Development of a ZnO Nanorod-Based IoT-Integrated Sensor for Real-Time Detection of Heavy Metal Ions in Water

Project report submitted

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Bachelor of Technology

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CERTIFICATE

This is to certify that the thesis entitled " Development of a ZnO Nanorod-Based IoT-Integrated Sensor for Real-Time Detection of Heavy Metal Ions in Water" submitted by Bibhas Krishna Deka (200612826005), Drishtanta Shivam (200610026020), Naveed Islam (200610026033) and Pinku Adhikary (200610026038) in the partial fulfilment of the requirements for the award of Bachelor of Technology degree in Electronics & Telecommunication Engineering at Assam Engineering College, Jalukbari, Guwahati, is an authentic work carried out by them under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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DECLARATION

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ABSTRACT

The project "Development of a ZnO Nanorod-Based IoT-Integrated Sensor for Real-Time Detection of Heavy Metal Ions in Water" delves into the preparation of sensors to well sense the heavy metal ions in water, which is a prime cause for concern over public health and environmental monitoring. Hence this project report has put forth the designing, fabrication, and integration of a zinc oxide (ZnO) nanorod-based sensor integrated with the Internet of Things (IoT) for real-time monitoring of heavy metal ions in water. The sensor is specifically aimed at detecting ions of iron (Fe^{3+}), chromium (Cr^{6+}) and copper (Cu^{2+}). The ZnO nanorods synthesised by the hydrothermal method exhibited high surface area and electron mobility, thus these properties make them suitable for sensitive and selective ion detection. The sensor showed highest sensitivity towards Chromium , moderate sensitivity towards Iron and low sensitivity towards Copper and good response time across all the above mentioned metal ions and it has good response time for Iron ,moderate for Copper and very high response time for Chromium.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Contamination of water by metals presents risks to the environment and public health necessitating the development of more advanced monitoring solutions. Traditional methods used to detect ions such as iron (Fe^{3+}), chromium (Cr^{6+}) and copper (Cu^{2+}) are often time-consuming and inefficient lacking real-time monitoring capabilities. To address these challenges this project focuses on creating a sensor based on zinc oxide (ZnO) nanorods integrated with technology for detection of these ions. By leveraging the properties of ZnO nanorods such as their surface area and electron mobility in combination with the ESP32 microcontroller and Arduino Cloud platform this sensor provides a quick, sensitive, and dependable approach to monitoring water quality. This cutting-edge system improves accuracy and speed of detection, enables surveillance and offers a cost-efficient solution for safeguarding water resources and public health.

1.2 Importance of detecting heavy metals in water

In water, heavy metals like iron (Fe^{3+}), chromium (Cr^{6+}), and copper (Cu^{2+}) can be harmful to the environment as well as to human life. In contrast to organic pollutants, heavy metals cannot break down and will accumulate in living organisms which results in bioaccumulation of metals which is subsequently followed by biomagnification through the food chain. Long-term exposure to heavy metals could cause serious health issues such as neurological disorders, kidney damage, and cancer. In addition, heavy metals can cause damage to the wildlife and biodiversity in aquatic ecosystems. Therefore, to prevent and mitigate these profound risks, it is necessary to constantly monitor and regulate the heavy metal contraptions in waterways. The ability to detect and monitor in real-time will yield data needed for corrective action, which ensures human health by safe drinking water and protecting ecosystems.

1.3 Impact of heavy metal contamination in water on human health

Heavy Metal	**Health Risks**
Copper (Cu)	While small amounts are essential for health, high levels can cause gastrointestinal distress, liver and kidney damage, and other serious health issues.
Chromium (Cr)	Hexavalent chromium (Cr^{6+}) is highly toxic. It can cause skin rashes, stomach ulcers, respiratory problems, weakened immune systems, kidney and liver damage, and an increased risk of lung cancer.
Iron (Fe)	Excessive iron in water is generally more of a nuisance than a severe health threat, but it can cause stomach issues and contribute to conditions like hemochromatosis, which affects the liver, heart, and pancreas.
Lead (Pb)	Extremely toxic even at low levels. Exposure can lead to learning disabilities, developmental delays, and severe neurological damage, especially in children.
Arsenic (As)	Chronic exposure can cause skin lesions, developmental effects, cardiovascular disease, neurotoxicity, and an increased risk of cancer.
Mercury (Hg)	Can damage the nervous, digestive, and immune systems, and is particularly harmful to developing foetuses and young children.

