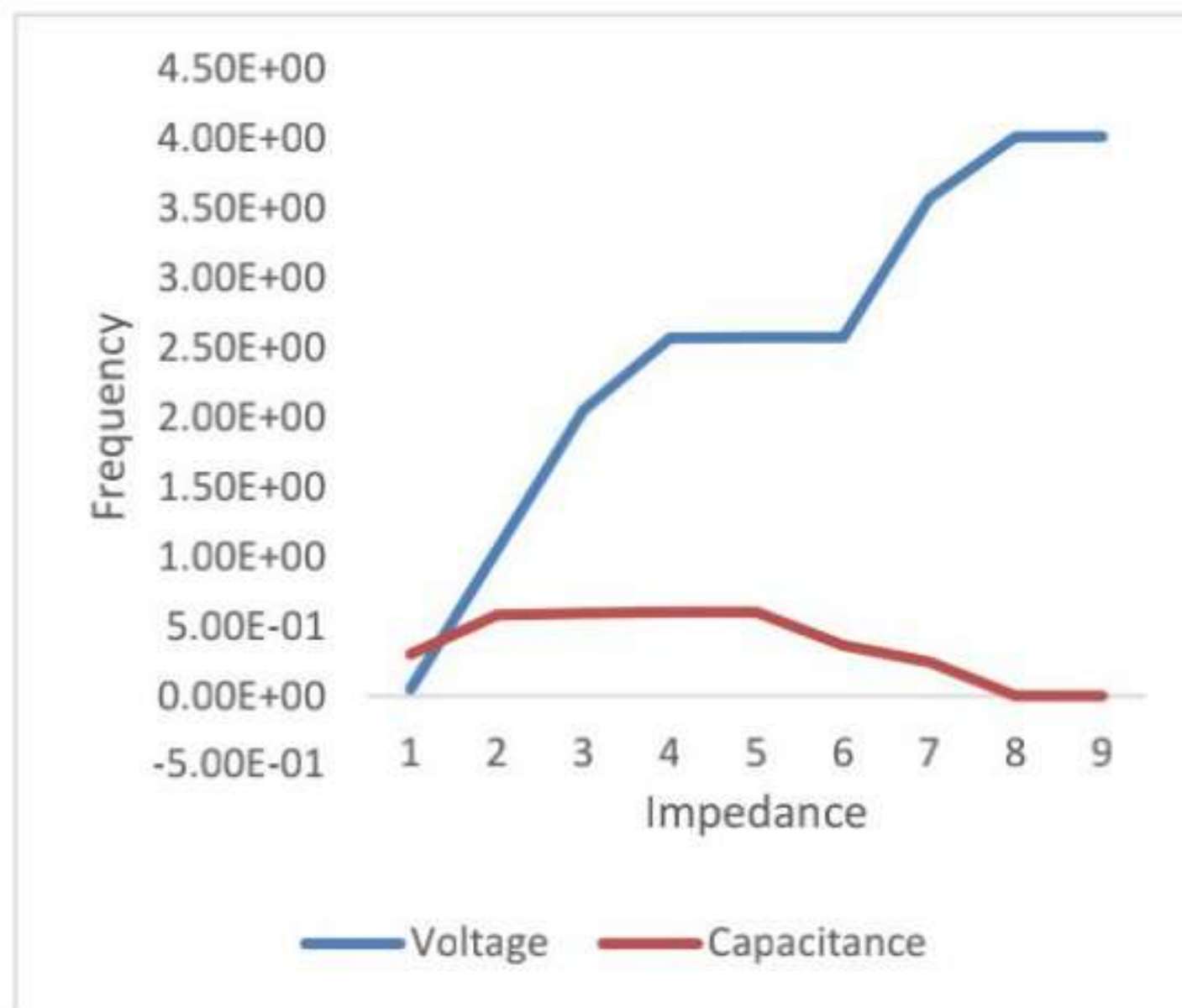
**Fig: 6.18 Discharge Voltage 18
mAg 0 to 06 V**



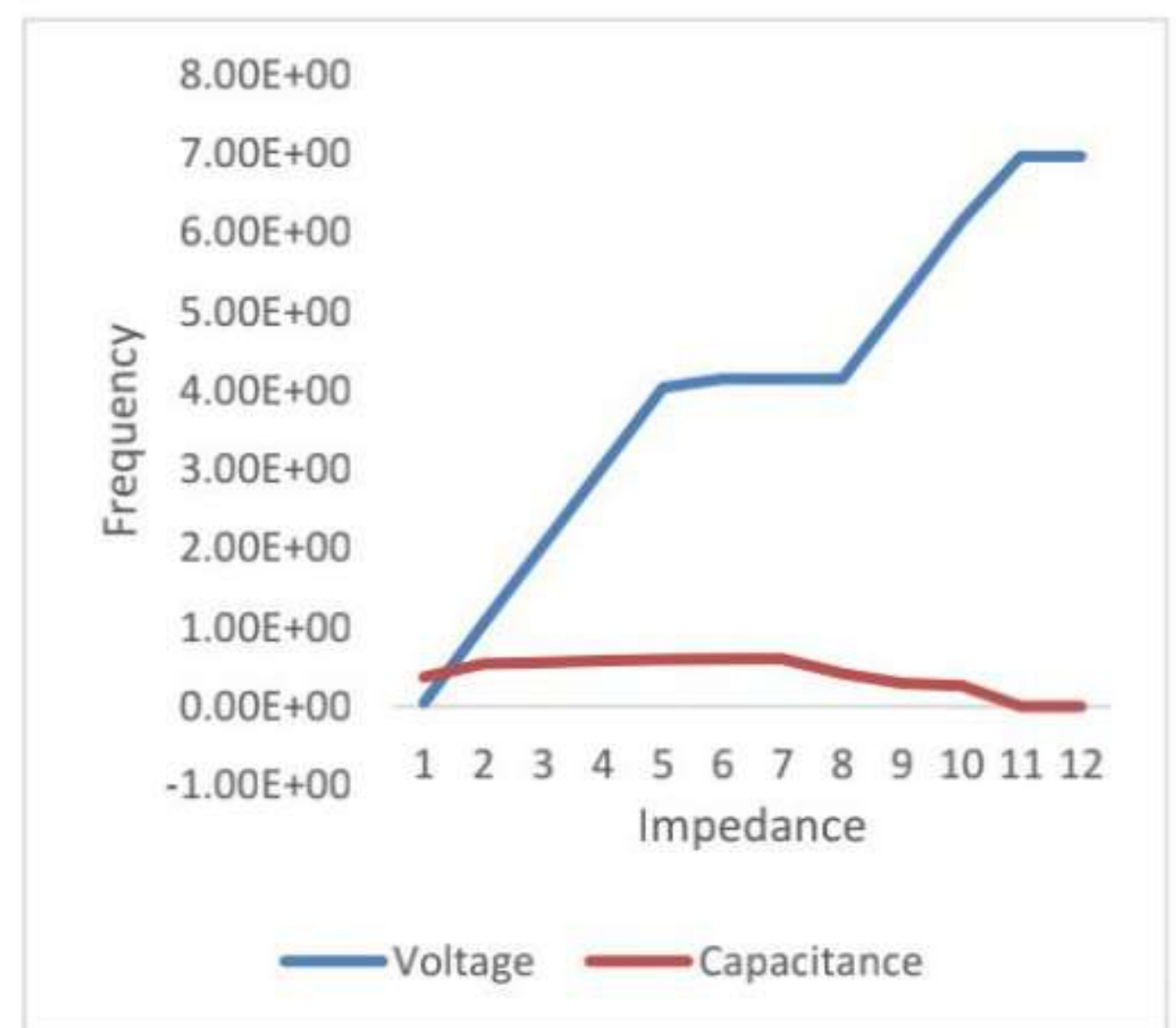
**Fig: 6.19 Discharge Voltage 14
mAg 0 to 06 V**



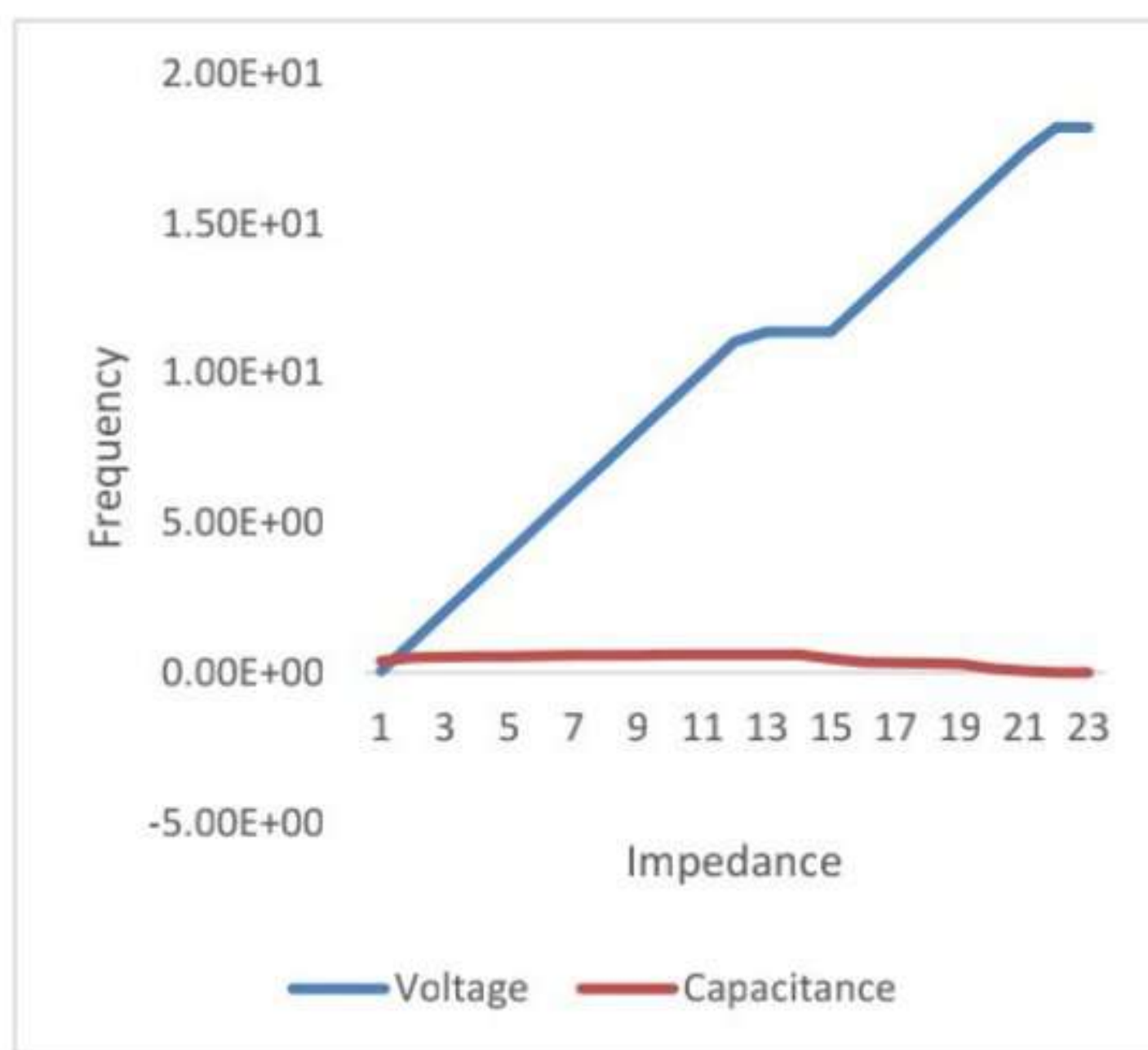
**Fig: 6.20 Discharge Voltage 12
mAg 0 to 06 V**



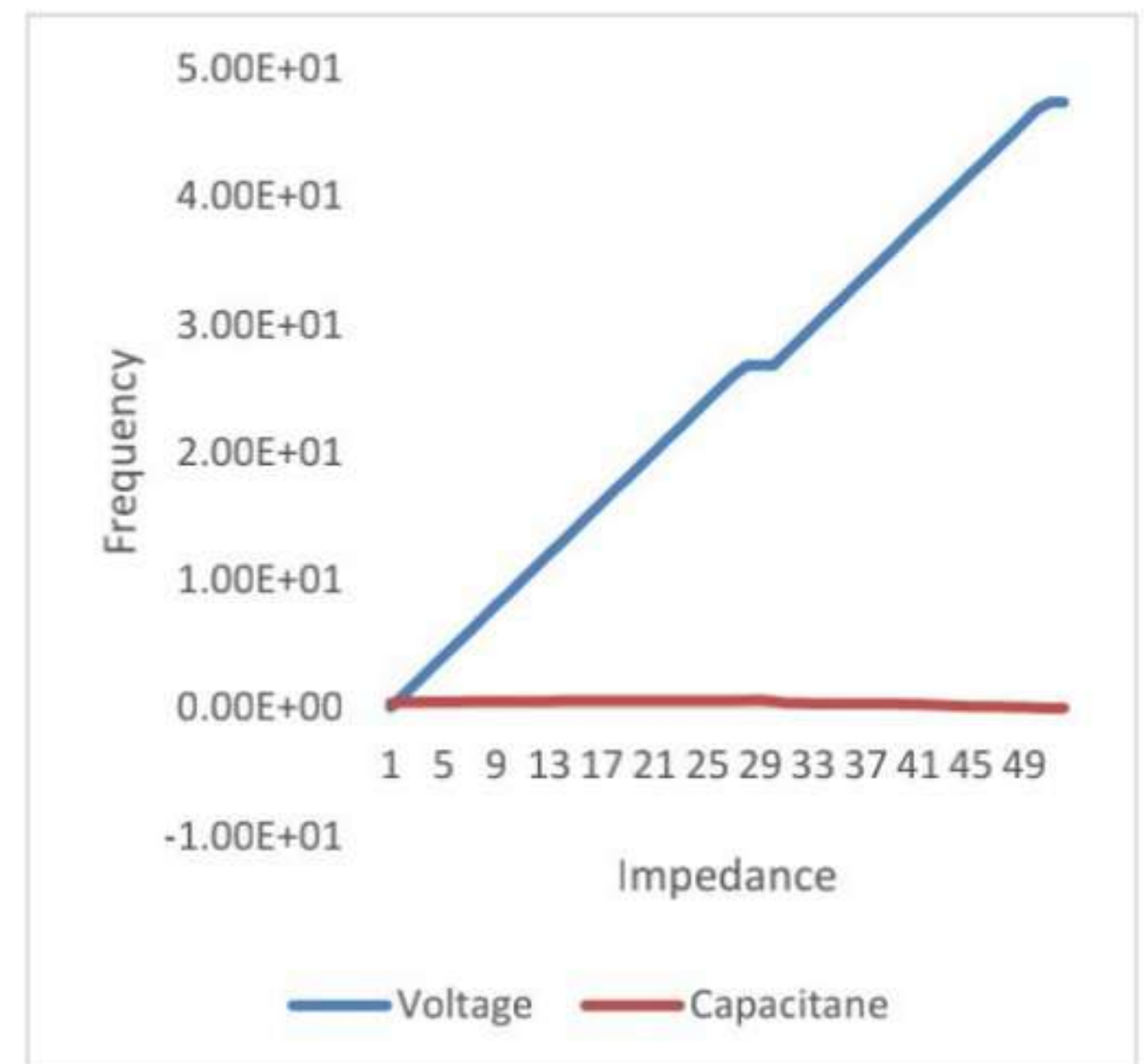
**Fig: 6.21 Charge Voltage 10
mAg 0 to 06 V**



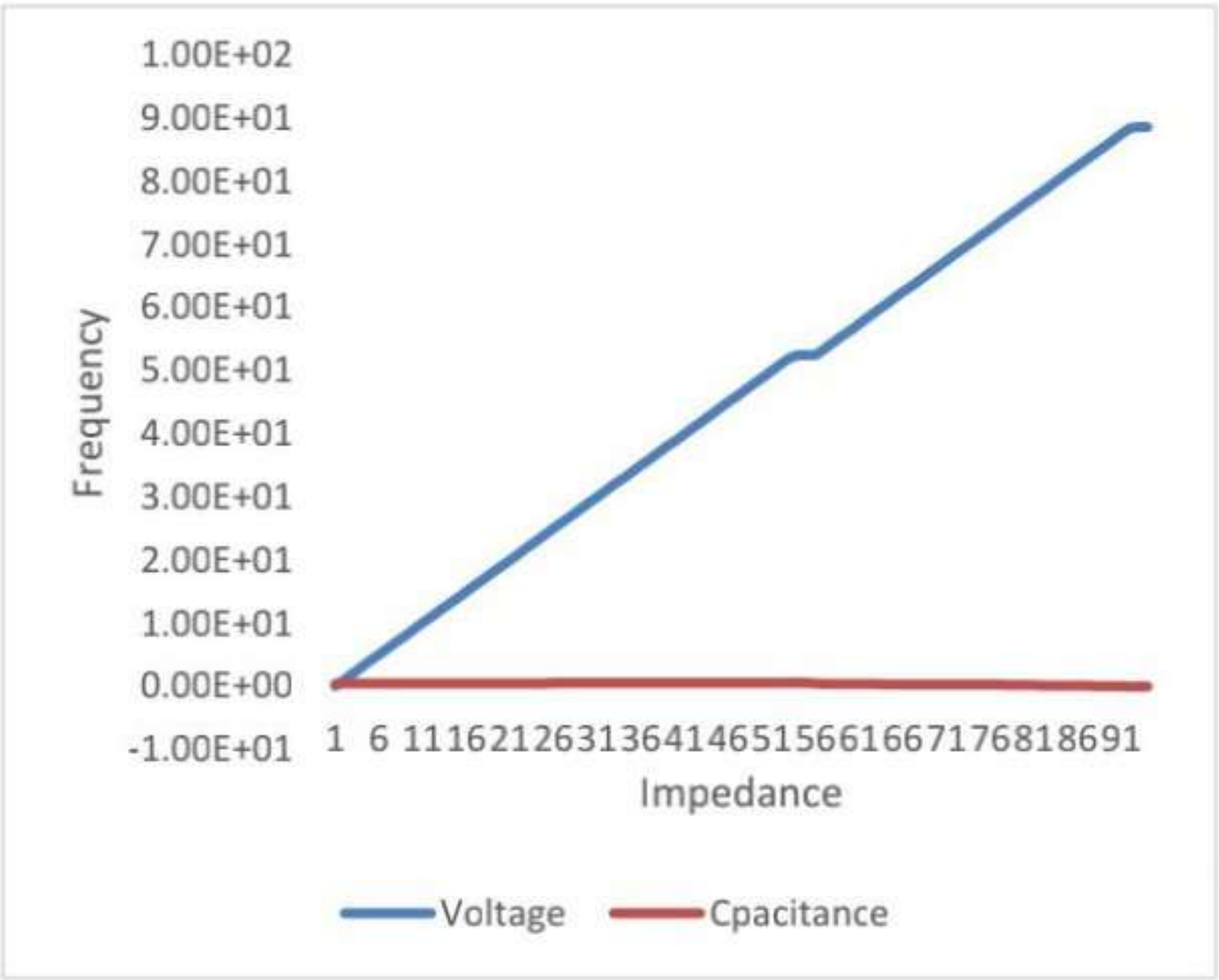
**Fig: 6.22 Charge voltage 8
mAg 0 to 06 V**



**Fig: 6.23 Charge Voltage 6
mAg 0 to 06 V**



**Fig: 6.24 Charge Voltage 4
mAg 0 to 06 V**



**Fig: 6.25 Charge Voltage 3
mAg 0 to 06 V**

6.4 ISSUES RELATED TO SYNTHESIS AND INTEGRATION OF CQDS

The synthesis and integration of Carbon Quantum Dots (CQDs) can involve various challenges and issues. CQDs are nanometer-sized carbon-based materials with unique optical and electronic properties, and they find applications in fields such as optoelectronics, bioimaging, and sensing. Here are some common issues related to the synthesis and integration of CQDs:

1. Synthesis Methodology:

Controllable Size and Morphology: Achieving precise control over the size and morphology of CQDs can be challenging. Uniformity in size is crucial for consistent properties and performance.

Reproducibility: Synthesis methods may not always be reproducible, leading to variations in the properties of CQDs produced in different batches.

2. Surface Functionalization:

Surface Passivation: Unpassivated CQDs may exhibit low stability and can be prone to aggregation. Developing effective surface passivation strategies is essential to enhance stability and prevent aggregation.

Functional Group Uniformity: Achieving uniform functionalization of the CQD surface with specific groups can be challenging, affecting their solubility and biocompatibility.

3. Optical Properties:

Photoluminescence Quantum Yield (PLQY): Obtaining high PLQY is crucial for applications like bioimaging and sensing. Optimizing the synthesis conditions to maximize PLQY can be challenging.

Emission Wavelength Control: Achieving precise control over the emission wavelength is important for specific applications. Controlling the bandgap of CQDs during synthesis is critical for tuning the emission wavelength.

4. Integration into Devices:

Device Compatibility: Integrating CQDs into various devices, such as solar cells or LEDs, may pose challenges due to differences in material properties and compatibility issues.

Stability in Functional Environments: Ensuring the stability of CQDs when integrated into functional environments, such as biological systems or electronic devices, is essential for long-term performance.

5. Scale-up Challenges:

Economical Synthesis: Developing cost-effective and scalable synthesis methods for CQDs is crucial for their commercial viability.

Large-Scale Production Consistency: Maintaining consistency in the properties of CQDs at a larger scale can be challenging and requires robust synthesis processes.

6. Characterization Techniques:

Characterization Accuracy: Accurate characterization of CQDs is essential for understanding their properties. The availability of suitable characterization techniques and the interpretation of results can be challenging.

6.5 STABILITY AND DEGRADATION CONCERNS

Supercapacitors, including those made from Carbon Quantum Dots (CQDs), are energy storage devices known for their high-power density, rapid charge/discharge rates, and long cycle life. However, they are not without stability and degradation concerns. Here are some issues related to stability and degradation in supercapacitors made from CQDs.

1. Cycling Stability:

Over repeated charge and discharge cycles, the electrode material, including CQDs, can undergo degradation. This can lead to a decrease in the capacitance and overall performance of the supercapacitor.

2. Chemical Stability:

The choice of electrolyte in a supercapacitor is crucial for its stability. Some electrolytes may chemically react with CQDs, leading to degradation and a decrease in performance.

Functional Group Stability: The stability of functional groups on the surface of CQDs, which may contribute to the capacitance, is important. Chemical reactions or alterations to these groups can impact the overall stability.

3. Coulombic Efficiency:

Redox Reactions: Redox reactions occurring at the electrode-electrolyte interface can lead to Coulombic inefficiencies, affecting the overall energy efficiency of the supercapacitor over time.

4. Environmental Factors:

Moisture Sensitivity: CQDs, especially if not properly passivated, can be sensitive to moisture. Exposure to humid environments can lead to undesired chemical reactions and affect the stability of the supercapacitor.

5. Temperature Sensitivity:

Elevated temperatures can accelerate the degradation of both the electrode material and the electrolyte, impacting the overall stability and lifespan of the supercapacitor.

6. Synthesis-Related Issues:

Impurities: Impurities in the synthesis of CQDs can contribute to instability. The presence of impurities may introduce additional redox reactions or chemical instabilities.

7. Internal Resistance:

Contact Resistance: Over time, the contact resistance at the electrode-electrolyte interface may increase due to factors like material degradation or the formation of insulating layers. This can lead to a decrease in performance.

8. Mechanical Stress:

Flexibility and Mechanical Stress: Depending on the application, supercapacitors may be subjected to mechanical stress. Ensuring the mechanical integrity of the CQD electrodes is crucial for long-term stability.

6.7 THE SCALABILITY AND COST CONSIDERATIONS OF SUPERCAPACITORS

The scalability and cost considerations of supercapacitors made from Carbon Quantum Dots (CQDs) are essential factors in determining their practical viability for large-scale commercial applications. Here are key points to consider:

The scalability of CQD-based supercapacitors is closely tied to the synthesis methods used for CQD production. Developing scalable and cost-effective synthesis techniques is crucial for large-scale manufacturing. **Batch-to-Batch Consistency:** Achieving consistency in CQD properties across different batches is important for reliable performance in large-scale production.

The cost of raw materials used in the synthesis of CQDs, such as carbon precursors, can significantly impact the overall cost of the supercapacitor. Finding economical sources for these materials is essential. Optimizing the synthesis process to reduce waste, increase yield, and minimize energy consumption contributes to cost-

effectiveness. As the production scale increases, challenges related to maintaining quality, efficiency, and reproducibility may arise. Addressing these challenges is crucial for successful scalability.

Besides CQDs, the cost of other electrode materials, such as binders and conductive additives, needs to be considered. Finding affordable yet efficient materials is important. Developing scalable and cost-effective manufacturing processes for electrode fabrication and device assembly is critical for large-scale production. The performance characteristics of CQD-based supercapacitors, including energy density and power density, need to be balanced with cost considerations. Striking the right balance is crucial for competitiveness in the market.

Ensuring that CQD-based supercapacitors maintain their performance over a long operational life is vital for cost-effectiveness, as frequent replacements would increase the overall cost of the energy storage solution.

CQD-based supercapacitors need to compete with other energy storage technologies in terms of both performance and cost. Understanding the market landscape and positioning the technology accordingly is essential.

Achieving economies of scale through large-scale production can help reduce costs per unit and make CQD-based supercapacitors more competitive. Meeting regulatory standards and environmental requirements may add to the overall cost. Understanding and addressing these factors from the early stages of development are important for successful commercialization.

CHAPTER-7

RESULTS AND DISCUSSIONS

7.1 MAJOR AREAS OF UPCOMING DEVELOPMENT

Researchers are continually working on enhancing the energy density and overall performance of supercapacitors, including those incorporating CQDs. Advances in materials design, synthesis methods, and device architecture may lead to supercapacitors with improved energy storage capabilities.

The unique properties of CQDs, including their tunable optical and electronic characteristics, make them promising for integration into wearable and flexible electronics. Future developments may focus on creating supercapacitors that are not only efficient but also flexible and adaptable to various form factors.

Supercapacitors, including those using CQDs, may find increased application in combination with energy harvesting technologies, such as solar cells and piezoelectric devices. This integration could lead to self-powered systems with improved efficiency and reliability. Ongoing research may yield more scalable and cost-effective synthesis methods for CQDs, addressing some of the scalability and cost concerns associated with their production. Improved synthesis methods could contribute to the commercial viability of CQD-based supercapacitors.

7.2 POTENTIAL APPLICATIONS AND INDUSTRIES BENEFITING FROM CQD BASED SUPERCAPACITORS

Carbon Quantum Dot (CQD)-based supercapacitors hold promise for a variety of applications due to their unique properties, such as high surface area, tunable electronic properties, and excellent conductivity. Here are potential applications and industries that could benefit from CQD-based supercapacitors:

CQD-based supercapacitors could be used in smartphones, tablets, and other portable electronic devices for rapid energy storage and release during charging and discharging cycles.