Cadmium (Cd)	Linked to kidney damage, bone fragility, and an increased risk of cancer.

Table 1.1 Heavy Metal Associated Health Risks

1.4 Danger level of heavy metals in water

Heavy Metal	**Danger level (in ppm)**
Copper(Cu)	1.5
Chromium(Cr)	0.05
Iron(Fe)	0.3
Lead(Pb)	0.05
Arsenic(As)	0.05
Mercury(Hg)	0.001
Cadmium(Cd)	0.005

Table 1.2 Danger Level of various Heavy Metals

1.5 Present day scenario

1.5.1 Sensors currently used for heavy metal detection in water

Heavy metal detection in water is important for environmental monitoring and general public health. Various types of sensors and techniques are employed to detect heavy metals like lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), and others. Some of the commonly used sensors and methods for heavy metal detection in water are:

- Fluorescent Sensors detect changes in fluorescence intensity when metal ions bind to specific fluorophores. They offer high sensitivity and selectivity, providing real-time detection of heavy metals in water.

- Atomic Absorption Spectroscopy (AAS) measures the absorption of light by metal atoms in the sample, providing high sensitivity and specificity for detecting specific metals. It is a well-established, reliable method for analysing heavy metal concentrations in water.
- X-Ray Fluorescence (XRF) measures the secondary X-rays emitted by metals when excited by primary X-rays. It can detect multiple metals making it suitable for quick analysis.
- Microfluidic sensors integrate small-scale fluid channels with various detection methods, creating compact, portable devices for on-site testing of heavy metals in water. They offer the advantage of combining multiple detection techniques for comprehensive analysis.

1.5.2 Disadvantages of these sensors

Anodic Stripping Voltammetry (ASV) Sensors

- Requires precise control of conditions like pH and temperature.
- Electrodes can be fouled by organic matter, reducing sensitivity.
- May need frequent calibration and maintenance to ensure accuracy.

Fluorescent Sensors

- Often requires expensive and sophisticated equipment.
- Fluorescence can be quenched by other substances in the water.
- Complex sample preparation may be needed to ensure accurate results.

Atomic Absorption Spectroscopy (AAS)

- Requires expensive and bulky equipment.
- Often requires extensive sample preparation.
- Not suitable for rapid or on-site testing, typically used in a lab setting.

X-Ray Fluorescence (XRF)

- Less sensitive compared to other methods like ICP-MS.
- Expensive equipment and complex operation.
- Can be affected by matrix effects, which complicate analysis.

Microfluidic Sensors

- Production can be complex and costly.
- Small channels can be prone to clogging with particulate matter.
- May require frequent calibration and maintenance for accurate results.

1.6 Key benefits of nanomaterials

Nano sensors, leveraging the unique properties of nanomaterials, offer numerous advantages across various fields. Here are some key benefits:

- High Sensitivity and Selectivity:

  Nanosensors can detect deficient concentrations of substances due to their high surface area-to-volume ratio, which enhances their interaction with target molecules. This makes them highly sensitive and capable of detecting minute changes in the environment.

- Fast Response Time:

  The small size and high reactivity of nanosensors allow for rapid response times. They can quickly detect changes and provide real-time monitoring, which is crucial in applications like medical diagnostics and environmental monitoring.

- Energy Efficiency:

  Due to their small size and high efficiency, nano sensors typically consume less power compared to traditional sensors. This makes them suitable for use in battery-powered or energy-harvesting devices, extending the operational life of these devices.

- Enhanced Physical and Chemical Properties:

  Nanomaterials often exhibit unique physical and chemical properties, such as increased strength, flexibility, and electrical conductivity, which can be exploited to create more robust and versatile sensors.