The flexibility and lightweight nature of CQD-based supercapacitors make them suitable for integration into wearable devices, such as smartwatches, fitness trackers, and electronic textiles. Supercapacitors, including those based on CQDs, can be used in conjunction with batteries in electric and hybrid vehicles. They offer quick energy bursts during acceleration and regenerative braking, enhancing overall energy efficiency.

could find applications in medical devices, providing reliable and rapid energy storage for devices like implantable medical sensors, defibrillators, and other portable medical equipment. Various consumer electronics, including cameras, audio devices, and electronic gadgets, could benefit from the rapid charging and discharging capabilities of CQD-based supercapacitors.

7.3 EMERGING TRENDS AND RESEARCH DIRECTIONS

Researchers are exploring novel synthesis methods to enhance the properties of CQDs, including size control, surface functionalization, and doping. Precise control over these factors is critical for optimizing the performance of supercapacitors. Tuning the electronic and optical properties of CQDs to achieve specific functionalities is an ongoing trend. Researchers are exploring ways to tailor the bandgap, energy levels, and other properties to meet the requirements of different applications.

Investigating the integration of CQD-based supercapacitors with other energy storage technologies, such as batteries, to create hybrid systems. This approach aims to combine the high-power density of supercapacitors with the high energy density of batteries for improved overall performance. Advancements in the development of flexible and wearable electronics have prompted research into CQD-

based supercapacitors that can conform to irregular shapes. This is particularly relevant for applications in smart clothing, flexible displays, and wearable health monitoring devices.

Exploring the biocompatibility of CQDs for potential use in biomedical applications. This includes investigating CQD-based supercapacitors for implantable medical devices, biosensors, and other healthcare-related applications. A growing emphasis on environmentally friendly synthesis methods for CQDs. Green synthesis approaches, such as using sustainable carbon sources and eco-friendly solvents, are gaining attention to address environmental concerns and increase the sustainability of the manufacturing process.

Research is focused on understanding and optimizing charge storage mechanisms in CQD-based supercapacitors. This includes exploring pseudocapacitive effects, redox reactions, and other electrochemical processes to improve energy density and overall performance. Efforts to address scalability and cost challenges associated with CQD-based supercapacitors. Researchers are working on developing cost-effective synthesis methods and manufacturing processes that can be scaled up for commercial production.

Considering the specific energy storage needs of IoT devices, researchers are exploring how CQD-based supercapacitors can meet the requirements for low-power, intermittent energy demand, and rapid charging cycles in IoT applications.

Innovations in electrode materials and structures to improve the overall performance and stability of CQD-based supercapacitors. This includes the exploration of new materials, such as nanocomposites and hybrid structures. Developing in situ characterization techniques to monitor and understand the electrochemical processes occurring within CQD-based supercapacitors during operation. Real-time monitoring can provide valuable insights for optimizing device performance.

7.4 COMMERCIALIZATION PROSPECTS

1. High Power Density:

CQD-based supercapacitors offer high power density and fast charge-discharge rates. This makes them suitable for applications where rapid energy storage and release are critical, such as in electric vehicles, consumer electronics, and certain industrial processes.

2. Flexibility and Lightweight Design:

The flexible and lightweight nature of CQDs makes them appealing for applications that require conformable energy storage solutions, such as in wearable electronics and flexible devices.

3. Tunable Properties:

The tunable properties of CQDs, including size, surface chemistry, and electronic structure, provide flexibility for tailoring their performance to specific applications. This tunability is advantageous for customization based on the requirements of different industries.

4. Potential for Green Synthesis:

Researchers are exploring environmentally friendly methods for synthesizing CQDs. Green synthesis approaches contribute to sustainability, aligning with the increasing demand for eco-friendly energy storage solutions.

5. Biocompatibility for Biomedical Applications:

The biocompatibility of CQDs opens up opportunities for biomedical applications. CQD-based supercapacitors could find use in implantable medical devices and other healthcare applications.

7.5 COMMERCIALIZATION CHALLENGES:

1. Scalability and Production Costs:

One of the primary challenges is the scalable production of high-quality CQDs at an affordable cost. Scaling up production while maintaining consistent properties is crucial for widespread commercial adoption.

2. Long-Term Stability:

Ensuring the long-term stability and reliability of CQD-based supercapacitors is essential for their acceptance in commercial applications. Researchers need to address issues related to degradation over extended usage periods.

3. Material Uniformity:

Achieving uniformity in the properties of CQDs, especially when produced on a large scale, is challenging. Variability in material properties could affect the performance and reliability of supercapacitors.

4. Competitive Technologies:

CQD-based supercapacitors face competition from other energy storage technologies, including conventional supercapacitors, batteries, and emerging technologies. For commercial success, CQDs must offer distinct advantages over existing solutions.

5. Regulatory and Certification Hurdles:

Meeting regulatory standards and obtaining certifications for safety, performance, and environmental impact is a significant challenge in the commercialization process.

6. Integration into Existing Devices:

Integrating CQD-based supercapacitors into existing devices and systems may require adaptations and modifications. Compatibility with established technologies is crucial for widespread adoption.

7. Awareness and Acceptance:

Creating awareness about the benefits of CQD-based supercapacitors and gaining acceptance in various industries is vital. Market education efforts are needed to showcase the advantages of this technology.

8. Economic Viability:

The economic viability of CQD-based supercapacitors compared to other energy storage options is a critical factor. Cost-effectiveness is essential for their integration into mass-market products.

CHAPTER – 8

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Sumanth Vinukonda

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ABSTRACT

This abstract explores the synthesis of carbon quantum dots (CQDs) from mushrooms and their potential utilization in supercapacitors, energy storage devices and energy production and conversion devices. Carbon quantum dots, a class of nanoscale carbon materials, have garnered considerable attention due to their unique properties and versatile applications. The process of deriving CQDs from mushrooms involves a carbonization process that transforms mushroom-derived precursors into nanoscale carbon structures. These CQDs exhibit remarkable optical, electronic, and electrochemical properties, making them suitable candidates for energy storage applications. In this particular study, fluorescent CQDs were successfully synthesized from edible mushrooms using a simple one-step hydrothermal process, assisted by diluted sulfuric acid. These spherical carbon quantum dots, with a mean diameter range of 4-5 nm, shows blue photoluminescence. They were further tested in FTIR Spectroscopy, XRD (X-Ray diffraction) and SEM images. Our results demonstrated that edible mushroom can be used to produce multi-faceted carbon dots with diverse application.

The integration of CQDs into supercapacitors and energy storage devices capitalizes on their high surface area, tuneable bandgap, and excellent charge transport characteristics. This allows for enhanced energy storage and rapid charge-discharge cycles, crucial for efficient supercapacitor performance. Moreover, the abundance of precursor sources, such as agricultural waste from mushrooms, adds to the environmental appeal of this synthesis approach. By utilizing mushroom-derived CQDs in energy storage devices, a sustainable and efficient route to advancing energy storage technologies can be achieved, contributing to the development of more reliable and environmentally friendly energy solutions

CHAPTER - 1 INTRODUCTION

Utilizing Carbon Quantum Dots (CQDs) derived from mushrooms presents an innovative avenue in the development of supercapacitor technology. These naturally sourced CQDs offer remarkable charge storage capabilities, owing to their unique structural and compositional properties. By harnessing the renewable potential of mushroom based CQDs, supercapacitors can achieve sustainable energy storage solutions. The compatibility of these biogenic materials with existing electrode systems fosters the creation of efficient and eco-friendly energy storage devices. As we explore the diverse applications of mushroom derived CQDs in supercapacitors, a greener and more efficient energy landscape comes into focus.

1.1 PURPOSE OF THE PROJECT

The purpose of this project is to explore the utilization of Carbon Quantum Dots (CQDs) extracted from mushrooms as a novel and sustainable material for enhancing supercapacitor performance. By investigating the unique properties of mushroom based CQDs, the project aims to unlock their potential in advancing energy storage technologies. Through comprehensive analysis and experimentation, the project seeks to contribute to the development of efficient, eco-friendly, and cost-effective supercapacitors for diverse applications.

1.2 OVERVIEW ON CARBON QUANTUM DOTS (CQDs)

Carbon Quantum Dots (CQDs) sourced from mushrooms are nanoscale carbon particles with exceptional electrical properties. Extracted from natural biomass, these CQDs offer a sustainable and renewable material option. Their distinctive structure and composition make them suitable for energy storage applications like supercapacitors, due to their high surface area and conductivity. Harnessing these biogenic CQDs presents a promising avenue for greener and more efficient energy storage solutions.

1.3 BACKGROUND

⁶⁵ Carbon quantum dots (CQDs) are small carbon nanoparticles with dimensions less than 10 nm. They ³ have gained significant attention in the recent years due to their unique optical, electronic and chemical properties. The synthesis of CQDs from natural sources is a promising area of research as it is an eco-friendly and cost-effective alternative to synthetic methods.

¹⁰ CQDs have a range of fascinating properties that make them attractive for use in various applications. One of their most notable properties is their photoluminescence. CQDs emit bright and stable fluorescence, ¹ making them ideal for applications in areas such as bioimaging, biosensing, and optoelectronics. CQDs also possess excellent biocompatibility and low toxicity, ¹ making them suitable for use in biomedical applications. Furthermore, ¹⁷ their small size allows for efficient cellular uptake, making them promising candidates for drug delivery systems.

¹ Over the past few decades, CQDs have been extensively studied for their unique optical and electronic properties, which arise due to quantum confinement effects. These properties have led to their use in ⁴² a wide range of applications such as solar cells, light-emitting diodes (LEDs), and bioimaging.

² The development of CQDs has also played a significant role in the field of nanotechnology. Researchers have developed a range of synthetic methods for producing CQDs with precise control over size, shape, and composition. These developments have enabled the study of fundamental quantum phenomena and opened up new avenues for developing advanced materials with tailored properties. Overall, the study of CQDs continues to be an exciting area of research with promising prospects for future technological applications.

1.4 IMPORTANCE OF SUPERCAPACITORS IN ENERGY STORAGE

Supercapacitors play a vital role in energy storage by offering rapid energy discharge and high-power density. They bridge the gap between traditional batteries and capacitors, providing quick bursts of energy for applications like regenerative braking in vehicles and smoothing out power fluctuations in renewable energy systems. Their extended cycle life, rapid charging, and ability to store and release energy efficiently make them crucial for enhancing grid stability, extending battery life, and supporting emerging technologies such as electric vehicles and portable electronics.

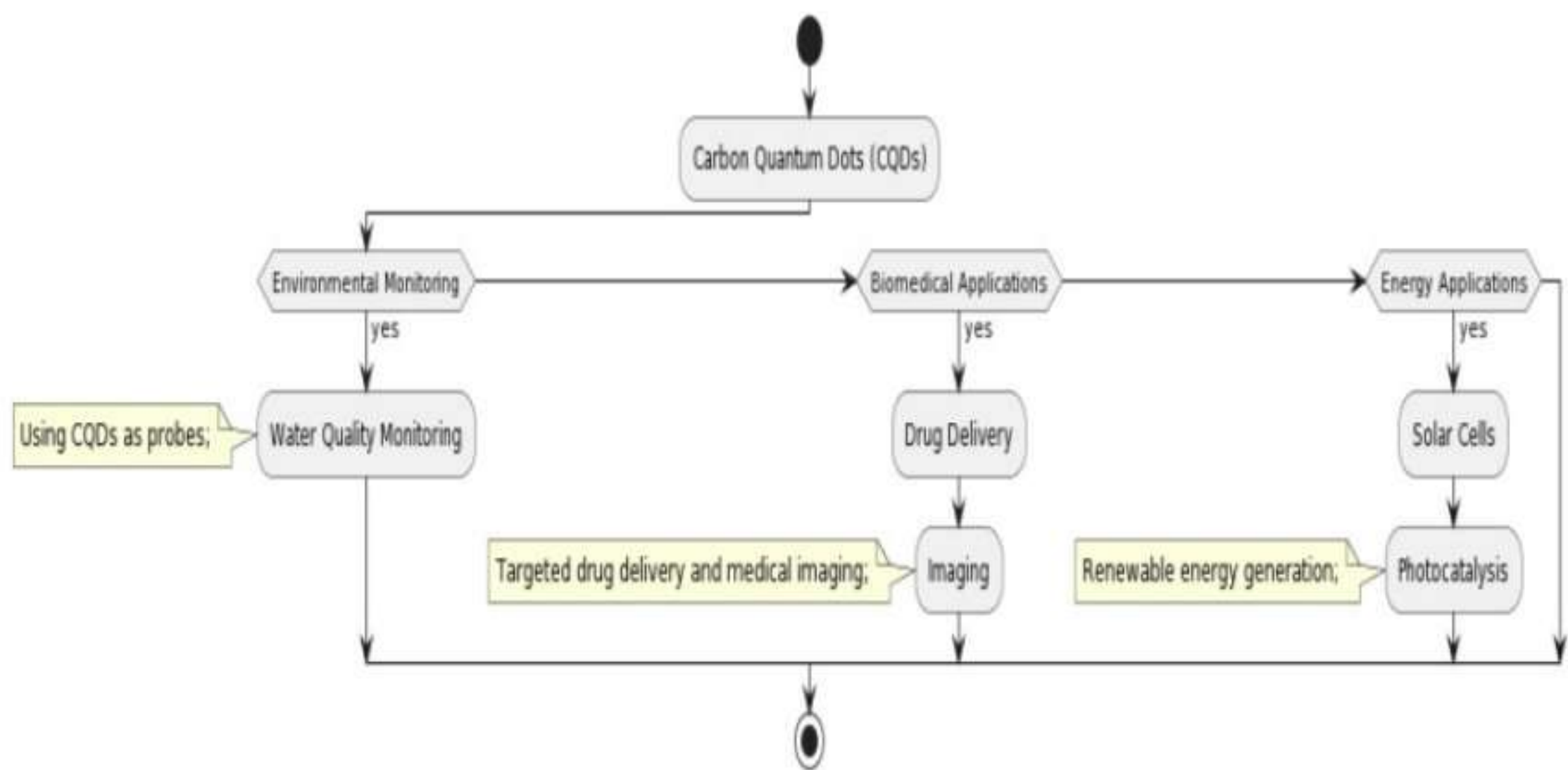


Fig:1.1 Different applications of CQDs

CHAPTER - 2

LITERATURE REVIEW

2.1 CARBON QUANTUM DOTS.

One of the most widely used top-down approaches for the synthesis of CQDs from mushrooms is the hydrothermal method. In this method, the mushroom-derived precursors are subjected to hydrothermal treatment in the presence of an acid or base catalyst. The hydrothermal treatment leads to the breakdown of the precursors into smaller CQDs. The size and properties of the CQDs can be controlled by varying the reaction parameters such as temperature, time, and precursor concentration.

Another top-down approach for the synthesis of CQDs from mushrooms is the microwave-assisted method. In this method, the mushroom-derived precursors are subjected to microwave irradiation in the presence of a suitable solvent. The microwave irradiation leads to the formation of CQDs by the thermal decomposition of the precursors.

The bottom-up approach for the synthesis of CQDs from mushrooms involves the controlled assembly of smaller molecular units into larger nanoscale materials. One of the most widely used bottom-up approaches is the solvothermal method. In this method, the mushroom-derived precursors are dissolved in a suitable solvent, followed by the addition of a reducing agent and a stabilizing agent. The mixture is then subjected to solvothermal treatment, leading to the formation of CQDs by the controlled assembly of the precursor molecules.

2.2 SOURCES OF CARBON QUANTUM DOTS.

Carbon quantum dots (CQDs) can be derived from a variety of sources including:

- Carbon-rich materials such as graphite, carbon black, carbon nanotubes, and carbon fibers.
- Biomass waste such as fruit peels, vegetable waste, and eggshells.
- Organic molecules such as glucose, citric acid, and amino acids.
- Industrial waste such as fly ash, soot, and coal.
- Carbon dioxide (CO₂) through electrochemical or photocatalytic reduction.

The choice of source material depends on the desired properties of the CQDs and the specific application for which they will be used. For example, CQDs derived from biomass waste are considered eco-friendly and sustainable, while those derived from industrial waste may offer cost-effective solutions for large-scale production.

2.3 APPLICATIONS OF CARBON QUANTUM DOTS.

- **Bioimaging:** CQDs have excellent optical properties, including high fluorescence quantum yield, photo-stability, and biocompatibility. They can be used as imaging agents for bioimaging applications, such as fluorescent labeling of cells, tissues, and organs. CQDs can also be functionalized with targeting moieties, such as antibodies or peptides, to specifically bind to biomolecules of interest, making them an excellent tool for targeted imaging and disease diagnosis.
- **Sensing:** CQDs can be used as sensors for the detection of various analytes, such as metal ions, organic pollutants, and biological molecules. The sensing mechanism is based on the fluorescence quenching or enhancement of CQDs

in the presence of analytes. For example, CQDs functionalized with specific receptors can selectively detect target molecules through fluorescence quenching or enhancement, providing a sensitive and rapid detection method.

- **Energy conversion:** CQDs have shown potential applications in energy conversion, including solar cells and photocatalysis. In solar cells, CQDs can be used as sensitizers to convert light energy into electrical energy, while in photocatalysis, CQDs can be used as photocatalysts to accelerate chemical reactions under visible light irradiation. CQDs have also been used as electrocatalysts for fuel cells, showing excellent catalytic activity and stability.
- **Environmental remediation:** CQDs can be used for the removal of various pollutants, such as heavy metal ions, organic dyes, and antibiotics, from wastewater. The removal mechanism is based on the strong adsorption capacity of CQDs, which can efficiently remove pollutants from aqueous solutions. CQDs have also been used for the detection of environmental pollutants, providing a sensitive and selective detection method.
- **Biomedical applications:** CQDs have shown great potential in biomedical applications, including drug delivery, photodynamic therapy, and bioimaging. CQDs can be used as carriers for drug delivery, providing a controlled release of drugs with high efficacy and low toxicity. CQDs can also be used as photosensitizers for photodynamic therapy, which involves the use of light to activate photosensitizers to produce reactive oxygen species that can kill cancer cells.

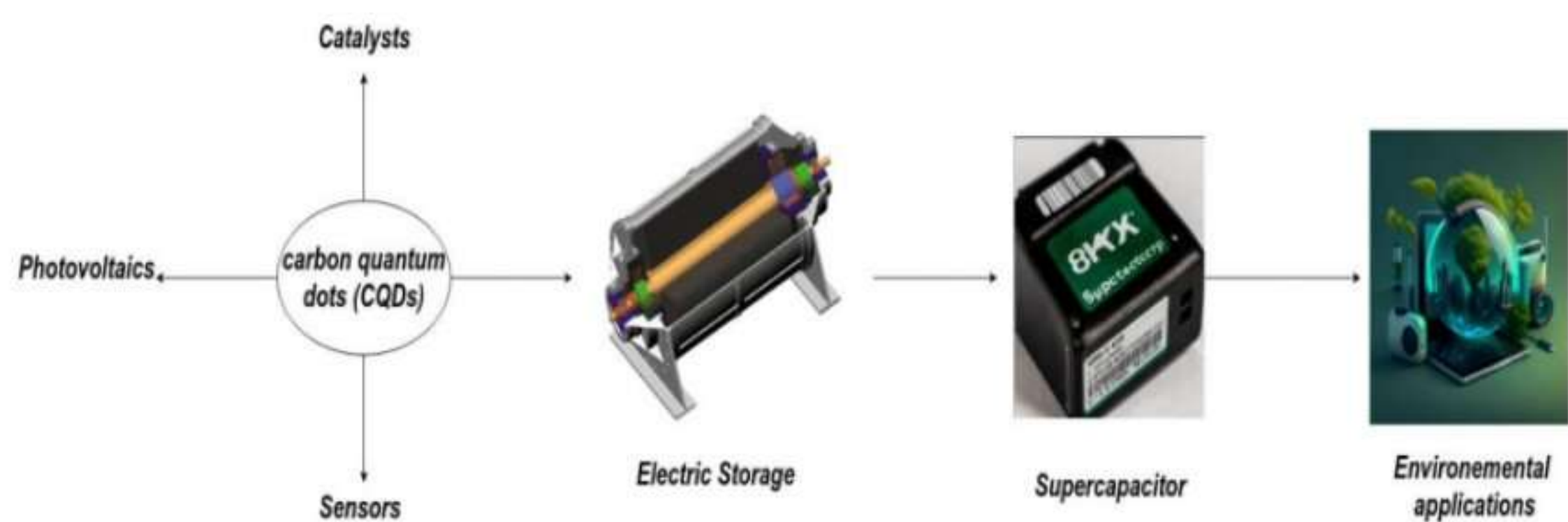


Fig:2.1 scope for future in technical aspects

2.4 SYNTHESIS METHODS OF CARBON QUANTUM DOTS.

Carbon quantum dots (CQDs) can be synthesized through various methods, including top-down and bottom-up approaches. Here are some commonly used synthesis methods for CQDs.

- **Hydrothermal method:** This method involves the hydrothermal treatment of carbon sources, such as citric acid, glucose, or sucrose, in the presence of a strong acid or base at high temperature and pressure. The resulting CQDs are typically small in size and have a narrow size distribution.
- **Microwave-assisted synthesis:** This method involves the microwave-assisted pyrolysis of carbon sources, such as citric acid or glucose, in the presence of a surfactant or a stabilizer. The microwave irradiation leads to the rapid heating and decomposition of the carbon source, resulting in the formation of CQDs.
- **Electrochemical synthesis:** This method involves the electrochemical oxidation of carbon sources, such as graphite or carbon black, in the presence of a supporting electrolyte. The electrochemical process leads to the formation of CQDs on the surface of the electrode.
- **Laser ablation method:** This method involves the laser ablation of carbon targets, such as graphite or carbon nanotubes, in a liquid medium. The laser irradiation leads to the fragmentation of the carbon targets, resulting in the formation of CQDs.
- **Solvothermal method:** This method involves the solvothermal treatment of carbon sources, such as citric acid or glucose, in a polar solvent at high temperature and pressure. The resulting CQDs are typically small in size and have a narrow size distribution.

- **Template-assisted method:** This method involves the use of a template, such as a surfactant or a polymer, to control the size and morphology of the CQDs during synthesis. The template can also act as a stabilizer to prevent the aggregation of CQDs. In summary, there are several methods for synthesizing CQDs, each with its own advantages and disadvantages. The choice of method depends on the desired properties of the CQDs, such as size, morphology, and optical properties.

2.5 PREVIOUS STUDIES ON CARBON QUANTUM DOTS FROM MUSHROOMS.

- **CQDs from *Lentinula edodes*:** A study published in the journal Nanomaterials in 2020 reported the synthesis of CQDs from *Lentinula edodes* (shiitake mushrooms) using a hydrothermal method. The CQDs showed excellent photoluminescence properties and were found to have potential applications in bioimaging and drug delivery.
- **CQDs from *Pleurotus ostreatus*:** Another study published in the Journal of Nanoscience and Nanotechnology in 2020 reported the synthesis of CQDs from *Pleurotus ostreatus* (oyster mushrooms) using a hydrothermal method. The CQDs showed excellent fluorescent properties and were found to have potential applications in bioimaging and sensing.
- **CQDs from *Ganoderma lucidum*:** A study published in the Journal of Nanoparticle Research in 2018 reported the synthesis of CQDs from *Ganoderma lucidum* (lingzhi mushrooms) using a hydrothermal method. The CQDs showed excellent photoluminescence properties and were found to have potential applications in bioimaging and cancer therapy.

Overall, these studies highlight the potential of mushrooms as a source of CQDs with excellent properties for various applications in biomedicine, sensing, and imaging.

CHAPTER – 3

AIM AND SCOPE OF THE PROJECT

3.1 AIM OF THE PROJECT.

- To develop a sustainable and eco-friendly method for the synthesis of CQDs.
- To obtain CQDs with excellent photoluminescence properties, high stability, and low toxicity.
- To explore the potential of mushroom-derived CQDs for various applications such as electrochemical performance.
- To use CQDs in energy storage devices is to enhance their energy storage capacity and power density.
- To contribute to improved electrochemical performance, allowing for efficient charge storage and rapid energy release.

3.2 SCOPE

- **Lighting:** CQDs can be used in LED lighting technology to produce high- quality, energy-efficient lighting.
- **Solar cells:** CQDs have shown promise as materials for use in solar cells due to their ability to absorb light over a broad range of wavelengths.
- **Biomedical imaging:** CQDs can be used as contrast agents in biomedical imaging due to their unique optical properties.
- **Sensing:** CQDs can be used to develop sensors that are capable of detecting specific chemical or biological compounds.

- **Data storage:** CQDs can be used as materials for high-density data storage, as their small size allows for a larger amount of data to be stored in a smaller space.
- **Catalysis:** CQDs can be used as catalysts in chemical reactions due to their unique surface properties.
- **Quantum computing:** CQDs can be used as building blocks in the development of quantum computers, due to their ability to trap and manipulate individual electrons.
- **Water purification:** CQDs can be used in water purification technology to remove harmful contaminants from water.
- **Energy storage:** CQDs can be used as materials for high-performance energy storage devices such as batteries and supercapacitors.
- **Printable electronics:** CQDs can be used to develop printable electronics, which are flexible, lightweight, and low-cost electronic devices.

3.3 SUPERCAPACITORS: BASICS AND WORKING PRINCIPLE.

Supercapacitors store energy between two activated carbon electrodes in an electrolyte. Charge is stored through physical separation (double layer capacitance) and certain materials' reversible redox reactions (pseudo capacitance). This rapid energy exchange, distinct from batteries, suits high power demands in applications like electric vehicles and grid stabilization.

Supercapacitors, or ultracapacitors, are energy storage devices that store charge through reversible physical and electrochemical processes, distinct from batteries.

Classification of supercapacitors:

- Electrostatic Double Layer Capacitors (EDLCs)
- Pseudo capacitors
- Hybrid Supercapacitors

Supercapacitors Vs Batteries

- Supercapacitors store energy through physical separation and electrochemical processes, enabling rapid charge and discharge, whereas batteries rely on slower chemical reactions.
- Supercapacitors have shorter charge/discharge cycles, making them suitable for high power applications, while batteries offer higher energy density and longer cycle life.
- Supercapacitors excel in power delivery and energy capture during braking (regenerative braking) in vehicles, while batteries provide sustained energy over a longer period.
- Supercapacitors have lower energy density compared to batteries, but they can bridge the gap between batteries and conventional capacitors.

Supercapacitors vs. Normal Capacitors:

- Supercapacitors store much more energy than normal capacitors due to their higher surface area and specialized materials.
- Normal capacitors store energy through the electrostatic separation of charges without electrochemical reactions, resulting in much lower energy storage capacity.
- Supercapacitors are designed for higher energy and power densities, suitable for rapid energy exchange, while normal capacitors are mainly used for energy storage and discharge in simple electronic circuits.

3.4 WORKING OF SUPERCAPACITORS

Supercapacitors function by utilizing two key energy storage mechanisms: double layer capacitance and pseudo capacitance. In double layer capacitance, charges accumulate at the electrode electrolyte interface, creating a physical separation of charge. This process allows for rapid charge and discharge cycles, making supercapacitors adept at delivering high power bursts. Pseudo capacitance involves reversible redox reactions at the electrode surface, increasing energy storage capacity compared to conventional capacitors. When charging, ions from the electrolyte collect at the electrode surfaces, creating a potential difference. This stored energy is rapidly released during discharge, enabling supercapacitors to swiftly provide bursts of power for various applications.

CHAPTER – 4

MATERIALS AND METHODS

4.1 MATERIALS.

The following materials were used for the synthesis of CQDs:

- Fresh mushrooms (Agaricus biporous Or Button Mushrooms)
- blender
- sulfuric acid (H_2SO_4)
- Magnetic pellet.
- water
- Zinc Oxide (ZnO)

4.2 PREPARATION OF MUSHROOM EXTRACT

Select a mushroom species that contains high amounts of natural carbon, such as Shiitake mushrooms or button mushrooms. Wash the mushrooms thoroughly with water to remove any dirt or debris. Pat them dry with a clean towel. Cut the mushrooms into small pieces and put them into a blender. Blend the mushrooms in the blender until they are finely chopped.

Add enough water to the blender to cover the mushrooms completely. Blend the mixture for a few minutes until it becomes a smooth liquid. Pour the mushroom extract through a filter to remove any solid particles. Collect the filtered extract in a clean container. Boil the extract on low heat until it becomes concentrated. let the extract cool down to ambient room temperature. Store the mushroom extract in a clean and dry container until ready to use for CQDs synthesis. The concentration of the mushroom extract can be adjusted according to the desired concentration of the final CQDs solution.

4.3 SYNTHESIS OF MUSHROOM EXTRACT.

The synthesis of CQDs from mushrooms was carried out in two steps:

Step 1: Extraction of raw material.

The fresh mushrooms were washed thoroughly with water to remove any dirt or debris. The mushrooms were cut into small pieces and blended to form a fine paste. The paste was filtered using a muslin cloth to remove any solid particles. The filtrate was collected in a beaker and subjected to centrifugation at 10,000 rpm for 15 minutes. The supernatant was collected and stored in a refrigerator for further use.

Step 2: Synthesis of CQDs

To synthesize the carbon quantum dots (CQDs), a procedure was followed as described below: Initially, 5 mL of mushroom extract was combined with 5 mL of H_2SO_4 in a gradually added manner while maintaining continuous stirring until the pH of the solution reached 2. The resulting mixture was then heated at 100°C for a duration of 2 hours. Subsequently, the mixture was allowed to cool down to room temperature, followed by the addition of 5 mL of acid dropwise until the pH was adjusted to 1. The contents were then heated at 100°C for 1 hour. Afterward, the mixture was cooled to room temperature, and 5 mL of H_2SO_4 solution was gradually added dropwise until the pH reached 7. The contents were heated at 80°C for an additional hour. Upon cooling to room temperature. To collect the CQDs, the reaction mixture was subjected to centrifugation at 10,000 rpm for 15 minutes. The collected CQDs were then washed multiple times with water and ethanol to eliminate any impurities present.

METHODOLOGY:

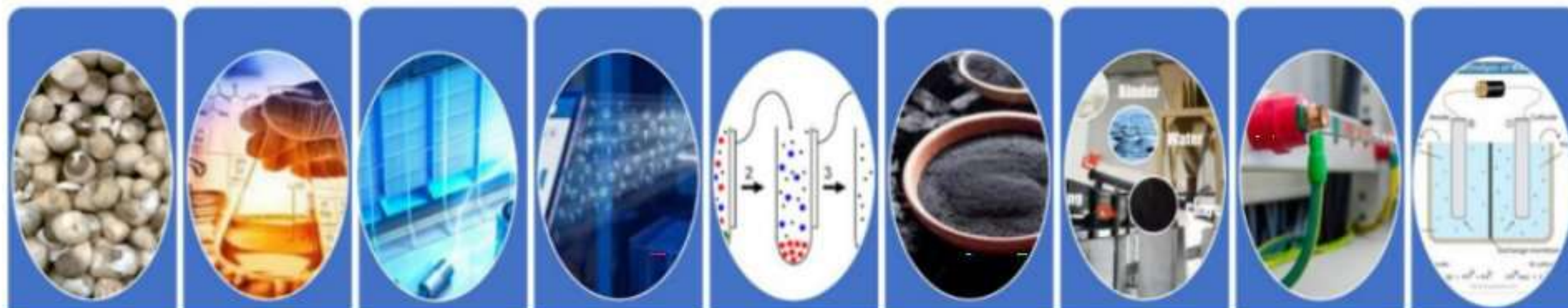


Fig 4.1 Methodology of synthesizing carbon quantum dots from Mushrooms

4.4 ACQUIRING MATERIALS AND BUILDING A CAPACITOR OUT OF THEM

MATERIALS REQUIRED: 2 copper mesh and 6 iron 3cm x 2cm, sulfuric acid (H_2SO_4) 30 ml, sodium sulfate (Na_2SO_4) 30ml, egg albumin, spatula, aluminum foil, hot air oven, adhesive glue, pH meter, activated char coal.

PROCEDURE:

1.Making of electrodes

2.Acquiring cell shells

3.Assembling

4.Testing

- Collect two copper mesh and six iron mesh of dimensions 3cm x 2cm.
- Make paste of activated char coal, quantum dots powder, egg albumin, and synthetic glue.

- Now apply the paste over every mesh taken and leave them over for drying in hot air oven
- After drying, let the mesh cool and roll them up in an aluminum foil, now select the Empty cells for assembling the capacitors.
- Clean and dry the cells before assembling, pour in the electrolyte along with quantum dots centrifuge liquid in 5:0.5 ratio.
- Bring in the electrodes without disturbing their physical structure into the cell and insert the terminal points into the lid
- Now seal every leak found with the glue in the apparatus.

CHAPTER – 5

CHARATERISATION RESULT ON SYNTHESIS

5.1 CHARACTERISTICS OF CARBON QUANTUM DOTS (ANALYSIS).

Carbon quantum dots (CQDs) are semiconductor nanocrystals with unique optical and electronic properties. The characterization of CQDs is an important step towards understanding their physical properties and potential applications.

One of the key characteristics of CQDs is their size-dependent optical properties. As the size of the CQD decreases, the bandgap energy increases, leading to a blue-shift in the absorption and emission spectra. This tunability in the absorption and emission spectra makes CQDs useful for various applications, including photovoltaics, light-emitting diodes, and sensors.

Another important characteristic of CQDs is their surface chemistry. The surface of CQDs is usually passivated with ligands, which can influence the electronic properties of the CQDs. The type of ligand used and the ligand-to-CQD ratio can affect the stability and optical properties of CQDs.

Additionally, the morphology and crystal structure of CQDs can also influence their properties. For example, the shape of CQDs can affect their electronic and optical properties, and the crystal structure can determine the exciton lifetime and carrier transport properties.

Overall, the characterization of CQDs is crucial for understanding their properties and potential applications. Techniques such as absorption and photoluminescence spectroscopy, transmission electron microscopy, and X-ray diffraction can provide valuable information about the size, morphology, and crystal structure of CQDs.

FTIR Spectroscopy results for carbon quantum from mushrooms.

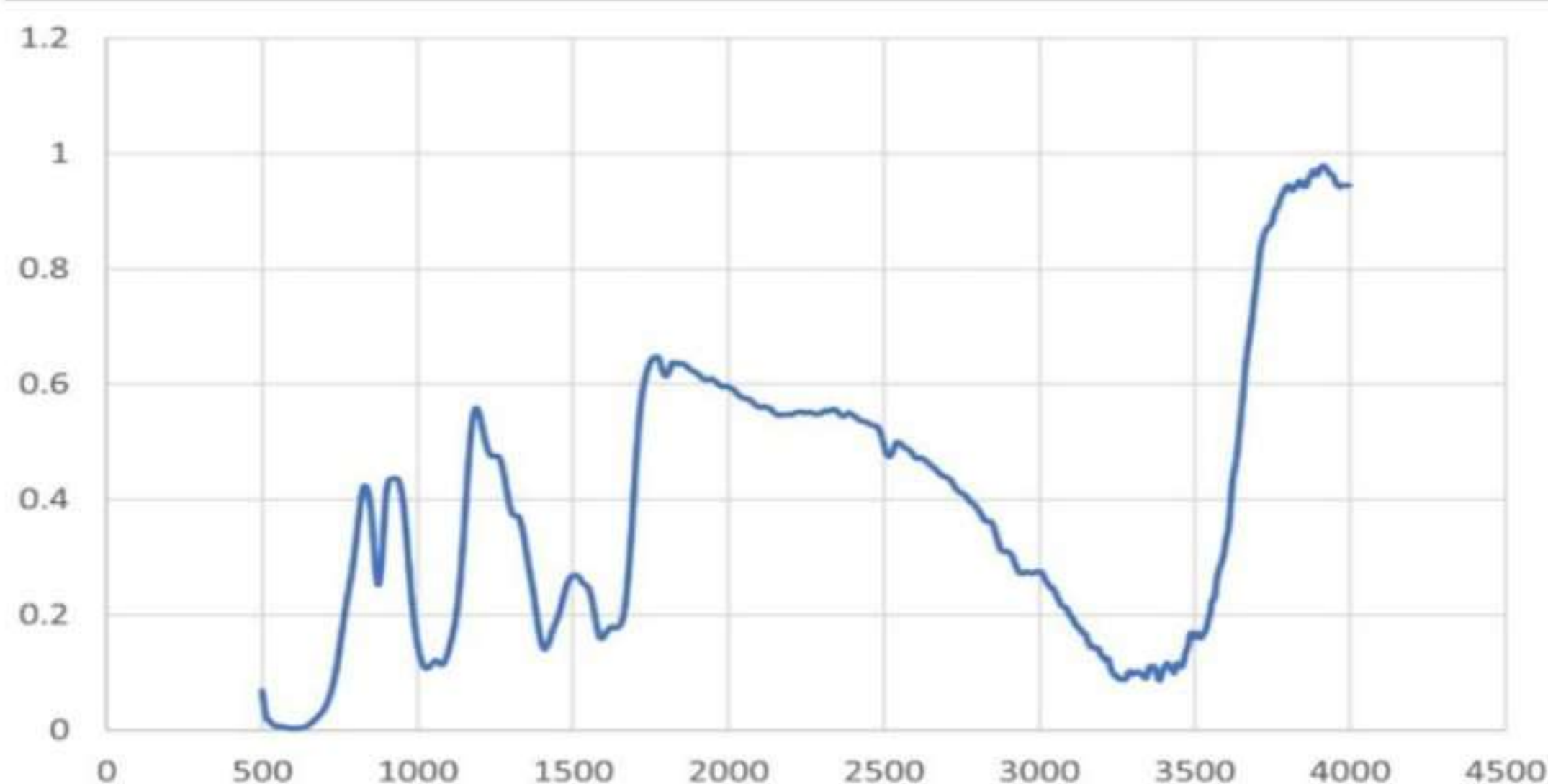


Fig.5.1. FTIR (blue at 3500 in X-axis line represents carbon)

Peaks in the FTIR spectrum can be assigned to specific chemical bonds, allowing researchers to identify the types of functional groups present on the surface of the CQDs. For example, peaks in the region between 1200 and 1800 cm^{-1} can indicate the presence of carbonyl or carboxyl groups.

1. Broad Peak around 3400-3300 cm^{-1} : This peak corresponds to the O-H stretching vibration, indicating the presence of hydroxyl (OH) groups on the CQD surface. These groups may be responsible for CQDs' hydrophilic nature and potential applications in biological systems.

2. Peak at 1620-1680 cm^{-1} : This region typically represents the C=O stretching vibration, indicating the presence of carbonyl groups (C=O) on the CQD surface. These groups can be associated with functionalization and reactivity of CQDs.

3. Peak around 1400-1600 cm^{-1} : This region corresponds to the C=C stretching vibration, suggesting the presence of sp^2 -hybridized carbon atoms, which are typical in the graphene-like structure of CQDs.

4. Peak at approximately 1100 cm^{-1} : This peak is often associated with C-O-C stretching vibrations, indicating the presence of ether or epoxy groups, which can affect CQDs' stability and chemical reactivity.

5. Absence of Peaks in the 2800-3000 cm^{-1} Range: The absence of peaks in this range suggests the low presence of aliphatic C-H stretching vibrations, indicating that CQDs are less likely to contain significant amounts of aliphatic carbon chains.

By analyzing the FTIR spectrum, researchers can gain insights into the chemical composition and structure of the CQD surface, as well as any functionalization or modification that may have occurred. This information can be valuable in understanding the properties of CQDs and optimizing their performance in various applications

XRD (X-Ray diffraction).

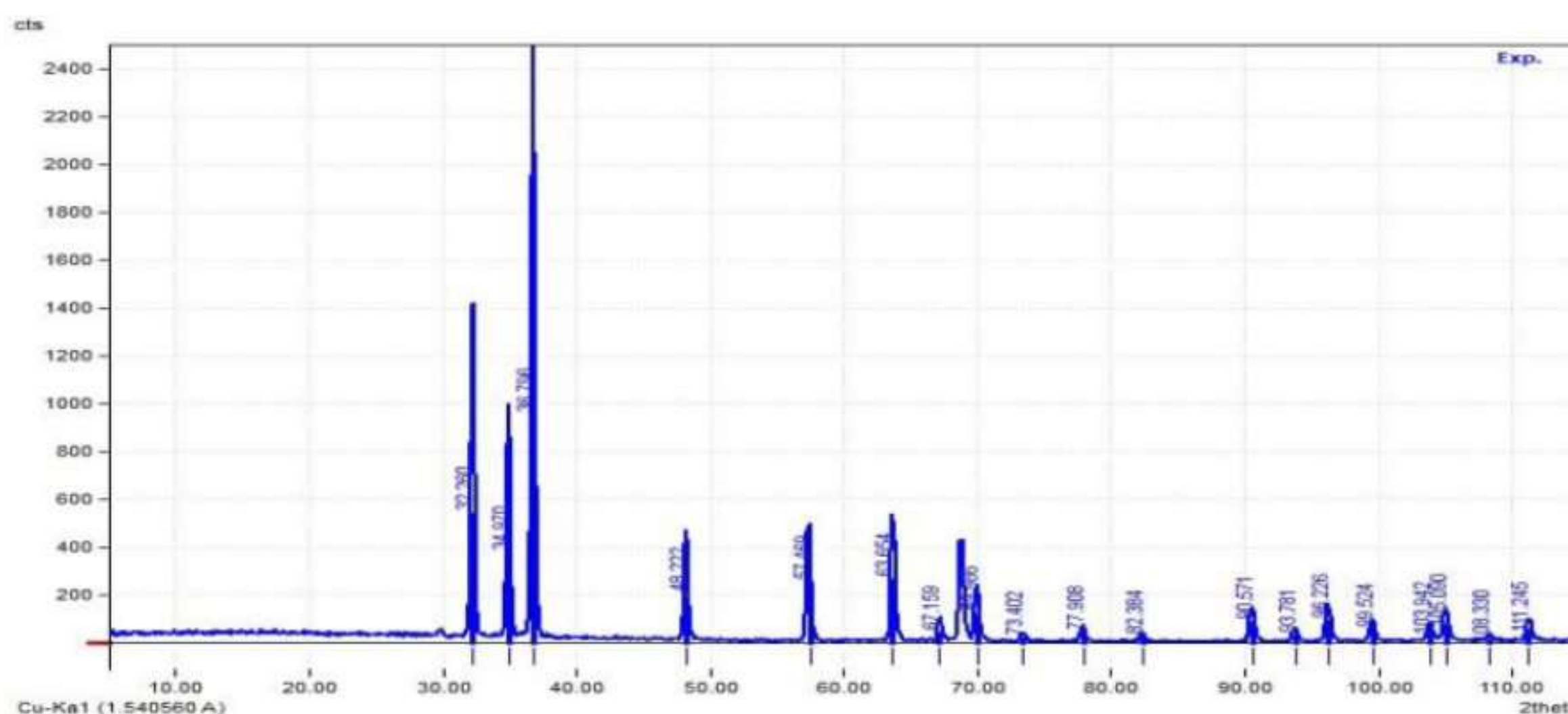


Fig .5.2 X-Ray diffraction spectroscopy

At wave length below 200 and angle (theta) below 50 carbon quantum dots are found. More precisely the CQDs are found at wavelength under 50 and angle up to 30 in our XRD results.

1. Broad Diffraction Peak at Low Angles (around 22-26 degrees 2θ): This peak indicates the presence of amorphous or disordered carbon structures within the CQDs.

The broadness suggests that CQDs may lack long-range crystallinity, which is typical of graphene.

2.Graphitic Carbon Peak (around 42-44 degrees 2θ): A small, intense peak in this range indicates the presence of graphitic carbon structures within the CQDs. It suggests the existence of graphene-like domains in the CQD structure.

3.Lack of Sharp Crystalline Peaks: Unlike traditional crystalline materials, CQDs typically lack sharp and well-defined XRD peaks, reinforcing their amorphous or quasi-amorphous nature. This amorphous character is due to their small size and disordered structure.

4.No Presence of Other Crystalline Phases: The absence of peaks corresponding to other crystalline phases (e.g., metal oxides or impurities) indicates the purity of the CQD sample and suggests that they consist primarily of carbon-based materials.

5.Peak Shifts and Broadening: The positions and broadening of XRD peaks can provide information about the size and strain within CQDs. Peaks that are shifted or broadened compared to bulk carbon materials can be indicative of the quantum confinement effect due to CQDs' nanoscale size.

At 70 wavelength and angle 110, SO_3 is found in the test sample. At 600 wavelength and angle 65 ZnO is seen.

FESEM Images of Sample

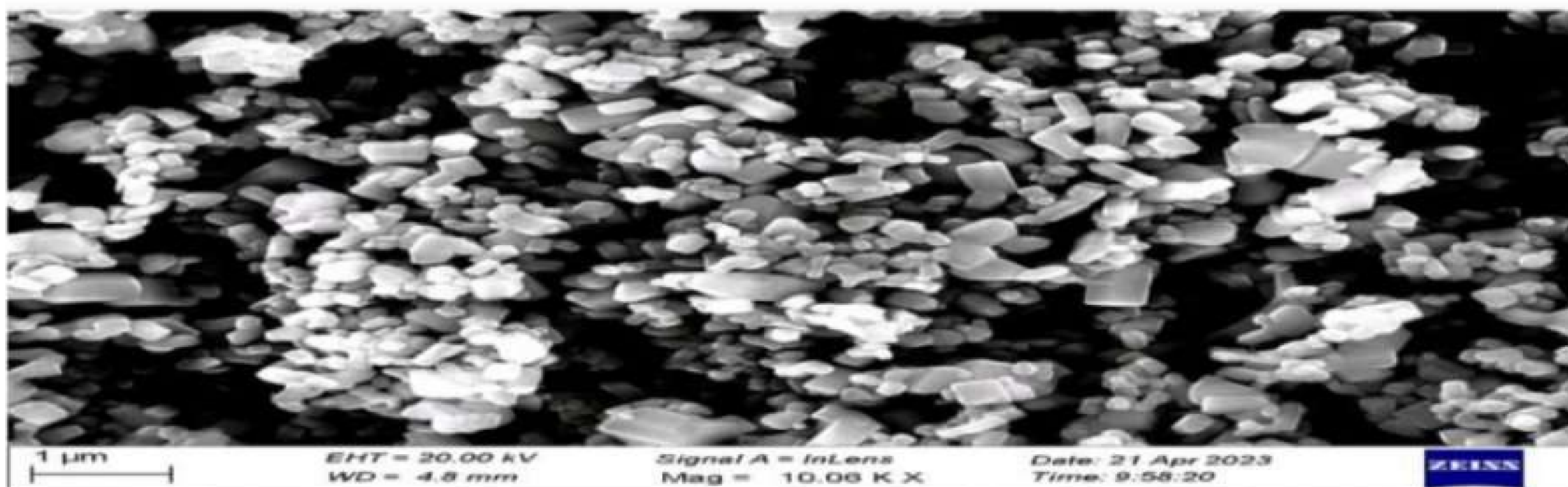


Fig.5.3 SEM Image under 10.05 KX magnification

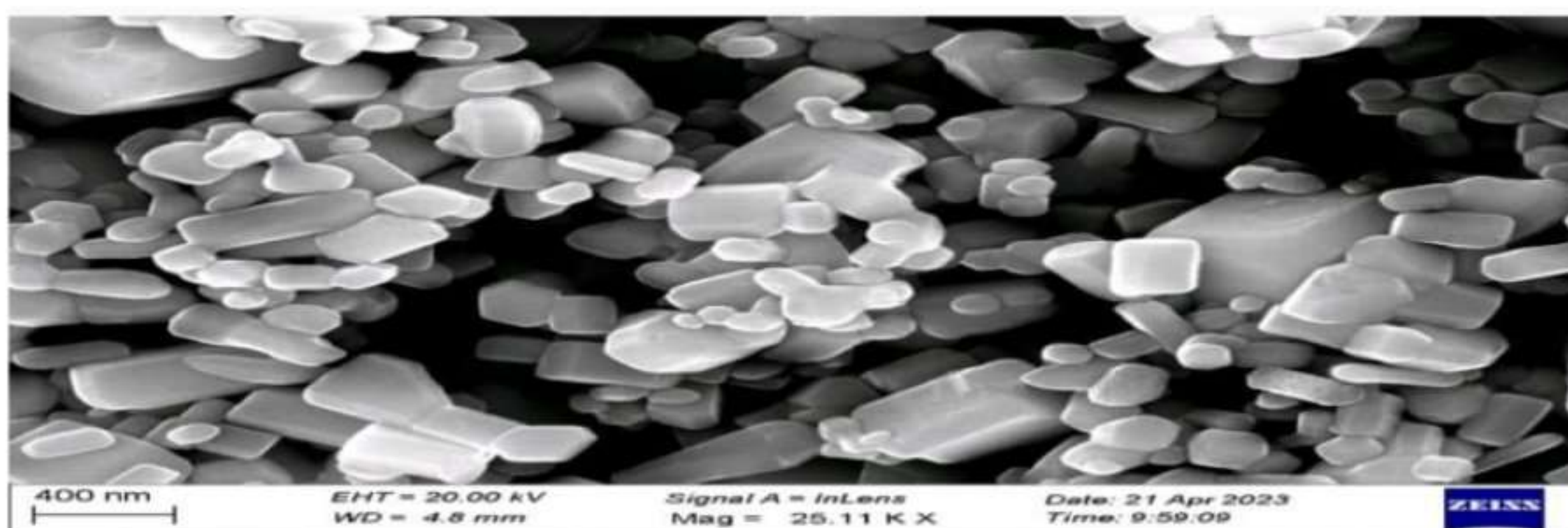


Fig.5.4 SEM Image under 25.11 KX magnification

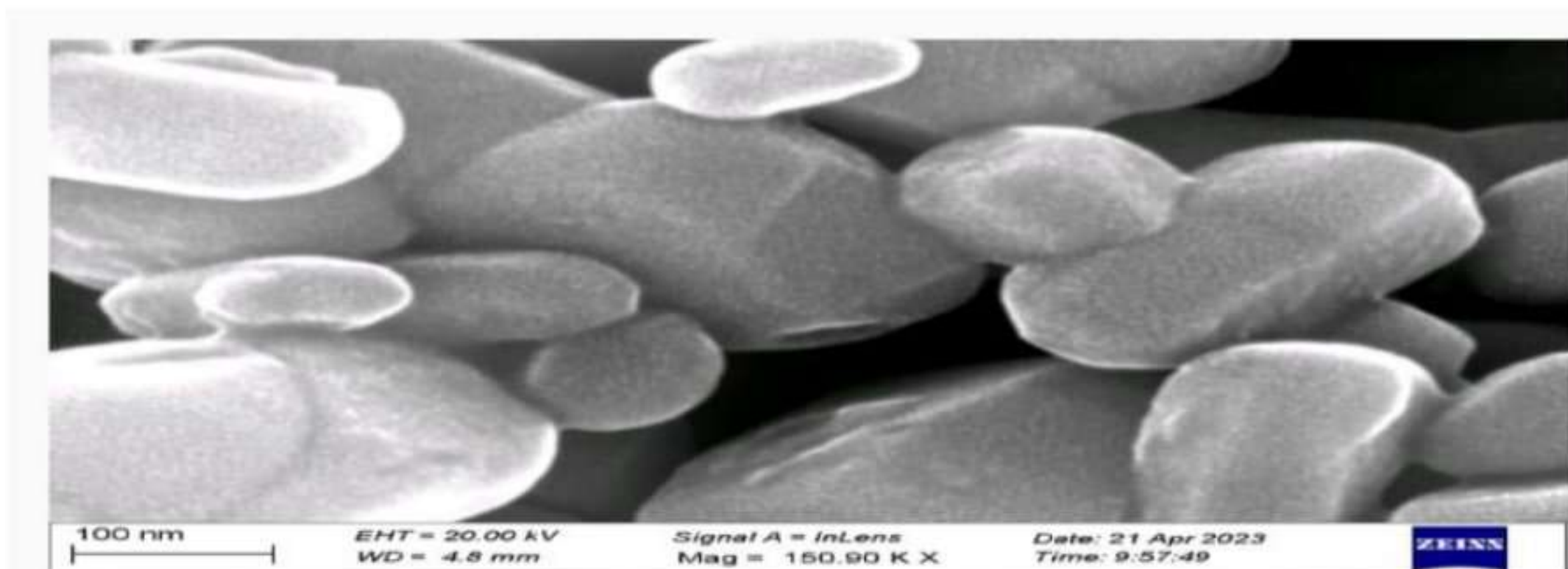


Fig.5.5 SEM Image under 150.90 KX magnification

HRTEM RESULTS

Black color blemishes show the presence of CQDs in the below image.