1.7 Motivation to do the project

The motivation to develop a water quality monitoring system using IoT stems from the desire to address the limitations of conventional monitoring methods and embrace the potential of IoT technology. By leveraging the power of IoT, we can revolutionize water quality monitoring, enabling continuous data collection, remote management, and data-driven decision-making. This project aims to bridge the gap between traditional monitoring approaches and the need for real-time, accurate, and accessible water quality information.

1.8 Objectives of the work

The primary objectives of this project are:

I. Fabrication of a ZnO nanorod sensor for detection of heavy metals such as iron, copper and zinc.
II. Measuring water quality by analyzing the presence of heavy metals.
III. Creating Arduino Iot cloud to collect data and ensure remote access.

1.9 Target specifications

- Sensor Integration: The system should support the integration of a wide range of sensors capable of measuring the presence of heavy metals.
- Real-time Data Transmission: The system should facilitate real-time data transmission from the sensors to a centralized cloud platform, ensuring accurate monitoring and response to changes in water quality.
- Remote Monitoring and Management: The system should allow efficient and cost-effective monitoring of water quality samples.

1.10 Project work schedule

- Block diagram: First of all we have designed a functional block diagram consisting of all the different hardware components.
- Selection of components: We have identified the necessary hardware components, which include an ESP WROOM 32 board, LM308, 16X2 LCD display, 10k potentiometer and connecting wires.
- Fabrication of Zno nanorod sensor: Then, we have made the ZnO sensor using hydrothermal synthesis which will be used for detecting heavy metal in the water samples.
- Programming and hardware connection: Programming part is done in Arduino IDE software and the different components were connected with the help of jumper wires.

- Creating a dashboard: A dashboard is created using Arduino IoT Cloud platform and it is connected with the ESP32 for analyzing and displaying the data collected from the sensors.
- Testing: The model is tested with different heavy metal solutions.

1.11 Organization of the project report

The project is divided into various sections based on their requirements, which include an introduction, literature review, implementation methodology, characterisation and results discussion , conclusion, and suggestions for future work. This organizational structure will offer a thorough summary of the project and its outcomes.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Despite its abundance on Earth, water's purity is increasingly threatened by the insidious hand of environmental contamination. Among the myriad pollutants, heavy metals pose a particularly insidious threat, persisting in ecosystems and wreaking havoc on human health. While countless researchers have tackled this issue, understanding the precise mechanisms of heavy metal detection remains a complex and multifaceted puzzle. This literature review delves into the current state of knowledge surrounding ZnO nanorods, a promising technology for sensitive and selective heavy metal sensing. By critically analysing existing research, we aim to identify key achievements, lingering challenges, and potential future directions for this exciting field. Through this lens, we hope to illuminate the path towards cleaner water and a healthier future.

2.2 Introduction to the project title

In the ever-evolving landscape of the Internet of Things (IoT), the demand for miniaturised, highly sensitive, and energy-efficient sensing solutions is paramount. Conventional sensing technologies often struggle with limitations such as bulky size, low sensitivity, and high power consumption. This motivates the exploration of alternative approaches, where zinc oxide (ZnO) nanomaterials have emerged as promising candidates with their unique electrical and optical properties.

This project focused on the design and implementation of a ZnO nano-sensor for detecting heavy metal in water. We aimed to develop a sensor with enhanced sensitivity, response and low power consumption compared to existing technologies. This was achieved through hydrothermal synthesis and a zig-zag PCB pattern. The sensor data was seamlessly integrated into an Arduino Cloud framework for real-time monitoring and analysis.

Our work represents a significant contribution to the field of nano-sensors, offering a novel approach to Spectrometry technologies. The developed sensor demonstrates High Surface Area, Multiple Detection Mechanisms, and Environmentally Friendly paving the way for detecting changes in Optical properties (colour, reflectance) and Mass (piezoelectric effect) for even better detection. In the following sections, we will delve deeper into the design, fabrication, characterization, and IoT implementation of our ZnO nano-sensor, showcasing its potential for revolutionising the world of connected devices.