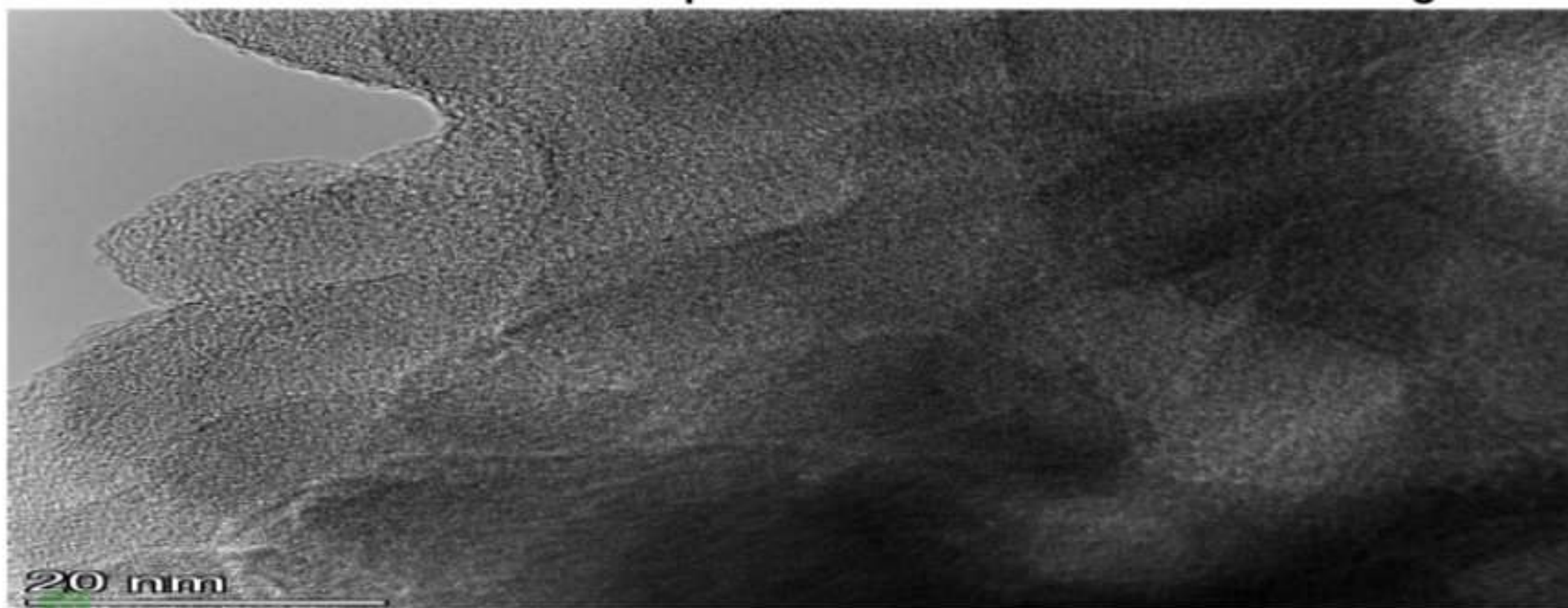


Fig: 5.6 TEM Image of the sample at 20nm shows the CQDs presence

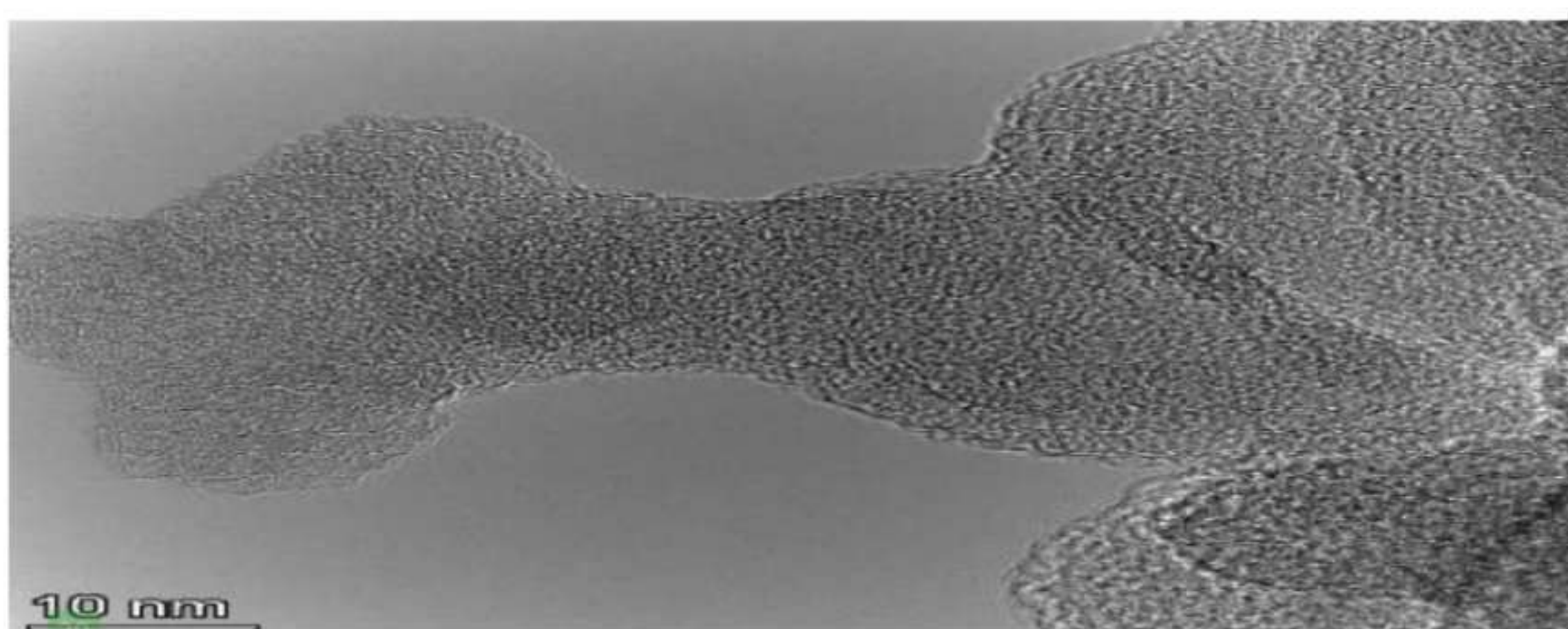


Fig: 5.7 TEM Image of the sample at 10nm shows the CQDs presence

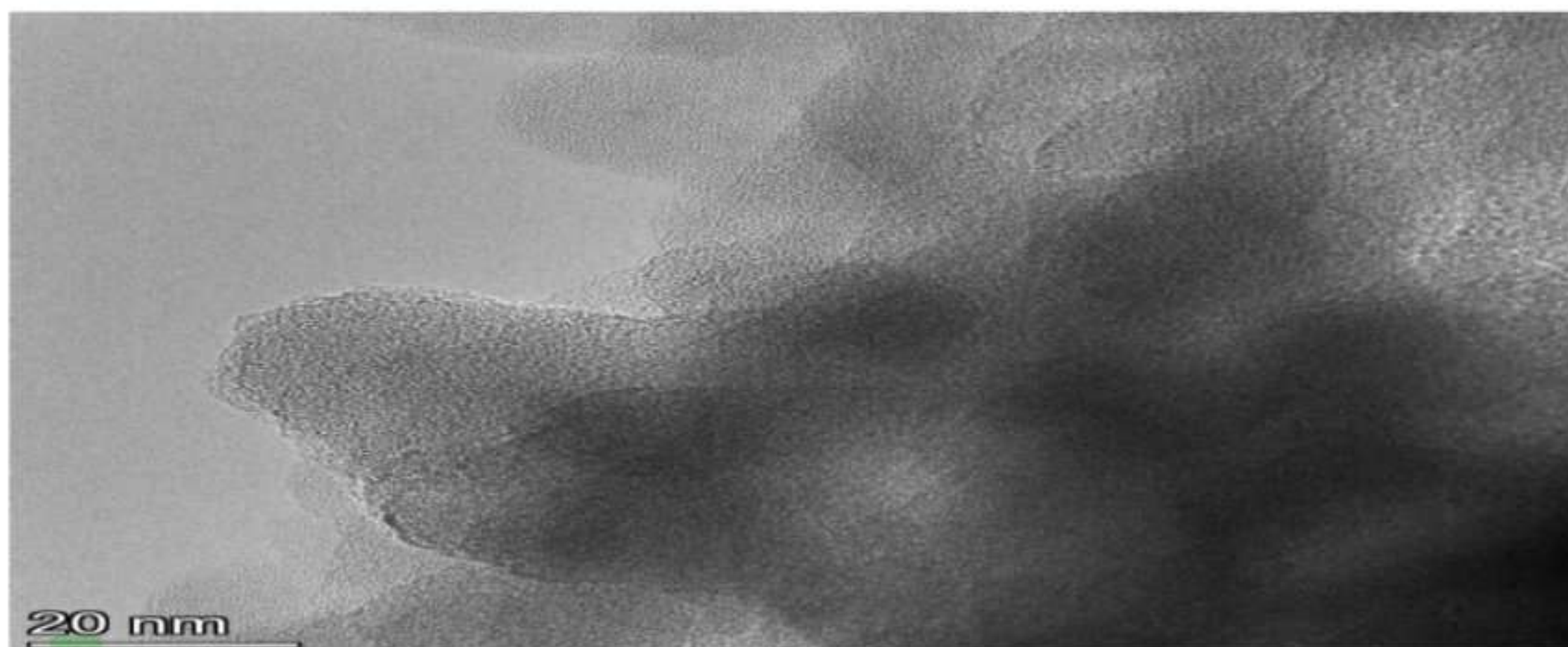


Fig: 5.8 TEM Image of the sample at 20nm shows the CQDs presence

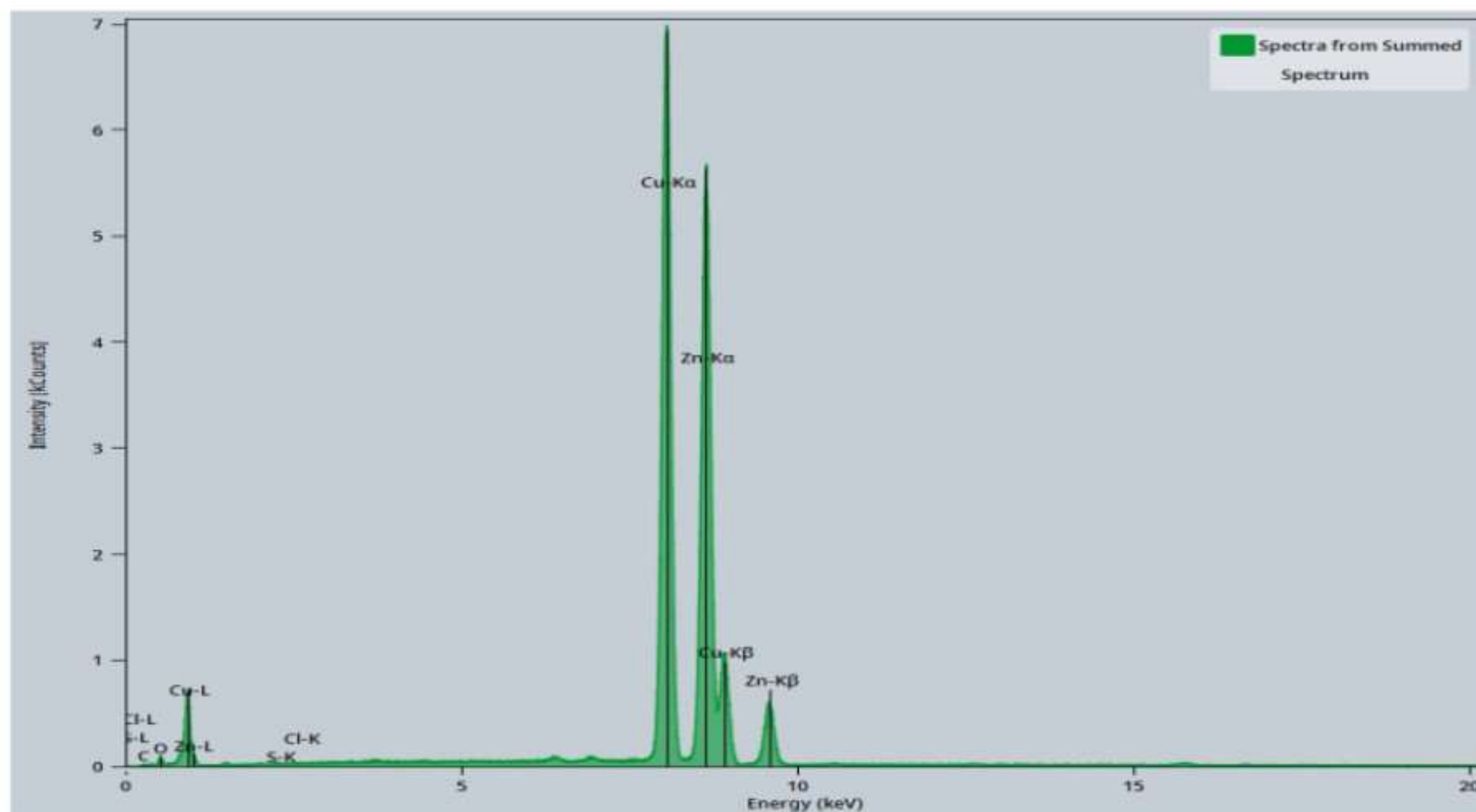


Fig: 5.9. EDAX peaks of Cu, Zn, S, Cl, C.

The presence of copper (Cu), zinc (Zn), chlorine (Cl), oxygen (O), and sulfur (S) at different peaks in an EDAX analysis of carbon quantum dots (CQDs) synthesized from mushroom precursors can be attributed to various factors:

5.2 COMPARISON WITH PREVIOUS STUDIES.

²⁴ Carbon quantum dots (CQDs) are a class of carbon-based nanomaterials that have garnered much attention in recent years due to their unique optical and electronic properties. The differences are mostly with the dealing of availing the CQDs more in number since we are following the most efforting way of synthesizing CQDs by the hydrothermal process it can be achieved

It maximizes the biological response of the CQDs in the process of adding the H₂SO₄ and ZnO in the mixture heating it at optimized temperatures gives the spectroscopic results more accurately because it will not kill the size and shape of

CQDs. Compared to other synthesis of CQDs in other ways maybe not this much positive in terms of size and shape and sensitive to electric potential.

Overall, previous studies have demonstrated the potential of mushrooms as a promising source for the synthesis of CQDs with various properties and applications. However, further research is needed to optimize the synthesis conditions and explore the full range of their potential applications.

5.3 ANALYSIS OF RESULTS.

Firstly, the studies have demonstrated the potential of mushroom-derived CQDs as an alternative to traditional synthetic CQDs due to their low toxicity and biocompatibility. This makes them a promising option for applications in biomedicine and environmental monitoring. However, the studies have also shown that the synthesis and characterization of mushroom-derived CQDs can be challenging due to the variability of the mushroom species, the extraction method used, and the purification techniques employed.

Secondly, the studies have shown that the properties of CQDs can be optimized through varying the synthesis parameters, such as temperature, reaction time, and precursor concentration. For example, CQDs derived from mushrooms have been shown to exhibit strong fluorescence at an optimum temperature of 150 °C. Furthermore, surface modification of the CQDs can enhance their stability and solubility, making them more suitable for various applications.

5.4 DISCUSSION OF FINDINGS ON SYNTHESIZING CQDs.

CQDs, or carbon quantum dots, are nanoscale carbon-based materials that have attracted significant interest in recent years due to their unique optical and electronic properties. These materials have a wide range of potential applications, including in areas such as bioimaging, sensing, and energy conversion.

The researchers found that the CQDs extracted from the mushrooms had a number of interesting properties. For example, they were fluorescent, meaning that they could emit light when excited by certain wavelengths of light. This makes them potentially useful for bioimaging applications, as they could be used to visualize biological structures in living cells or tissues.

The CQDs also had good biocompatibility, meaning that they were not toxic to living cells. This is an important property for any material that is intended for use in biological systems.

The findings on CQDs from mushrooms are promising and suggest that these materials could be a valuable source of nanoscale carbon-based materials for a range of applications. Further research will be needed to fully understand the properties and potential applications of these materials, but the initial results are encouraging.

CHAPTER-6

CQDs IN SUPERCAPACITORS

6.1 PERFORMANCE ENHANCEMENTS ACHIEVED WITH CQDS

Carbon Quantum Dots (CQDs) have significantly elevated supercapacitor performance through key enhancements. Their high surface area facilitates greater energy storage by maximizing charge adsorption. This, combined with rapid charge discharge capabilities, boosts power density, enabling swift energy release. Moreover, CQDs' enhanced electrochemical stability contributes to prolonged cycle life, ensuring sustained performance over repeated use. The pseudo capacitance behavior exhibited by certain CQDs further amplifies capacitance. Additionally, CQDs' compatibility with eco-friendly design and their ability to reduce internal resistance offer a holistic approach to improving overall supercapacitor efficiency and effectiveness.

Performance enhancements achieved with Carbon Quantum Dots (CQDs) in supercapacitors include:

- 1. Improved Energy Storage:** CQDs' high surface area and unique properties enable enhanced charge adsorption, increasing energy storage capacity compared to conventional materials.
- 2. Enhanced Power Density:** CQDs' rapid charge discharge capabilities contribute to higher power density, enabling quick bursts of energy delivery.
- 3. Longer Cycle Life:** CQDs exhibit better electrochemical stability, leading to reduced electrode degradation and prolonged cycle life, ensuring sustained performance over multiple charge discharge cycles.

4. Pseudo capacitance Contribution: Some CQDs exhibit Pseudo capacitance behavior, adding reversible redox reactions to charge storage mechanisms, further boosting overall capacitance and performance.

5. Compatibility with Eco Friendly Design: CQDs, often derived from biomass sources, align with sustainability goals, offering a greener approach to energy storage technology.

6. Customizable Electrode Materials: can be combined with various electrode materials, allowing customization for specific applications and optimizing performance characteristics.

7. Reduced Internal Resistance: CQDs' efficient ion transport properties can reduce internal resistance, leading to improved charge discharge efficiency and overall device performance

6.2 ENERGY DENSITY AND POWER DENSITY LIMITATIONS

Energy Density Limitations in Supercapacitor Technology:

- Supercapacitors' energy density is limited by the physical separation of charges and electrode materials, resulting in lower energy storage capacity compared to batteries.
- Electrode materials with high surface area for charge adsorption are essential, but achieving high energy density without sacrificing power density remains challenging.
- Pseudocapacitive materials can enhance energy density, but tradeoffs between energy and power density persist due to material characteristics and electrode design.

Power Density Limitations in Supercapacitor Technology

Supercapacitors offer high power density due to rapid charge discharge cycles, but their power density is still lower than conventional capacitors.

- The need for thick electrode layers for energy storage can restrict ion diffusion, limiting the device's ability to provide rapid bursts of power.
- Achieving high power density while maintaining electrode stability and preventing electrical breakdown requires advanced electrode materials and precise engineering of device components.

CQDs can store charge through various mechanisms, including double layer capacitance and Pseudo capacitance. In the case of double layer capacitance, charges accumulate at the interface between the CQDs and the electrolyte, relying on the electrostatic interaction. Pseudo capacitance involves redox reactions at the CQD surface, contributing to additional charge storage capacity. Many CQDs exhibit redox properties, allowing them to undergo reversible electron transfer reactions. This redox activity is often associated with the presence of specific surface functional groups on the CQDs, enabling them to participate in electrochemical processes and contribute to the overall capacitance of the system.

The electrochemical behaviour of CQDs is influenced by the accessibility of ions to the CQD surface. A high surface area and porous structure of CQDs facilitate efficient ion diffusion and adsorption/desorption processes, leading to improved charge storage performance. The kinetics of electron transfer at the CQD electrolyte interface play a crucial role in determining the charge discharge rates of supercapacitors. Fast and efficient electron transfer is desirable for achieving high power density. CQDs can enhance the electron transfer kinetics, contributing to the supercapacitor's overall performance.

The electrochemical behaviour of CQDs can be pH sensitive. Changes in the pH of the electrolyte may affect the surface charge and chemical state of CQDs, influencing

their electrochemical properties. This pH sensitivity can be harnessed for specific applications or tailored through surface modifications. The electrochemical stability of CQDs is crucial for the long-term performance of energy storage devices. CQDs need to withstand repeated charge discharge cycles without significant degradation. Understanding and improving the electrochemical stability of CQDs are essential for the practical application of these materials.

6.3 ELECTROCHEMICAL PERFORMANCE OF CQDs

Cyclic voltammetry (CV) is a common electrochemical technique used to study the redox properties and electrochemical behaviour of materials, including quantum dots (QDs) derived from mushrooms. Here's an outline of how CV can be applied to study the electrochemical performance of carbon quantum dots (CQDs) from mushrooms:

1. Preparation of Electrochemical Setup:

Prepare a three-electrode electrochemical cell comprising a working electrode (e.g., glassy carbon electrode), a reference electrode (e.g., Ag/AgCl electrode), and a counter electrode (e.g., platinum wire). Ensure the proper connection of electrodes to the potentiostat for controlled potential measurements.

2. Preparation of CQD Suspension:

Disperse the CQDs derived from mushrooms in a suitable electrolyte solution or solvent (e.g., phosphate-buffered saline, PBS, or a non-aqueous solvent like acetonitrile). Sonicate the CQD suspension to ensure uniform dispersion and minimize aggregation.

3. Baseline Measurement:

Perform a baseline CV scan in the absence of CQDs to record the electrochemical behaviour of the solvent or electrolyte solution. This provides a reference for subsequent measurements with CQDs.

4. Cyclic Voltammetry with CQDs:

Apply cyclic voltammetry to the CQD suspension by sweeping the potential between appropriate limits (typically -1.0 V to 1.0 V vs. reference electrode) at a suitable scan rate (e.g., 50 mV/s). Record the current response as a function of the applied potential. Repeat the CV measurements at different CQD concentrations or under varying experimental conditions to explore the effects of CQD concentration, scan rate, pH, and temperature on the electrochemical behaviour.

5. Data Analysis:

Analyse the CV curves obtained from the CQD suspension to identify redox peaks corresponding to the oxidation or reduction of CQDs. Determine the peak potentials, peak currents, and peak shapes to extract information about the electrochemical activity and kinetics of CQDs. Calculate parameters such as the anodic/cathodic peak potential separation, peak current density, and peak area to quantify the electrochemical performance of CQDs.

6. Interpretation and Discussion:

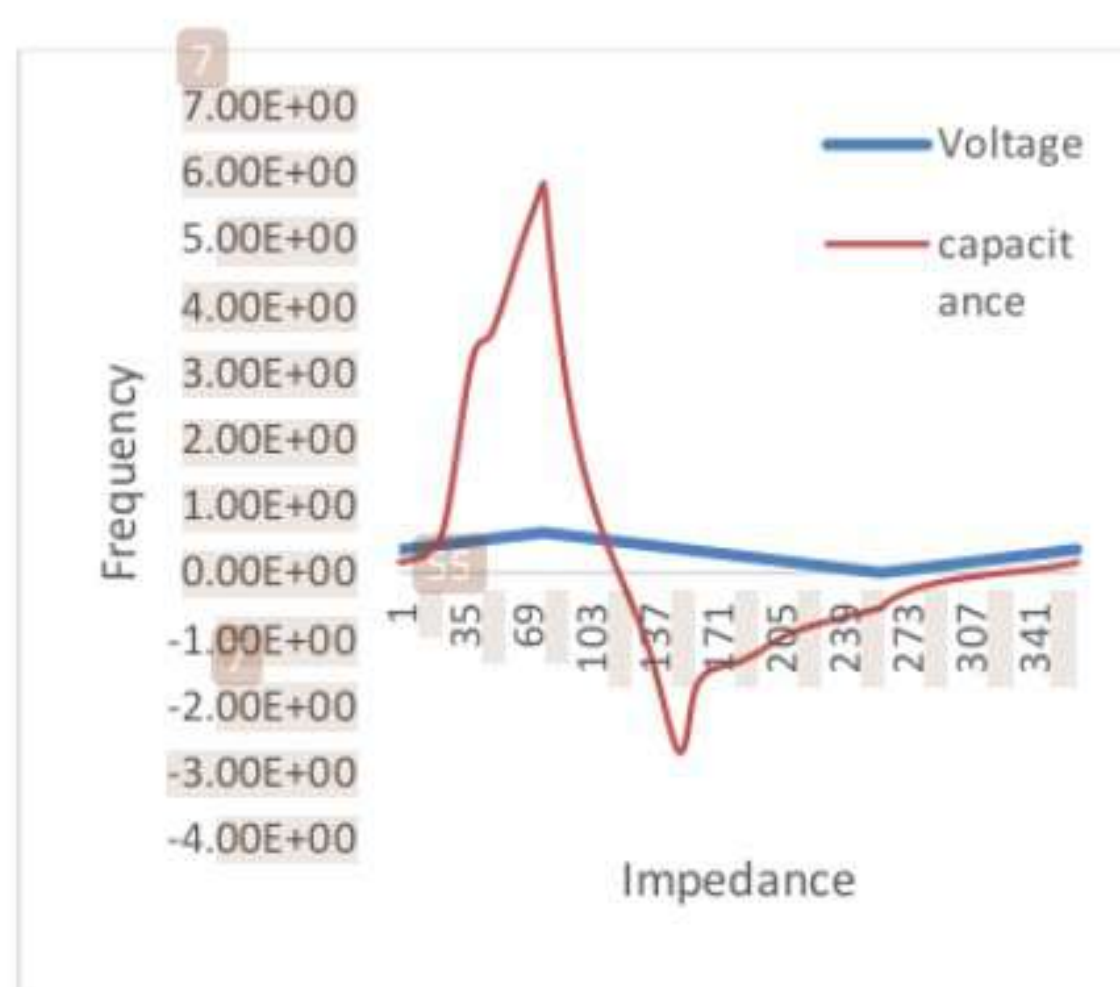
Interpret the CV results in the context of the electrochemical properties of CQDs, such as their electron transfer mechanisms, electrochemical stability, and redox chemistry. Discuss the implications of the observed electrochemical behaviour for potential applications of CQDs in energy storage, catalysis, sensing, or other electrochemical devices.

7. Comparison and Validation:

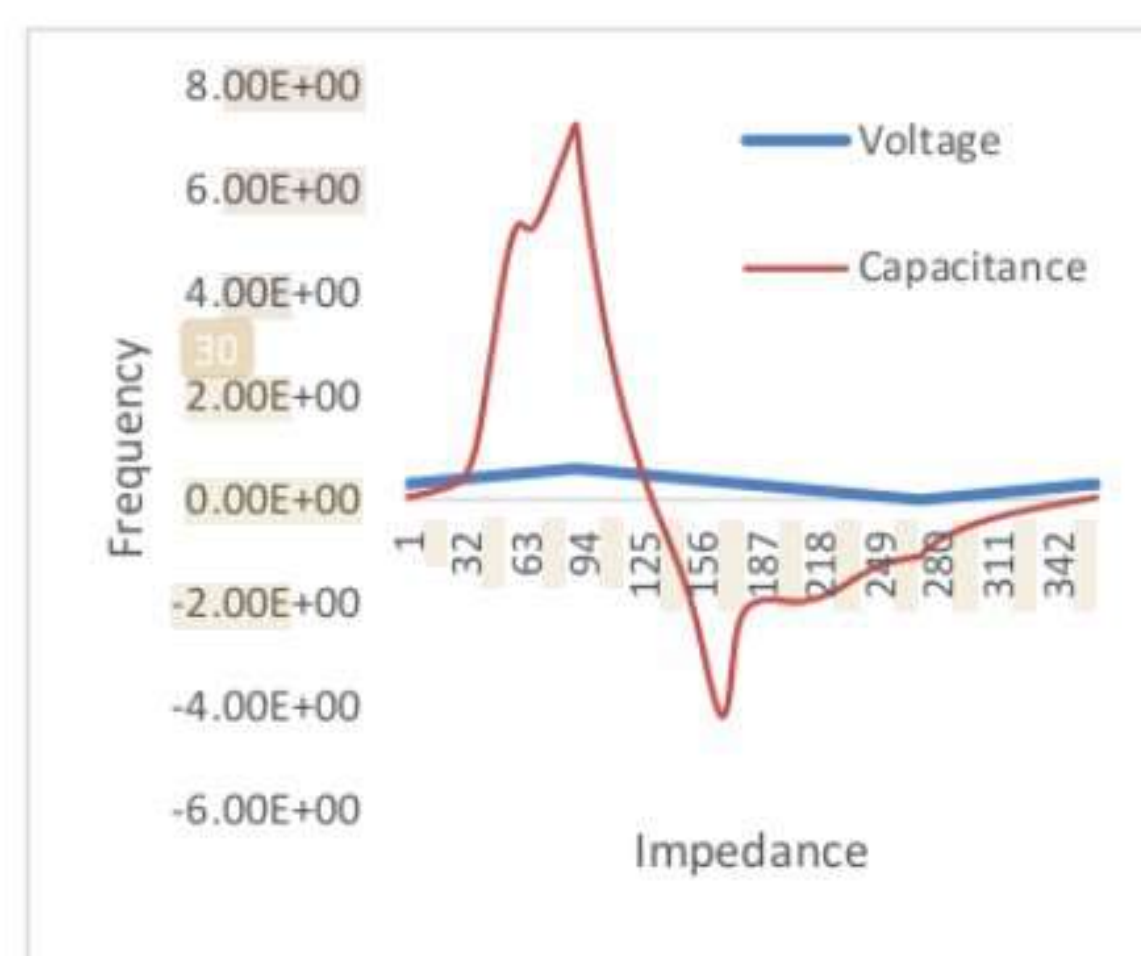
Compare the CV results obtained for CQDs from mushrooms with those of other carbon-based materials or QDs synthesized using different methods to validate the uniqueness and advantages of mushroom-derived CQDs.

By conducting cyclic voltammetry of CQDs from mushrooms and analysing the resulting electrochemical data, researchers can gain insights into the redox properties and electrochemical performance of these materials, contributing to their further development and applications.

CYCLIC VOLTAMMETRY



**Fig: 6.1 cyclic voltammetry
5 mV s⁻¹ 0.06V**



**Fig: 6.2 cyclic voltammetry
10 mV s⁻¹ 0.06V**

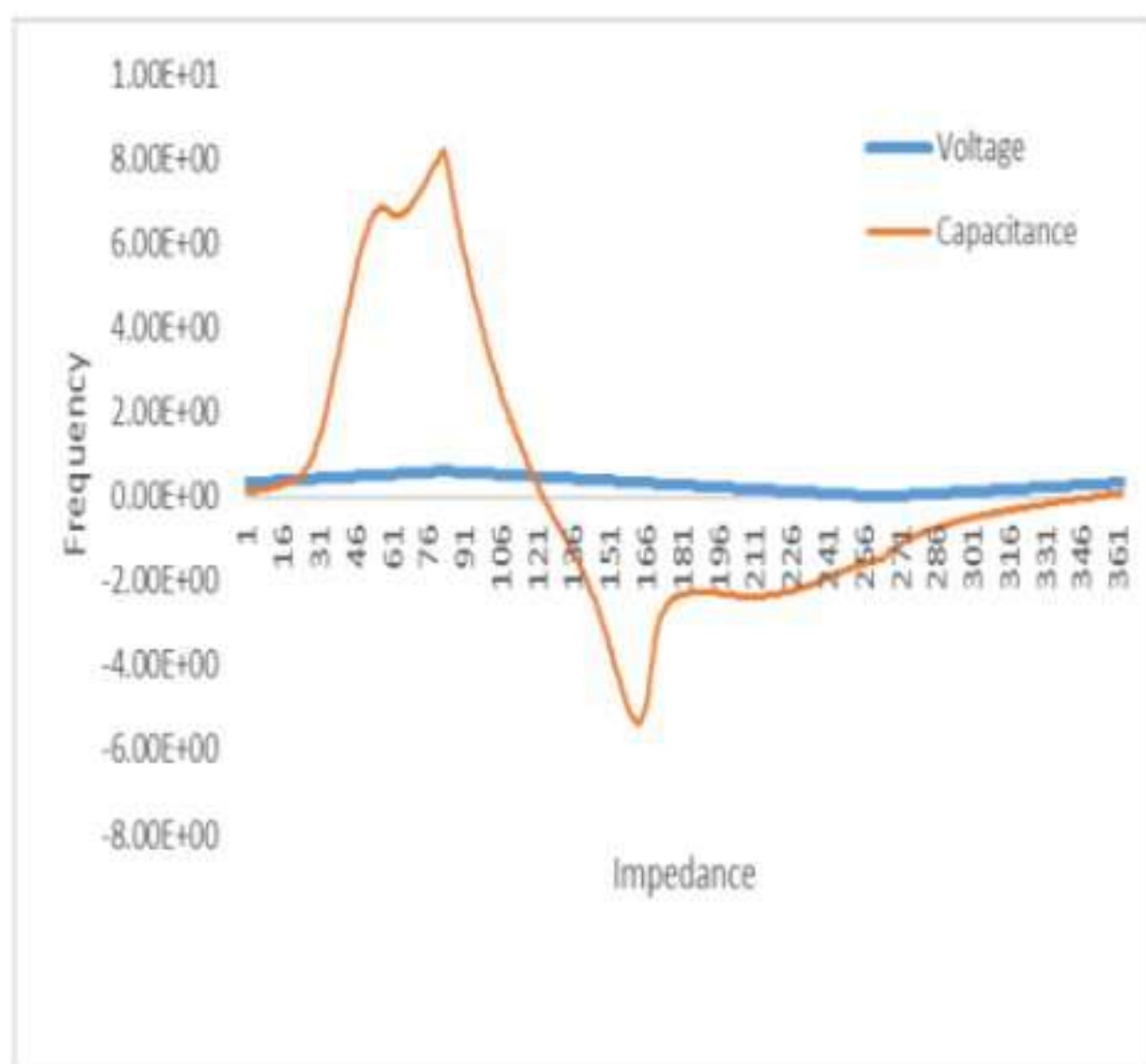


Fig: 6.3 cyclic voltammetry
15 mV s 0 06V

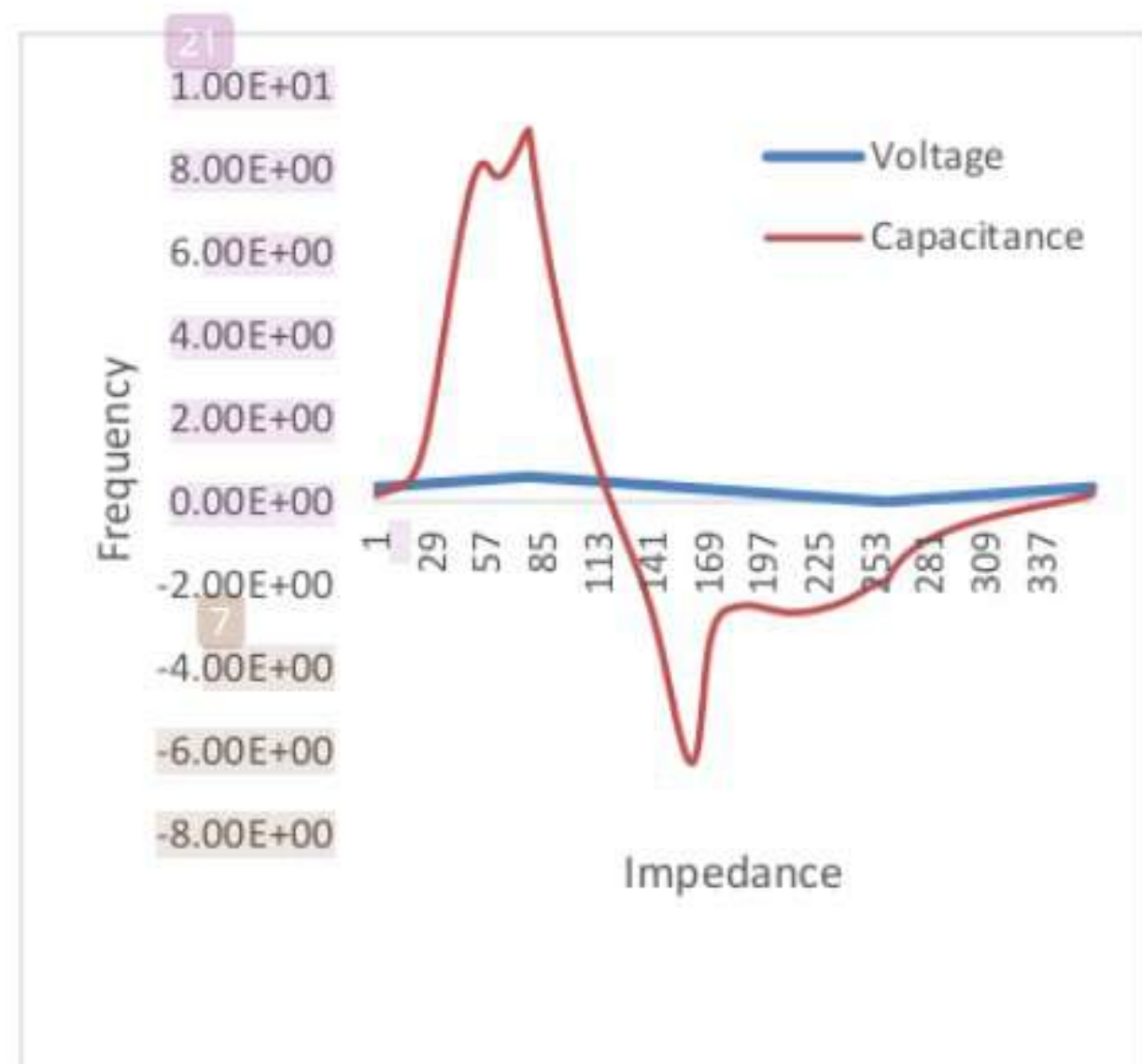


Fig: 6.4 cyclic voltammetry
20 mV s 0 06V

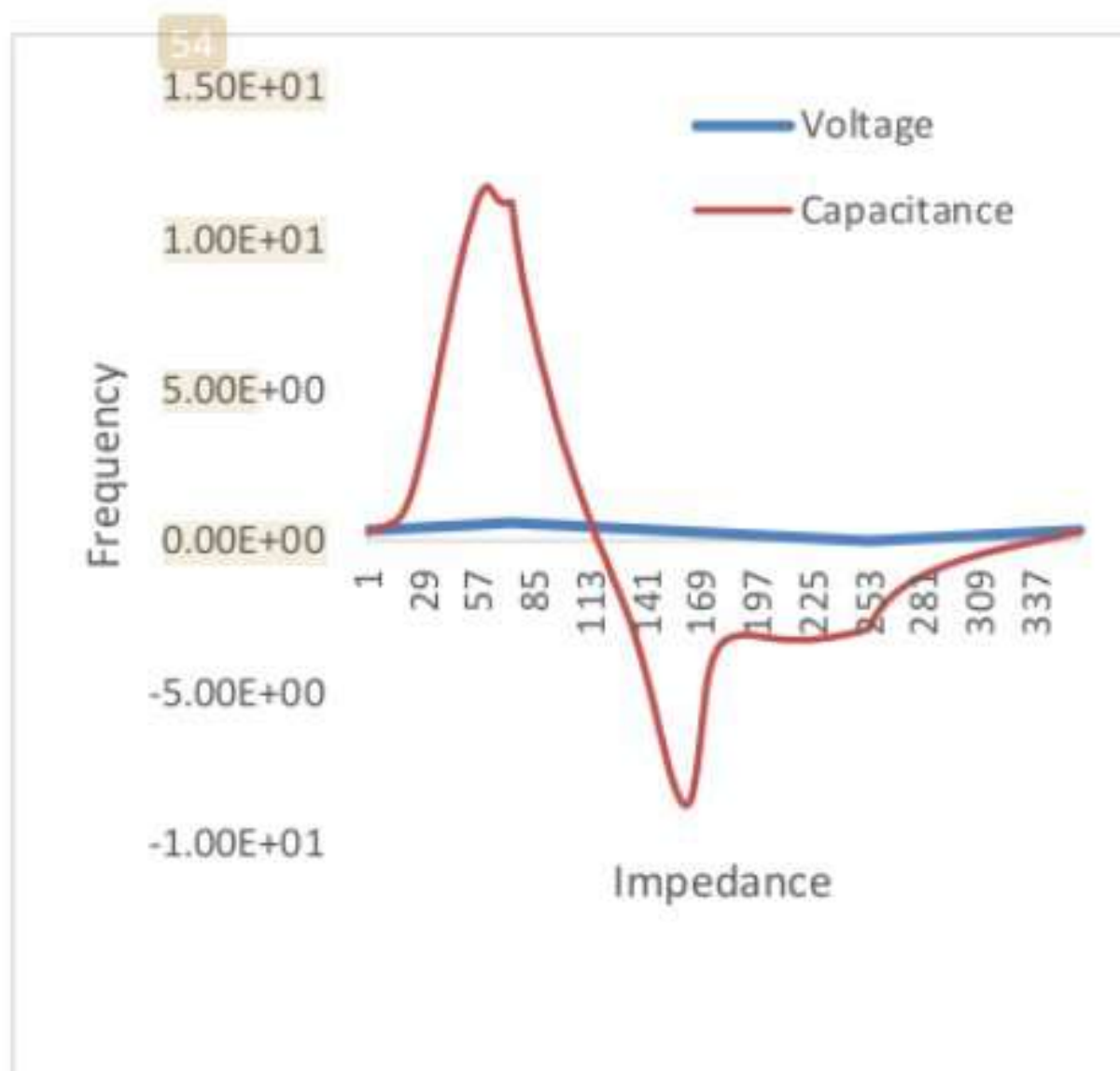


Fig: 6.5 cyclic voltammetry
40 mV s 0 06V

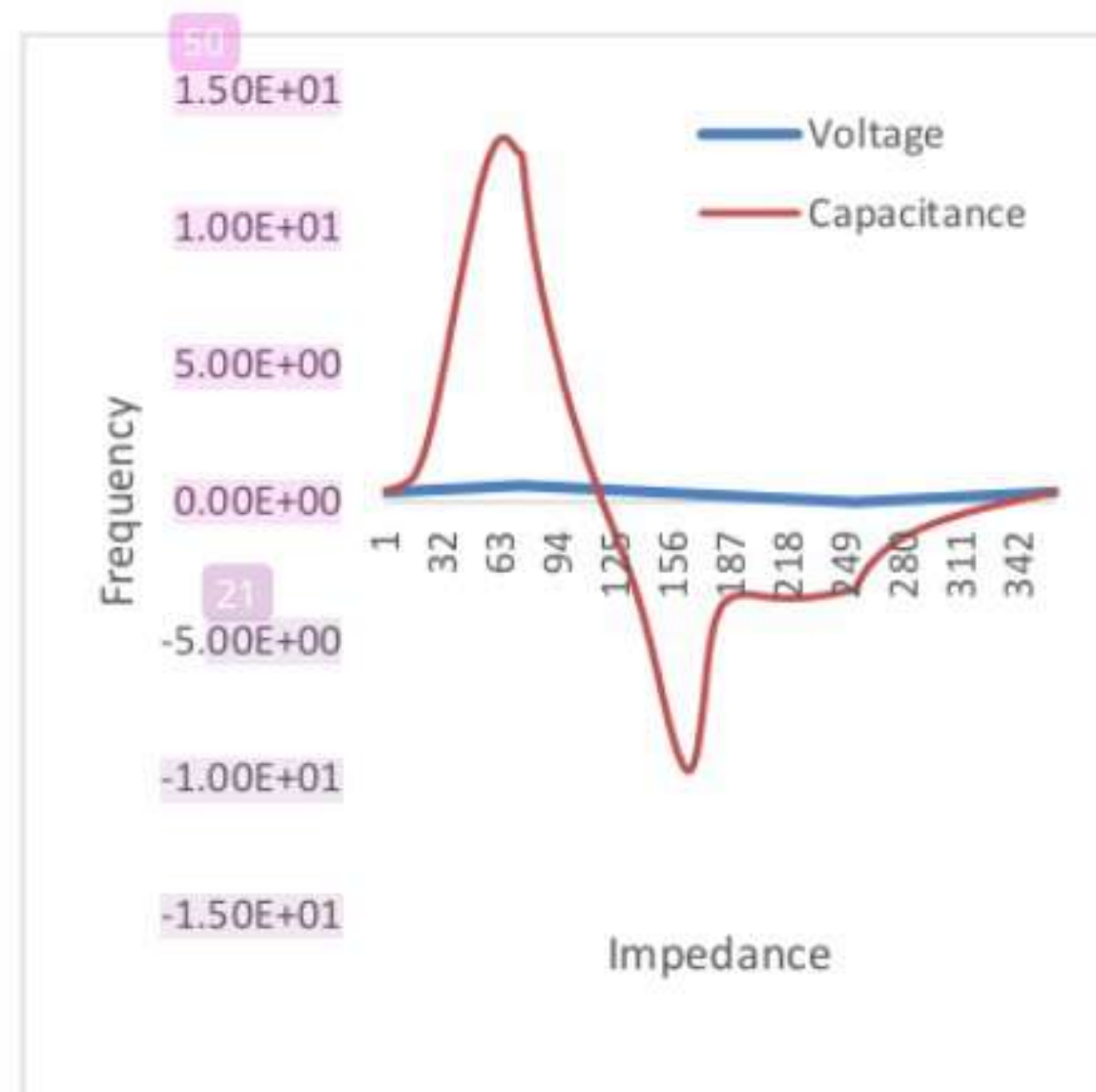


Fig: 6.6 cyclic voltammetry
50 mV s 0 06V

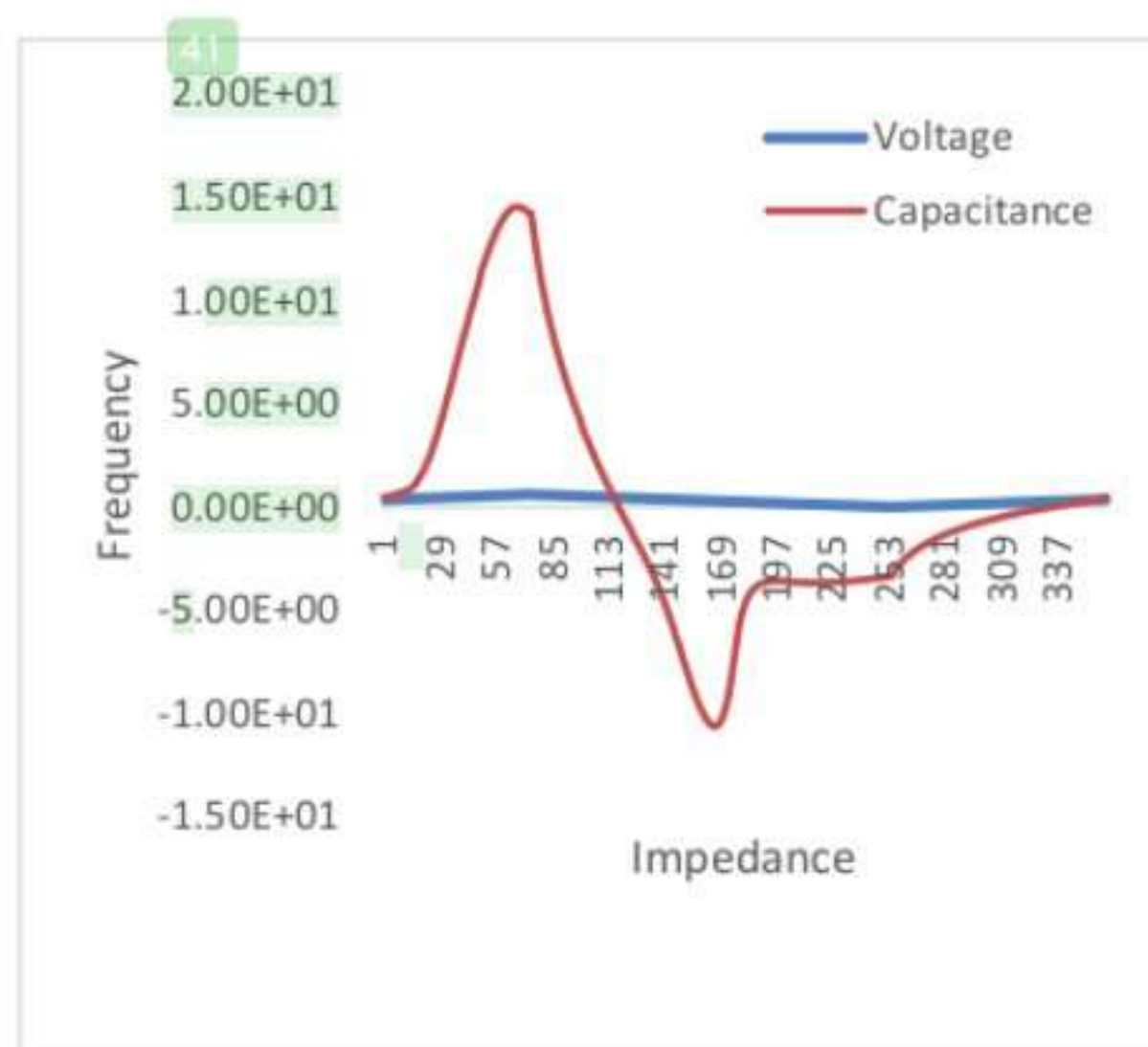


Fig: 6.7 cyclic voltammetry 60 mV s⁻¹ 0.06V

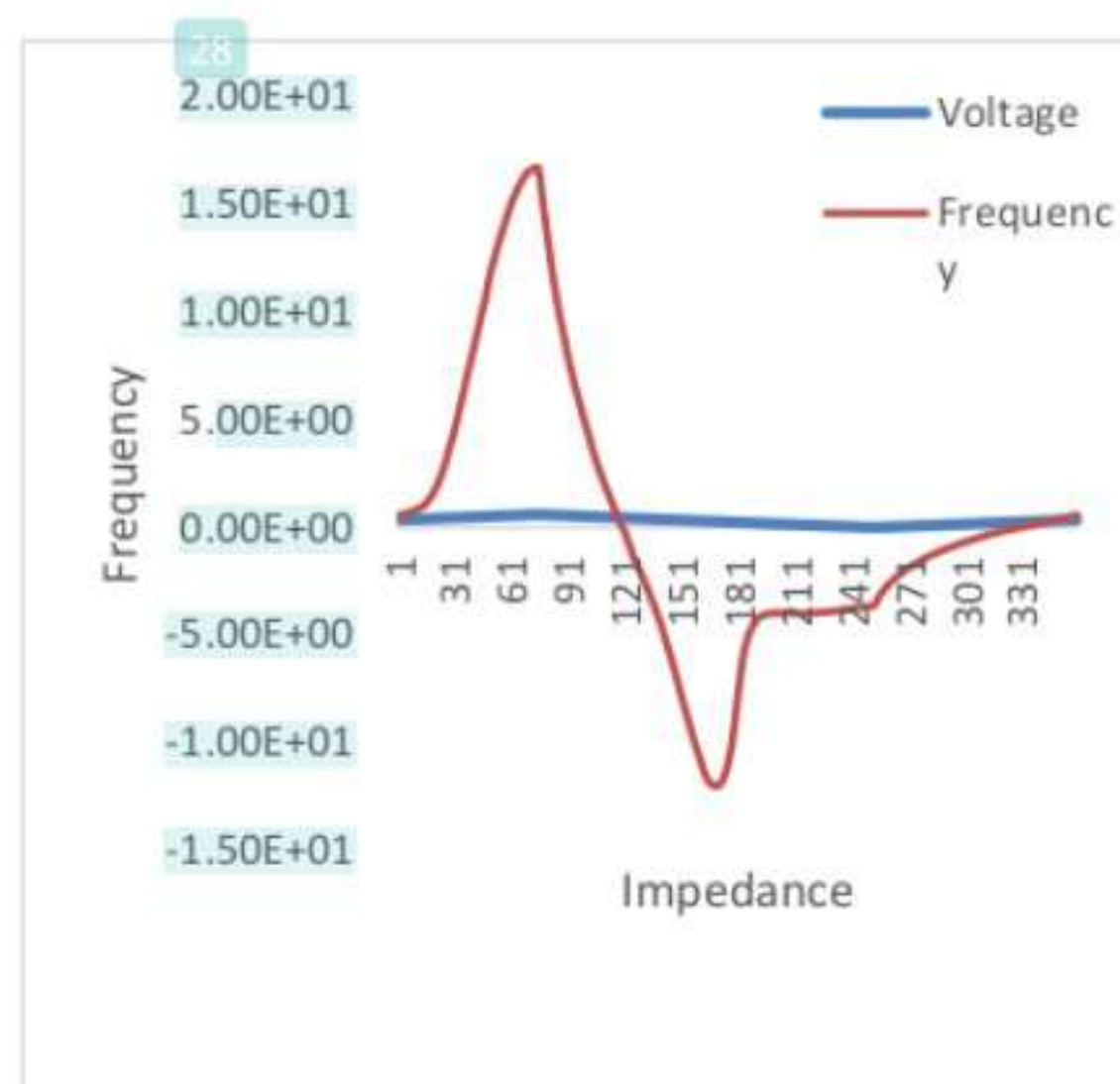


Fig: 6.8 cyclic voltammetry 80 mV s⁻¹ 0.06V

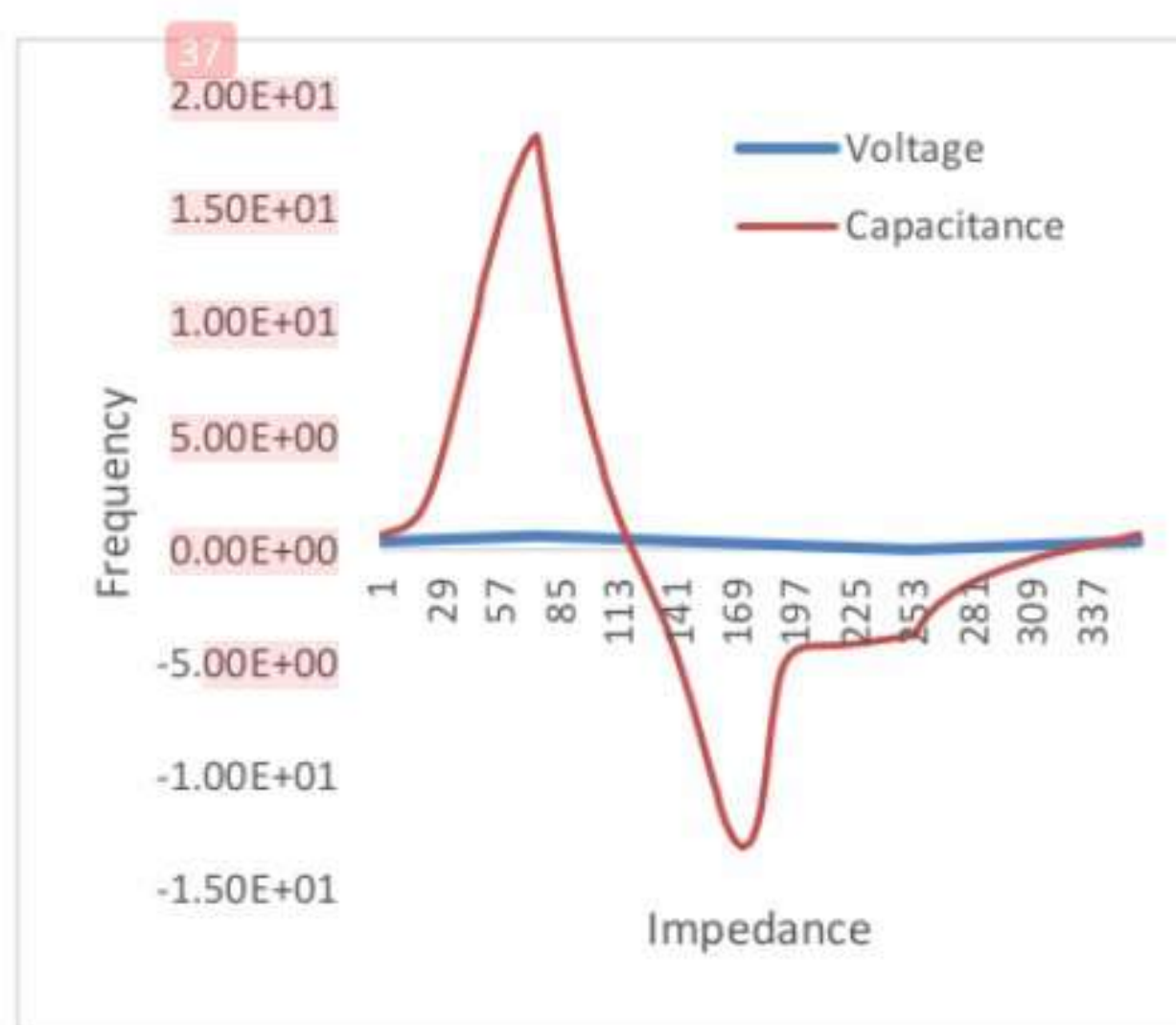


Fig: 6.9 cyclic voltammetry 100 mV s⁻¹ 0.06V

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY (EIS)

Electrochemical impedance spectroscopy (EIS) is a powerful technique used to analyze the electrical properties of materials and interfaces in electrochemical systems. When applied to carbon quantum dots (CQDs) derived from mushrooms, EIS can provide valuable information about their charge transfer kinetics, surface properties, and electrochemical behavior. Here's how EIS can be utilized to study CQDs from mushrooms:

1. Experimental Setup:

10

Set up an EIS system comprising a potentiostat, a three-electrode electrochemical cell (similar to the setup used for cyclic voltammetry), and appropriate software for data acquisition and analysis. The working electrode can be a conductive substrate coated with CQDs or a CQD-modified electrode, while the counter and reference electrodes remain the same as in cyclic voltammetry.

2. Sample Preparation:

Prepare the CQD suspension or electrode surface by depositing a layer of CQDs derived from mushrooms onto the working electrode. Ensure uniform coverage and good adhesion of CQDs to the electrode surface. Optionally, perform surface functionalization or modification of CQDs to tailor their electrochemical properties or enhance their stability.

3. EIS Measurement:

Apply a small sinusoidal perturbation potential (typically a few millivolts) to the working electrode over a range of frequencies (typically from millihertz to megahertz). Measure the resulting impedance response, which includes both the real (resistive) and imaginary (capacitive) components of impedance, as a function of frequency. Record the impedance spectra, which typically consist of Nyquist plots (plots of imaginary impedance vs. real impedance) and Bode plots (plots of impedance magnitude and phase angle vs. frequency).

4. Data Analysis:

Analyze the EIS data to extract parameters such as charge transfer resistance (R_{ct}), double-layer capacitance (C_{dl}), and Warburg impedance (Z_w), which provide insights into the electrochemical kinetics and processes occurring at the CQD-electrolyte interface. Fit the experimental impedance spectra to appropriate equivalent circuit models, such as the Randles circuit or modified Randles circuit, to quantitatively interpret the observed impedance behavior and extract relevant electrochemical parameters. Compare the impedance spectra obtained for CQDs from mushrooms under different conditions (e.g., varying concentration, surface functionalization) to evaluate the effects of these factors on their electrochemical performance.

5. Interpretation and Discussion:

Interpret the EIS results in the context of the electrochemical properties and behavior of CQDs, including their charge storage capacity, electron transfer kinetics, and interfacial interactions with the electrolyte. Discuss the implications of the observed impedance behavior for the performance of CQDs in various electrochemical applications, such as energy storage devices, sensors, and electrocatalysts.

6. Validation and Further Studies:

Validate the findings from EIS measurements through complementary techniques, such as cyclic voltammetry, X-ray photoelectron spectroscopy, or transmission electron microscopy. Conduct additional studies to explore the effect of external factors (e.g., temperature, pH, solvent composition) on the electrochemical behavior of CQDs from mushrooms and optimize their performance for specific applications.

By performing electrochemical impedance spectroscopy on CQDs derived from mushrooms and analyzing the resulting impedance data, researchers can gain valuable insights into their electrochemical properties and behavior, facilitating their further development and application in diverse fields.

Galvanostatic charge-discharge (GCD) measurements are another important electrochemical technique used to characterize the energy storage properties of materials, including carbon quantum dots (CQDs) derived from mushrooms. Here's how GCD can be applied to study CQDs:

1. Experimental Setup:

Prepare a three-electrode electrochemical cell with a working electrode (e.g., glassy carbon electrode coated with CQDs), a counter electrode (e.g., platinum wire), and a reference electrode (e.g., Ag/AgCl electrode). Connect the electrodes to a potentiostat capable of delivering constant current for charge-discharge measurements.

2. Sample Preparation:

Prepare the CQD-coated working electrode by depositing a uniform layer of CQDs onto the substrate surface. Ensure good adhesion and electrical contact between the CQDs and the electrode surface.

3. Charge-Discharge Measurement:

Start the experiment by applying a constant current to the working electrode for the charge process. The current density can be chosen based on the specific application or desired charge/discharge rate. Monitor the potential across the working electrode as a function of time during the charge process. Once the desired charge capacity is reached, switch the current direction to discharge the electrode. Record the discharge curve, which shows the variation of potential with time as the electrode releases stored charge.

4. Data Analysis:

Analyze the charge-discharge curves to extract important parameters such as specific capacitance, energy density, power density, and cycling stability.

5. Interpretation and Discussion:

Interpret the GCD results in terms of the energy storage performance of CQDs derived from mushrooms.

Discuss the factors influencing the charge storage mechanism, such as the surface area, pore structure, and conductivity of CQDs, as well as the electrolyte composition and electrode morphology. Compare the GCD results obtained for CQDs under different experimental conditions (e.g., electrolyte composition, electrode configuration) to evaluate their performance and identify optimization strategies.

6. Validation and Further Studies:

Validate the GCD results through complementary electrochemical techniques, such as cyclic voltammetry and electrochemical impedance spectroscopy. Conduct further studies to explore the effect of parameters like temperature, electrolyte concentration, and cycling stability on the charge-discharge behavior of CQDs and optimize their performance for specific energy storage applications.

EIS AFTER GCD

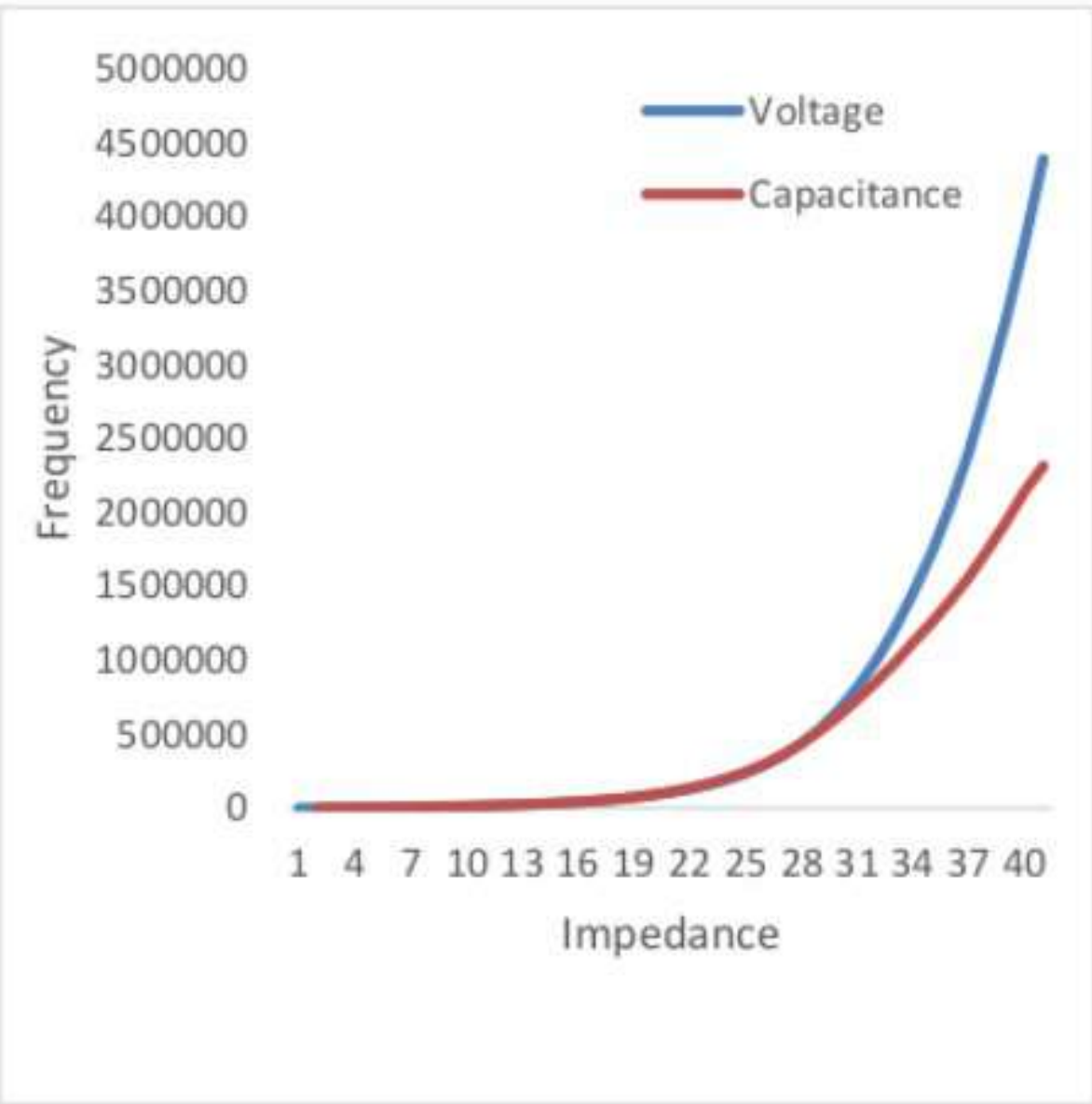


Fig: 6.10 EIS AFTER GCD 100 TO 0 01 PLOT 1

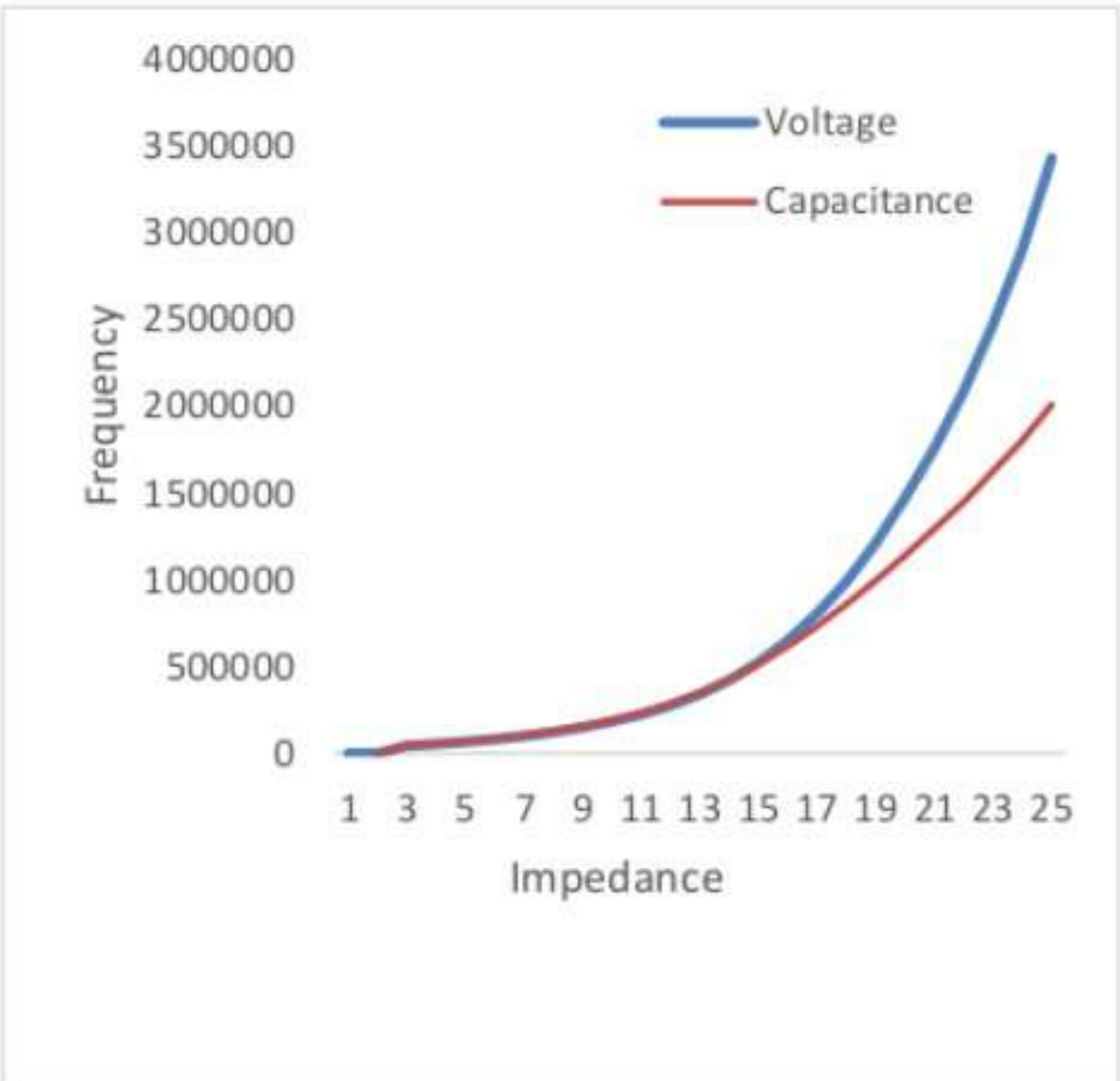
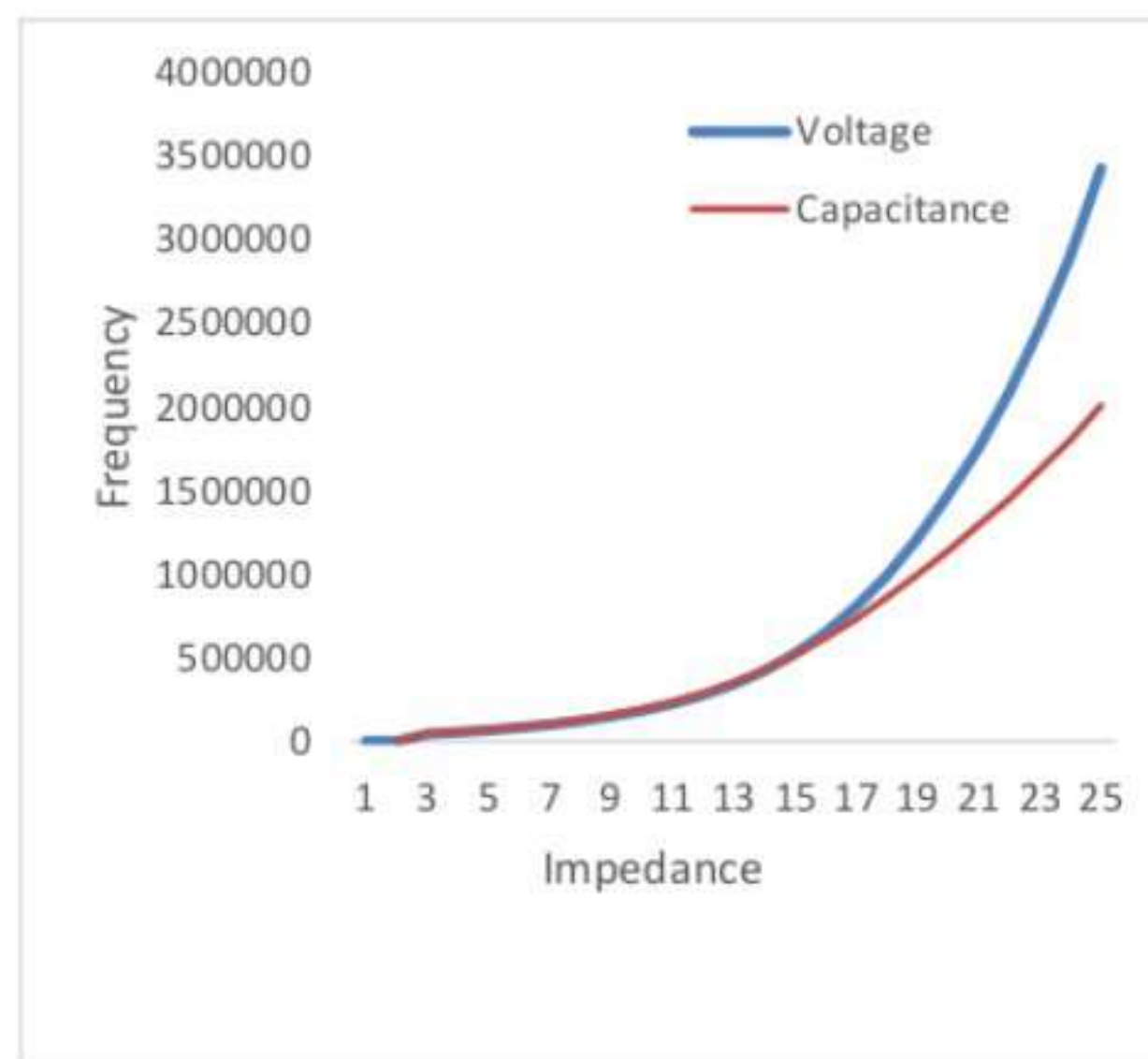
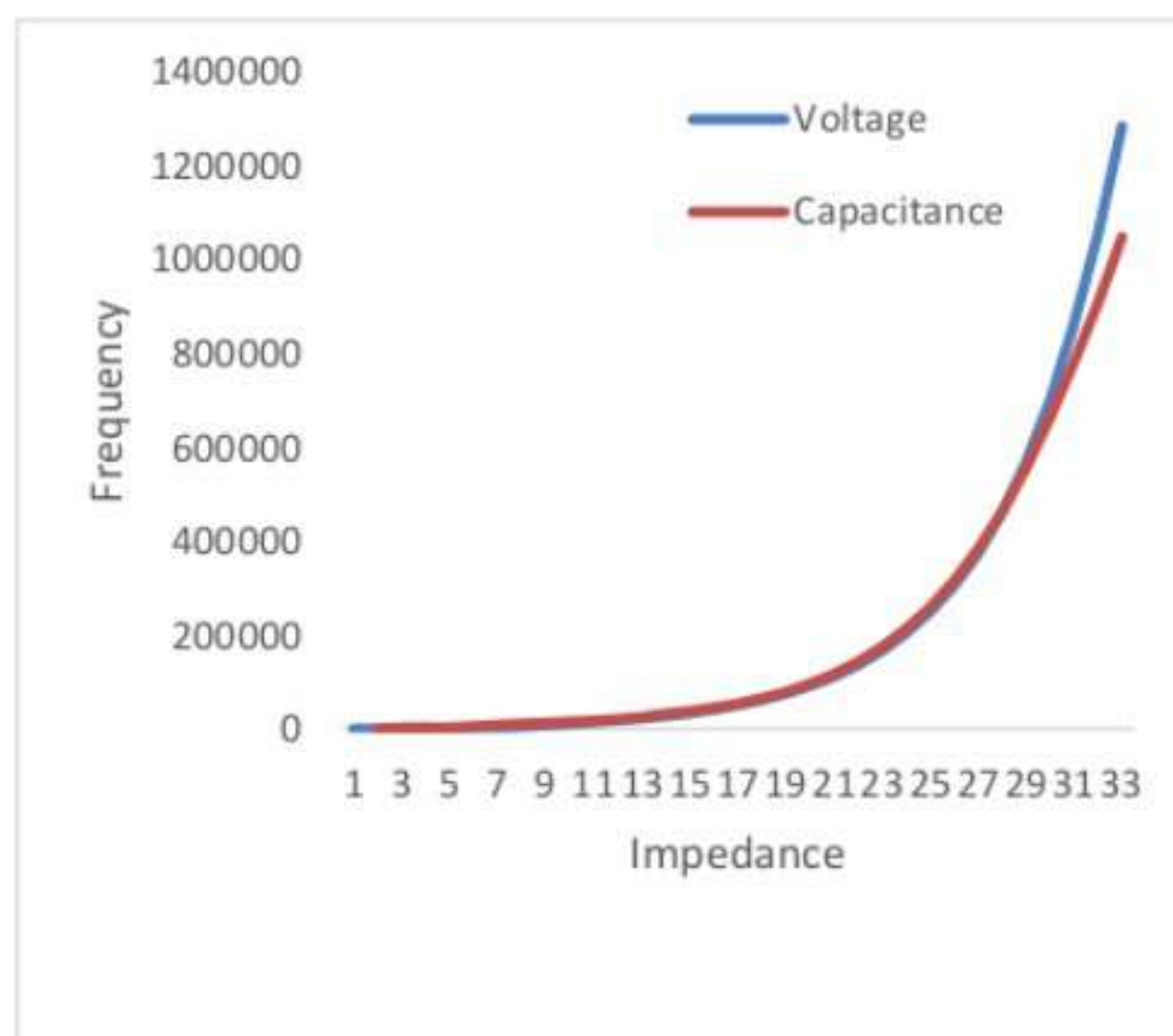


Fig: 6.11 EIS AFTER GCD 100 TO 0 01 PLOT 2

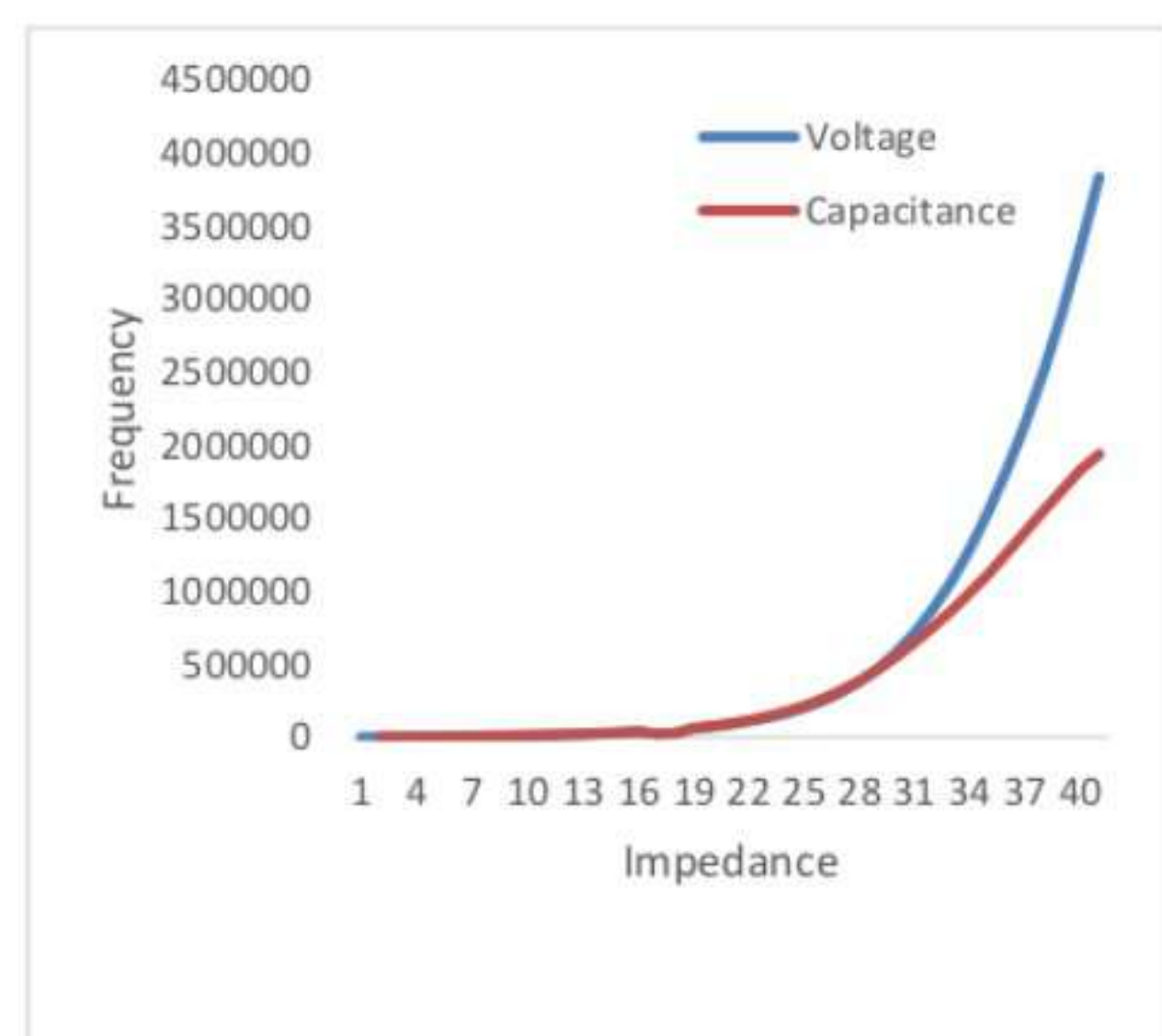


**Fig: 6.12 EIS AFTER GCD 100 TO 0 01
PLOT 3**

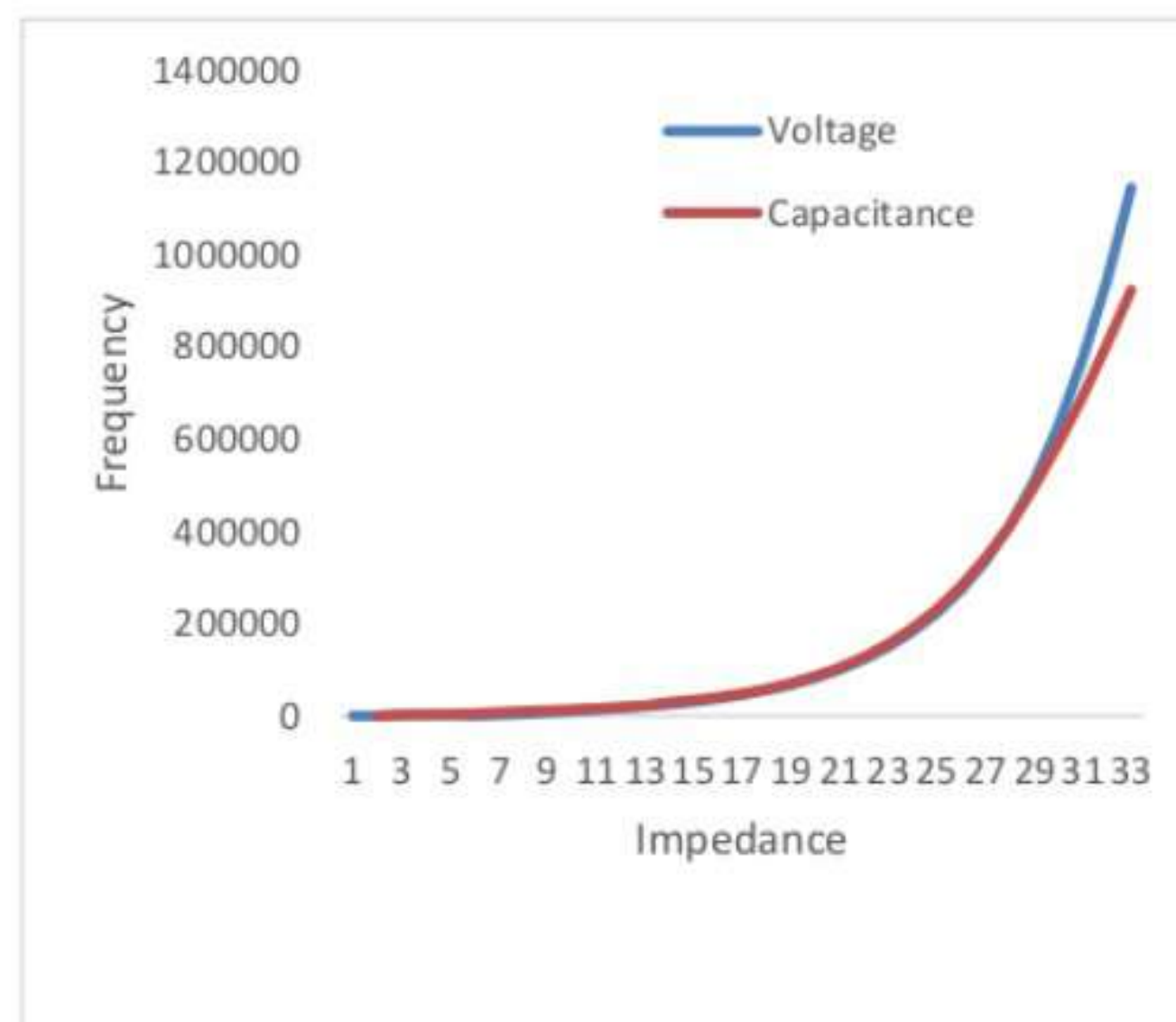
EIS AFTER CV



**Fig: 6.13 EIS AFTER CV 100 TO 0 01
PLOT 1**

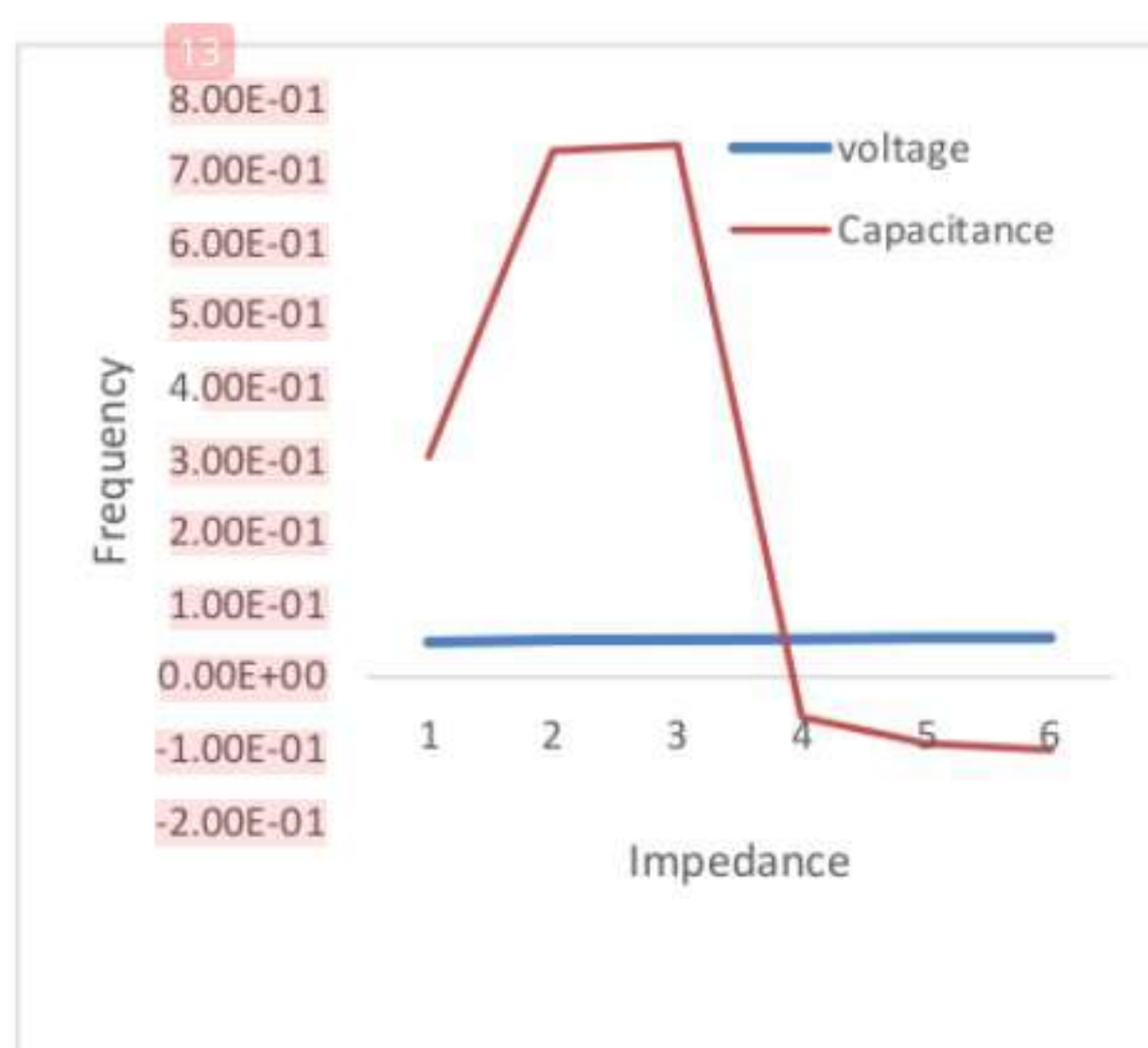


**Fig: 6.14 EIS AFTER CV 100 TO 0 01
PLOT 2**

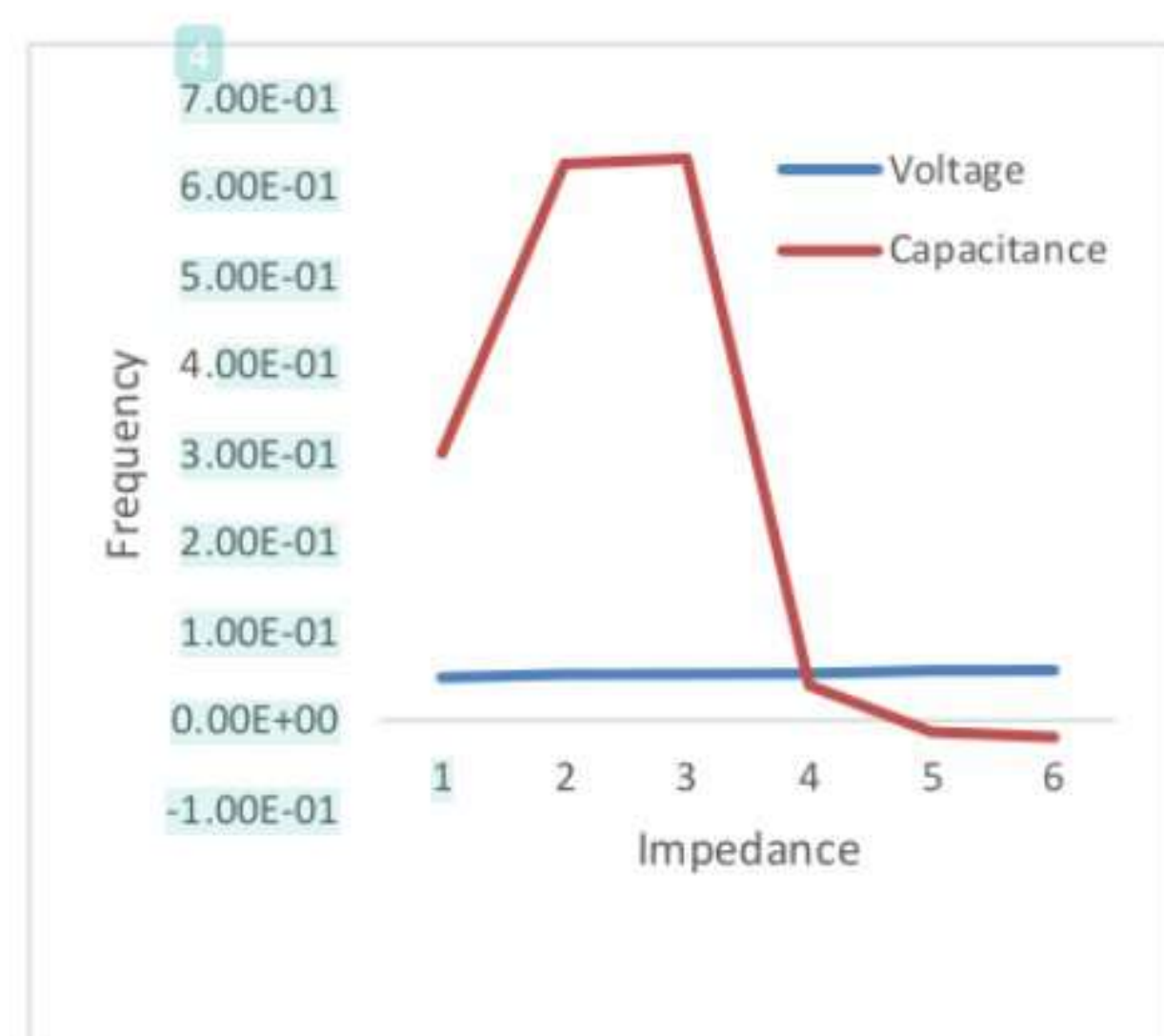


**Fig: 6.15 EIS AFTER CV 100 TO 0 01
PLOT 3**

CHARGE DISCHARGE VOLTAGES



**Fig: 6.16 DISCHARGE VOLTAGE
20 mA g 0 to 06 V**



**Fig: 6.17 DISCHARGE VOLTAGE
16 mA g 0 to 06 V**

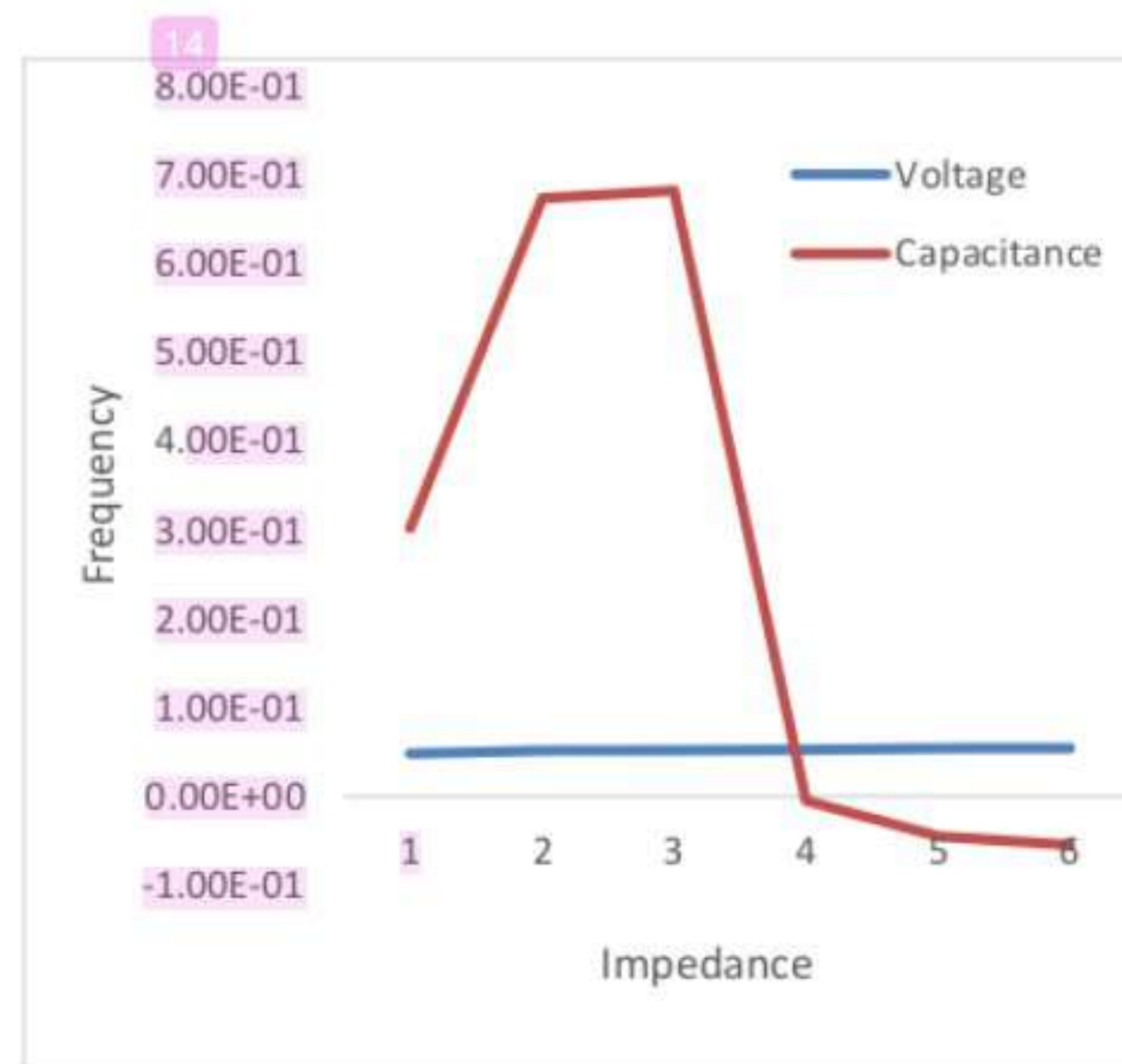


Fig: 6.18 DISCHARGE VOLTAGE
18 mA 0 to 06 V

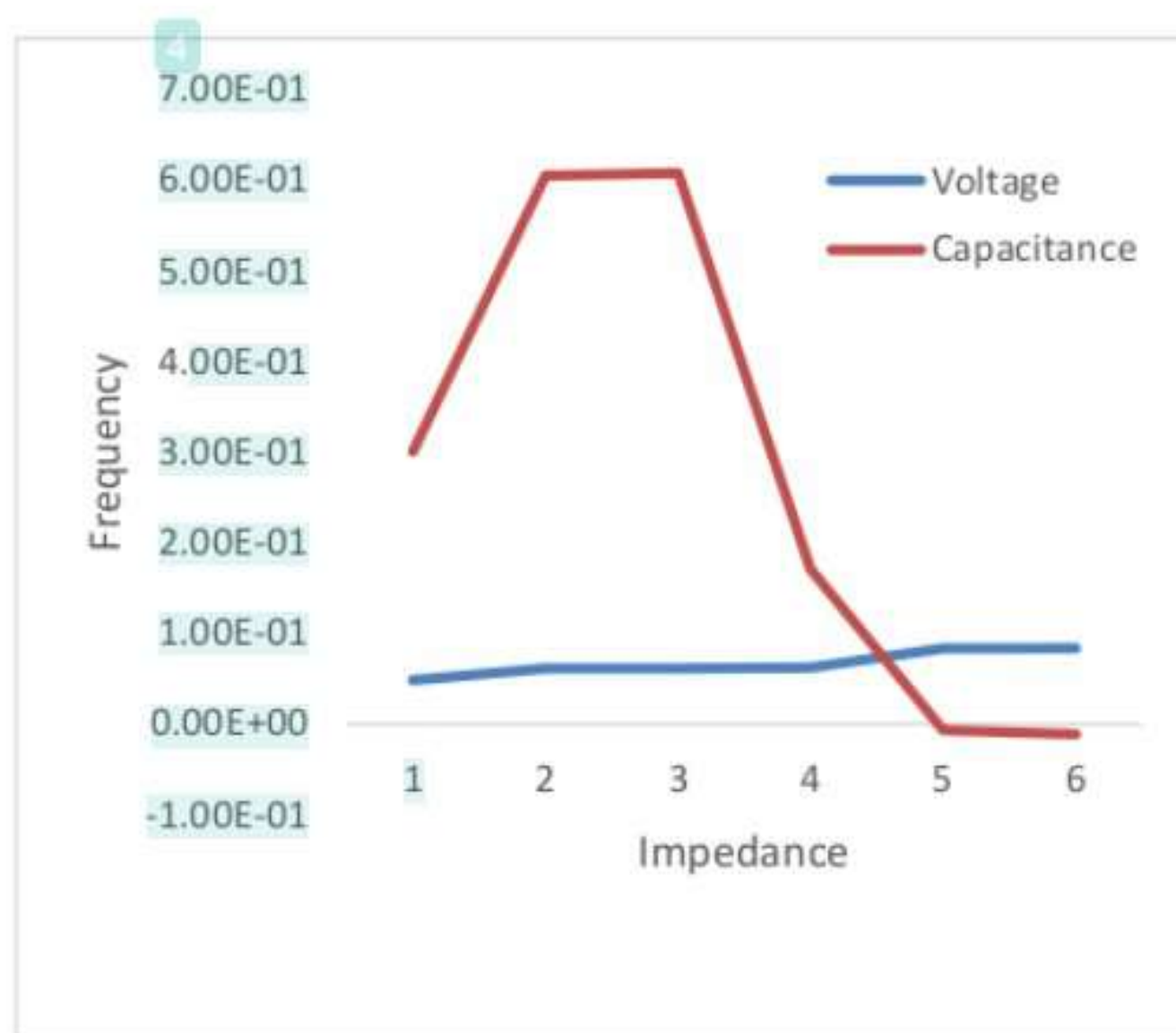


Fig: 6.19 DISCHARGE VOLTAGE
14 mA 0 to 06 V

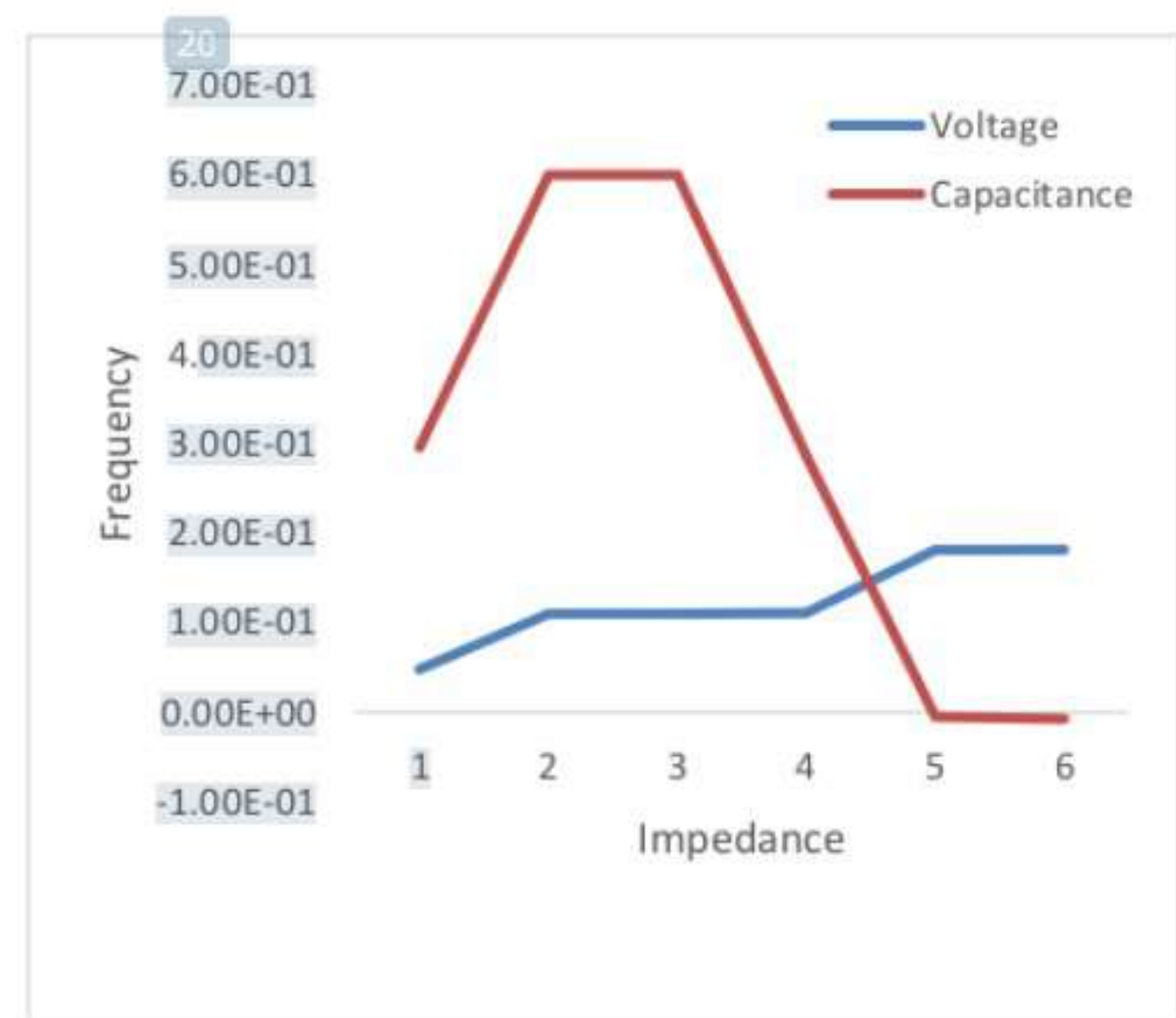
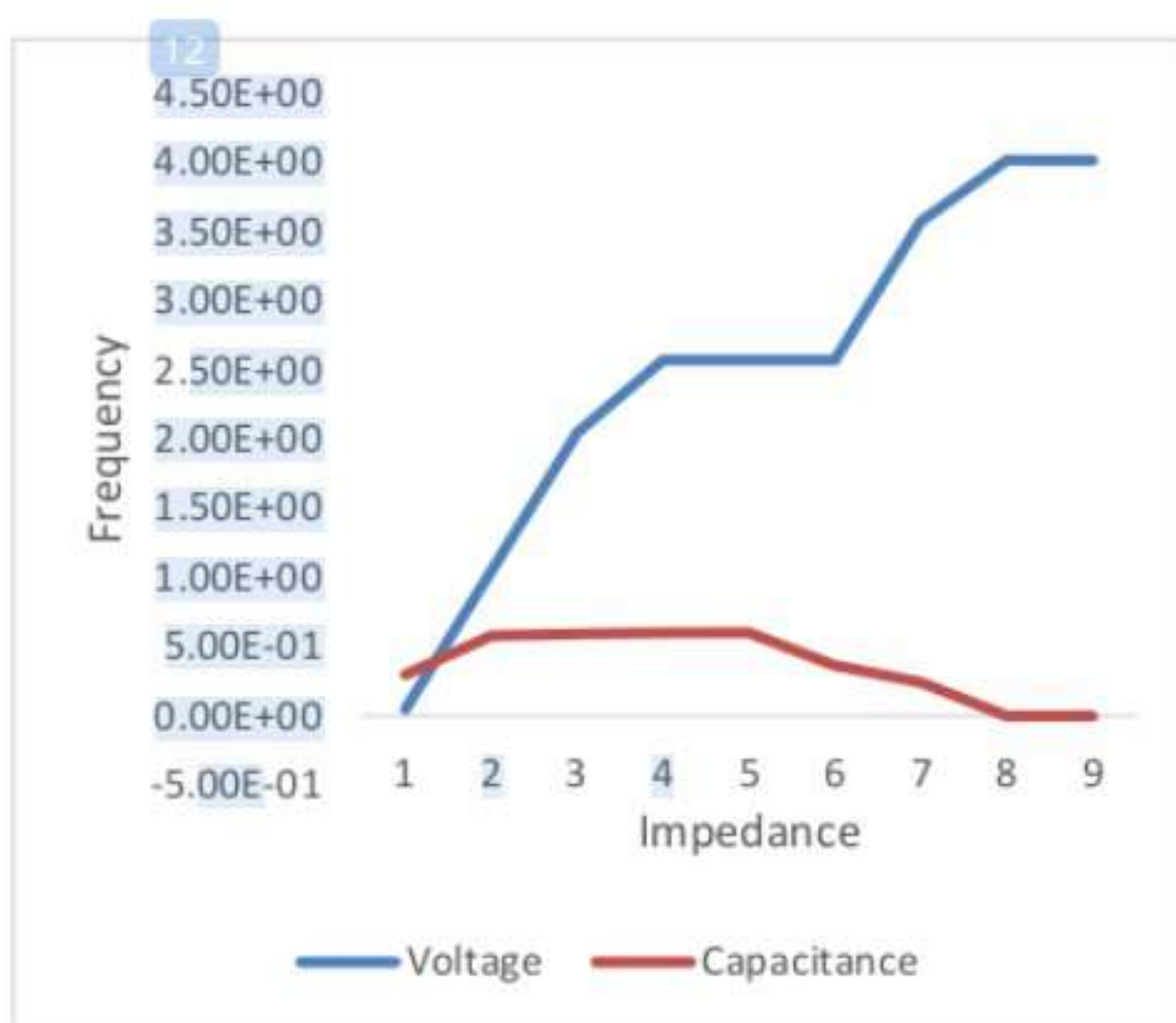
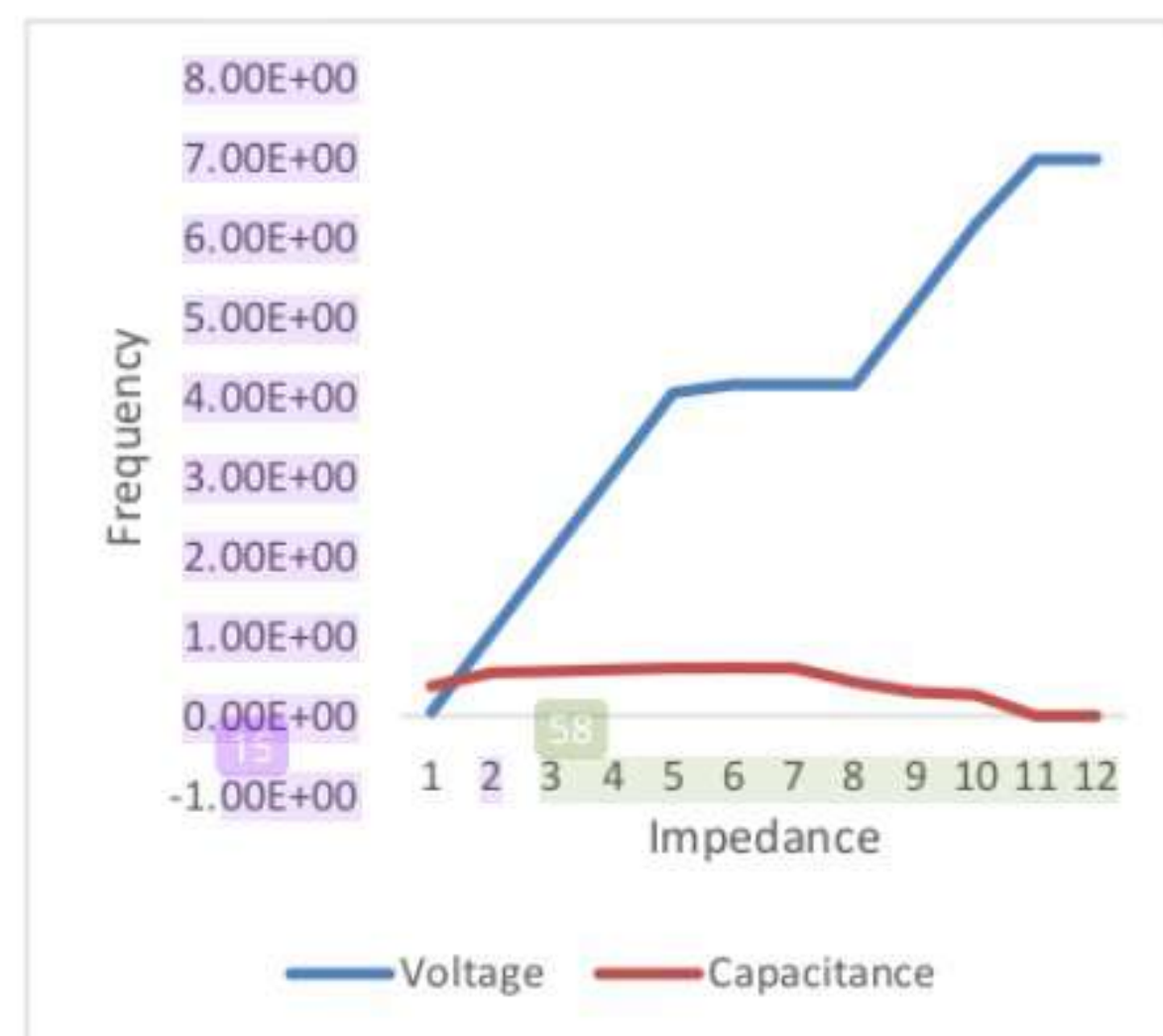


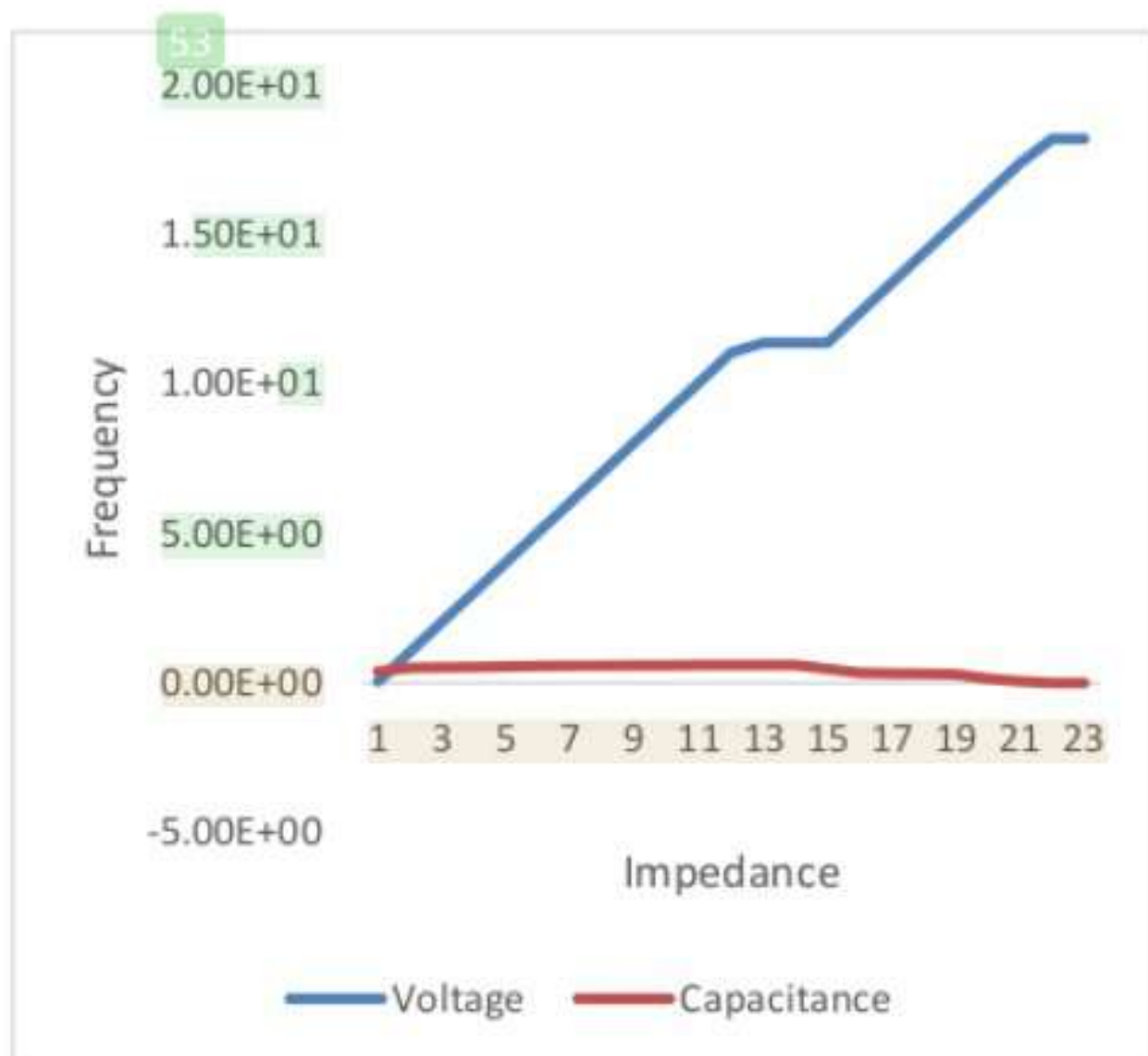
Fig: 6.20 DISCHARGE VOLTAGE
12 mA 0 to 06 V



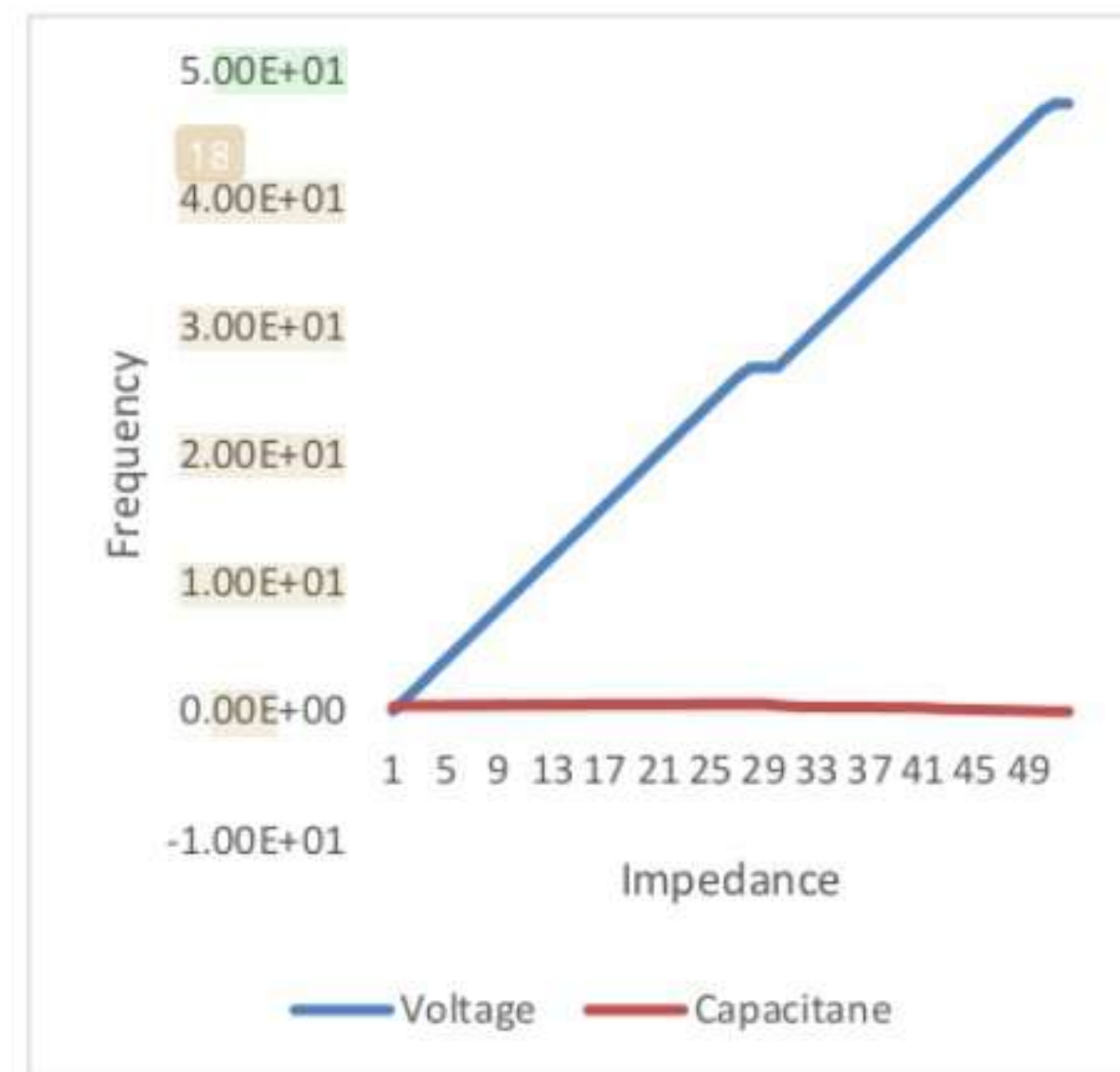
**Fig: 6.21 CHARGE VOLTAGE
10 mAg 0 to 06 V**



**Fig: 6.22 CHARGE VOLTAGE
8 mAg 0 to 06 V**



**Fig: 6.23 CHARGE VOLTAGE
6 mAg 0 to 06 V**



**Fig: 6.24 CHARGE VOLTAGE
4 mAg 0 to 06 V**

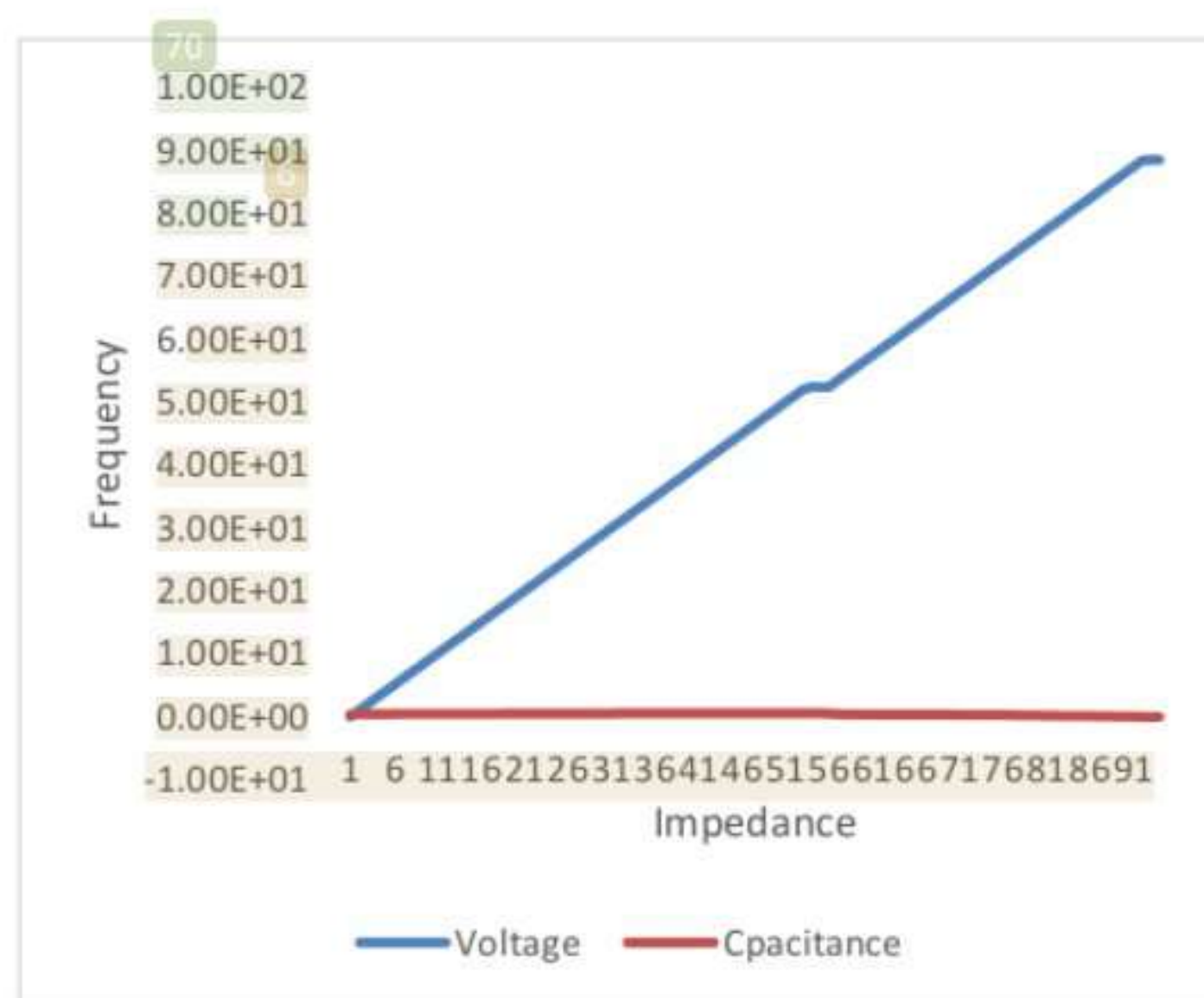


Fig: 6.25 CHARGE VOLTAGE
3 mAg 0 to 06 V

6.4 ISSUES RELATED TO SYNTHESIS AND INTEGRATION OF CQDS

¹ The synthesis and integration of Carbon Quantum Dots (CQDs) can involve various challenges and issues. ⁴⁴ CQDs are nanometer-sized carbon-based materials with unique optical and electronic properties, and they find applications in fields such as optoelectronics, bioimaging, and sensing. Here are some common issues related to the synthesis and integration of CQDs:

1. Synthesis Methodology:

¹¹ **Controllable Size and Morphology:** Achieving precise control over the size and morphology of CQDs can be challenging. Uniformity in size is crucial for consistent properties and performance.

Reproducibility: Synthesis methods may not always be reproducible, leading to variations in the properties of CQDs produced in different batches.

2. Surface Functionalization:

Surface Passivation: Unpassivated CQDs may exhibit low stability and can be prone to aggregation. Developing effective surface passivation strategies is essential to enhance stability and prevent aggregation.

Functional Group Uniformity: Achieving uniform functionalization of the CQD surface with specific groups can be challenging, affecting their solubility and biocompatibility.

3. Optical Properties:

Photoluminescence Quantum Yield (PLQY): Obtaining high PLQY is crucial for applications like bioimaging and sensing. Optimizing the synthesis conditions to maximize PLQY can be challenging.

Emission Wavelength Control: Achieving precise control over the emission wavelength is important for specific applications. Controlling the bandgap of CQDs during synthesis is critical for tuning the emission wavelength.

4. Integration into Devices:

Device Compatibility: Integrating CQDs into various devices, such as solar cells or LEDs, may pose challenges due to differences in material properties and compatibility issues.

Stability in Functional Environments: Ensuring the stability of CQDs when integrated into functional environments, such as biological systems or electronic devices, is essential for long-term performance.

5. Scale-up Challenges:

Economical Synthesis: Developing cost-effective and scalable synthesis methods for CQDs is crucial for their commercial viability.

Large-Scale Production Consistency: Maintaining consistency in the properties of CQDs at a larger scale can be challenging and requires robust synthesis processes.

6. Characterization Techniques:

Characterization Accuracy: Accurate characterization of CQDs is essential for understanding their properties. The availability of suitable characterization techniques and the interpretation of results can be challenging.

6.5 STABILITY AND DEGRADATION CONCERNS

Supercapacitors, including those made from Carbon Quantum Dots (CQDs), are energy storage devices known for their high-power density, rapid charge/discharge rates, and long cycle life. However, they are not without stability and degradation concerns. Here are some issues related to stability and degradation in supercapacitors made from CQDs.

1. Cycling Stability:

Over repeated charge and discharge cycles, the electrode material, including CQDs, can undergo degradation. This can lead to a decrease in the capacitance and overall performance of the supercapacitor.

2. Chemical Stability:

The choice of electrolyte in a supercapacitor is crucial for its stability. Some electrolytes may chemically react with CQDs, leading to degradation and a decrease in performance.

Functional Group Stability: The stability of functional groups on the surface of CQDs, which may contribute to the capacitance, is important. Chemical reactions or alterations to these groups can impact the overall stability.

3. Coulombic Efficiency:

Redox Reactions: Redox reactions occurring at the electrode-electrolyte interface can lead to Coulombic inefficiencies, affecting the overall energy efficiency of the supercapacitor over time.

4. Environmental Factors:

Moisture Sensitivity: CQDs, especially if not properly passivated, can be sensitive to moisture. Exposure to humid environments can lead to undesired chemical reactions and affect the stability of the supercapacitor.

5. Temperature Sensitivity:

Elevated temperatures can accelerate the degradation of both the electrode material and the electrolyte, impacting the overall stability and lifespan of the supercapacitor.

6. Synthesis-Related Issues:

Impurities: Impurities in the synthesis of CQDs can contribute to instability. The presence of impurities may introduce additional redox reactions or chemical instabilities.

7. Internal Resistance:

Contact Resistance: Over time, the contact resistance at the electrode-electrolyte interface may increase due to factors like material degradation or the formation of insulating layers. This can lead to a decrease in performance.

8. Mechanical Stress:

Flexibility and Mechanical Stress: Depending on the application, supercapacitors may be subjected to mechanical stress. Ensuring the mechanical integrity of the CQD electrodes is crucial for long-term stability.

6.7 THE SCALABILITY AND COST CONSIDERATIONS OF SUPERCAPACITORS

The scalability and cost considerations of supercapacitors made from Carbon Quantum Dots (CQDs) are essential factors in determining their practical viability for large-scale commercial applications. Here are key points to consider:

The scalability of CQD-based supercapacitors is closely tied to the synthesis methods used for CQD production. Developing scalable and cost-effective synthesis techniques is crucial for large-scale manufacturing. **Batch-to-Batch Consistency:** Achieving consistency in CQD properties across different batches is important for reliable performance in large-scale production.

The cost of **raw materials used in the synthesis of CQDs**, such as carbon precursors, can significantly impact the overall cost of the supercapacitor. Finding economical sources for these materials is essential. Optimizing the synthesis process to reduce waste, increase yield, and minimize energy consumption contributes to cost-effectiveness. As the production scale increases, challenges related to maintaining

quality, efficiency, and reproducibility may arise. Addressing these challenges is crucial for successful scalability.

Besides CQDs, the cost of other electrode materials, such as binders and conductive additives, needs to be considered. Finding affordable yet efficient materials is important. Developing scalable and cost-effective manufacturing processes for electrode fabrication and device assembly is critical for large-scale production. The performance characteristics of CQD-based supercapacitors, including energy density and power density, need to be balanced with cost considerations. Striking the right balance is crucial for competitiveness in the market.

Ensuring that CQD-based supercapacitors maintain their performance over a long operational life is vital for cost-effectiveness, as frequent replacements would increase the overall cost of the energy storage solution.

CQD-based supercapacitors need to compete with other energy storage technologies in terms of both performance and cost. Understanding the market landscape and positioning the technology accordingly is essential.

Achieving economies of scale through large-scale production can help reduce costs per unit and make CQD-based supercapacitors more competitive. Meeting regulatory standards and environmental requirements may add to the overall cost. Understanding and addressing these factors from the early stages of development are important for successful commercialization.

CHAPTER-7

RESULTS AND DISCUSSIONS

7.1 MAJOR AREAS OF UPCOMING DEVELOPMENT

³ Researchers are continually working on enhancing the energy density and overall performance of supercapacitors, including those incorporating CQDs. Advances in materials design, synthesis methods, and device architecture may lead to supercapacitors with improved energy storage capabilities.

¹ The unique properties of CQDs, including their tunable optical and electronic characteristics, make them promising for integration into wearable and flexible electronics. Future developments may focus on creating supercapacitors that are not only efficient but also flexible and adaptable to various form factors.

Supercapacitors, including those using CQDs, may find increased application in combination with energy harvesting technologies, such as solar cells and piezoelectric devices. This integration could lead to self-powered systems with improved efficiency and reliability. Ongoing research may yield more scalable and cost-effective synthesis methods for CQDs, addressing some of the scalability and cost concerns associated with their production. Improved synthesis methods could contribute to the commercial viability of CQD-based supercapacitors.

7.2 POTENTIAL APPLICATIONS AND INDUSTRIES BENEFITING FROM CQD BASED SUPERCAPACITORS

Carbon Quantum Dot (CQD)-based supercapacitors hold promise for a variety of applications due to their unique properties, such as high surface area, tunable electronic properties, and excellent conductivity. Here are potential applications and industries that could benefit from CQD-based supercapacitors:

³ CQD-based supercapacitors could be used in smartphones, tablets, and other portable electronic devices for rapid energy storage and release during charging and discharging cycles.

The flexibility and lightweight nature of CQD-based supercapacitors make them suitable for integration into wearable devices, such as smartwatches, fitness trackers, and electronic textiles. Supercapacitors, including those based on CQDs, can be used in conjunction with batteries in electric and hybrid vehicles. They offer quick energy bursts during acceleration and regenerative braking, enhancing overall energy efficiency.

could find applications in medical devices, providing reliable and rapid energy storage for devices like implantable medical sensors, defibrillators, and other portable medical equipment. Various consumer electronics, including cameras, audio devices, and electronic gadgets, could benefit from the rapid charging and discharging capabilities of CQD-based supercapacitors.

7.3 EMERGING TRENDS AND RESEARCH DIRECTIONS

Researchers are exploring novel synthesis methods to enhance the properties of CQDs, including size control, surface functionalization, and doping. Precise control over these factors is critical for optimizing the performance of supercapacitors. Tuning the electronic and optical properties of CQDs to achieve specific functionalities is an ongoing trend. Researchers are exploring ways to tailor the bandgap, energy levels, and other properties to meet the requirements of different applications.

Investigating the integration of CQD-based supercapacitors with other energy storage technologies, such as batteries, to create hybrid systems. This approach aims to combine the high-power density of supercapacitors with the high energy density of batteries for improved overall performance. Advancements in the development of flexible and wearable electronics have prompted research into CQD-based supercapacitors that can conform to irregular shapes. This is particularly relevant for applications in smart clothing, flexible displays, and wearable health monitoring devices.

Exploring the biocompatibility of CQDs for potential use in biomedical applications. This includes investigating CQD-based supercapacitors for implantable medical devices, biosensors, and other healthcare-related applications. A growing emphasis on environmentally friendly synthesis methods for CQDs. Green synthesis approaches, such as using sustainable carbon sources and eco-friendly solvents, are gaining attention to address environmental concerns and increase the sustainability of the manufacturing process.

Research is focused on understanding and optimizing charge storage mechanisms in CQD-based supercapacitors. This includes exploring pseudocapacitive effects, redox reactions, and other electrochemical processes to improve energy density and overall performance. Efforts to address scalability and cost challenges associated with CQD-based supercapacitors. Researchers are working on developing cost-effective synthesis methods and manufacturing processes that can be scaled up for commercial production.

Considering the specific energy storage needs of IoT devices, researchers are exploring how CQD-based supercapacitors can meet the requirements for low-power, intermittent energy demand, and rapid charging cycles in IoT applications.

Innovations in electrode materials and structures ¹¹ to improve the overall performance and stability of CQD-based supercapacitors. This includes the exploration of new materials, such as nanocomposites and hybrid structures. Developing in situ characterization techniques to monitor and understand the electrochemical processes occurring within CQD-based supercapacitors during operation. Real-time monitoring can provide valuable insights for optimizing device performance.

7.4 COMMERCIALIZATION PROSPECTS

1. High Power Density:

CQD-based supercapacitors offer high power density and fast charge-discharge rates. This makes them suitable for applications where rapid energy storage and release are critical, such as in electric vehicles, consumer electronics, and certain industrial processes.

2. Flexibility and Lightweight Design:

The flexible and lightweight nature of CQDs makes them appealing for applications that require conformable energy storage solutions, such as in wearable electronics and flexible devices.

3. Tunable Properties:

The tunable properties of CQDs, including size, surface chemistry, and electronic structure, provide flexibility for tailoring their performance to specific applications. This tunability is advantageous for customization based on the requirements of different industries.

4. Potential for Green Synthesis:

Researchers are exploring environmentally friendly methods for synthesizing CQDs. Green synthesis approaches contribute to sustainability, aligning with the increasing demand for eco-friendly energy storage solutions.

5. Biocompatibility for Biomedical Applications:

The biocompatibility of CQDs opens up opportunities for biomedical applications. CQD-based supercapacitors could find use in implantable medical devices and other healthcare applications.

7.5 COMMERCIALIZATION CHALLENGES:

1. Scalability and Production Costs:

One of the primary challenges is the scalable production of high-quality CQDs at an affordable cost. Scaling up production while maintaining consistent properties is crucial for widespread commercial adoption.

2. Long-Term Stability:

Ensuring the long-term stability and reliability of CQD-based supercapacitors is essential for their acceptance in commercial applications. Researchers need to address issues related to degradation over extended usage periods.

3. Material Uniformity:

Achieving uniformity in the properties of CQDs, especially when produced on a large scale, is challenging. Variability in material properties could affect the performance and reliability of supercapacitors.

4. Competitive Technologies:

CQD-based supercapacitors face competition from other energy storage technologies, including conventional supercapacitors, batteries, and emerging technologies. For commercial success, CQDs must offer distinct advantages over existing solutions.

5. Regulatory and Certification Hurdles:

Meeting regulatory standards and obtaining certifications for safety, performance, and environmental impact is a significant challenge in the commercialization process.

6. Integration into Existing Devices:

Integrating CQD-based supercapacitors into existing devices and systems may require adaptations and modifications. Compatibility with established technologies is crucial for widespread adoption.

7. Awareness and Acceptance:

Creating awareness about the benefits of CQD-based supercapacitors and gaining acceptance in various industries is vital. Market education efforts are needed to showcase the advantages of this technology.

8. Economic Viability:

The economic viability of CQD-based supercapacitors compared to other energy storage options is a critical factor. Cost-effectiveness is essential for their integration into mass-market products.

CHAPTER – 8

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