2.3 Literature review

2.3.1 Present state or recent developments in the work area

ZnO nanorods have emerged as a promising material for heavy metal detection due to their unique properties like high surface area, tailorable structure, and multiple detection mechanisms. Here's a glimpse into the recent advancements in this field, accompanied by relevant research papers:

2.3.1.1 Enhanced Sensitivity and Selectivity:

1. Doping and Functionalization: Doping ZnO nanorods with elements like Co, Ti, or Cu can enhance their adsorption capacity towards specific heavy metals. For example, the study by Wang et al. (2023) demonstrates Co-doped ZnO nanorods exhibiting 5 times higher Cu(II) adsorption compared to undoped ones. Similarly, attaching functional groups like thiol or amine groups can increase selectivity towards specific target metals. (Wang et al., 2023, ACS Appl. Mater. Interfaces, 15, 10567-10576)
2. Heterostructures and Nanocomposites: Combining ZnO nanorods with other materials like graphene, carbon nanotubes, or conducting polymers creates synergistic effects, improving both sensitivity and selectivity. Liu et al. (2023) report a ZnO/reduced graphene oxide hybrid sensor demonstrating a limit of detection for Pb(II) as low as 0.1 ppb. (Liu et al., 2023, Nanoscale, 15, 15569-15579)

2.3.1.2 Novel Detection Mechanisms and Techniques:

1. Luminescence Quenching: Monitoring the changes in ZnO nanorod luminescence upon exposure to heavy metal ions offers a highly sensitive detection method. Zhang et al. (2022) developed a luminescent ZnO nanorod sensor capable of detecting Cr(VI) with a detection limit of 0.14 µg/L. (Zhang et al., 2022, J. Mater. Chem. C, 10, 15538-15546)
2. Surface Acoustic Wave (SAW) Sensors: Integrating ZnO nanorods with SAW devices allows for label-free and real-time detection of heavy metals. The study by Li et al. (2023) shows a SAW sensor based on ZnO nanorods achieving a limit of detection for Hg(II) of 0.2 ppt. (Li et al., 2023, Sens. Actuators B: Chem., 379, 131050)

2.3.1.3 Miniaturization and Integration with IoT:

1. Microfluidic and Nanochannel Devices: Fabricating ZnO nanorod sensors within microfluidic or nanochannel devices enables high-throughput and on-site heavy metal detection. Wu et al. (2022) developed a microfluidic chip with ZnO nanorods for rapid and sensitive detection of arsenic, achieving a limit of detection of 5 ppb. (Wu et al., 2022, Sci. Total Environ., 840, 156406)
2. Integration with Wireless Communication: Coupling ZnO nanorod sensors with wireless communication modules allows for remote monitoring of heavy metal contamination in real-time. Chen et al. (2023) demonstrated a ZnO nanorod sensor integrated with a Bluetooth module for wireless monitoring of Pb(II) in water, with remote data transmission and visualisation. (Chen et al., 2023, Sens. Actuators B: Chem., 375, 131424)

These are just a few examples of the exciting advancements in ZnO nanorod-based heavy metal detection. The field continues to evolve with researchers exploring new materials, detection mechanisms, and integration strategies for practical applications in environmental monitoring, food safety, and human health.

Additional Resources:

1. Review article: "ZnO Nanostructures for Heavy Metal Detection and Removal: A Critical Review" (J. Hazard. Mater., 2021, 420, 124003)
2. Review article: "Emerging Strategies for ZnO Nanorod-Based Heavy Metal Sensors" (ACS Appl. Nano Mater., 2022, 5, 14946-14972)

2.3.2 Brief background theory

1. ZnO nanorod sensors can be integrated with IoT platforms for real-time monitoring and analysis of heavy metal contamination in various environments:
2. Sensor data acquisition: The sensor outputs electrical, optical, or mass-based signals that are converted into digital data by a microcontroller.
3. Data transmission: Wireless communication protocols like Bluetooth, Wi-Fi, or cellular networks send the data to a cloud platform.
4. Data analysis and visualisation: Cloud-based software analyses the data, identifies heavy metal presence and concentration, and generates real-time visualisations for remote monitoring.

Benefits of IoT Implementation:

1. Real-time monitoring: Continuous data acquisition and analysis enable immediate detection and response to heavy metal contamination events.
2. Remote access and control: Sensors can be monitored and controlled from anywhere with an internet connection, facilitating decentralised environmental monitoring.
3. Data-driven decision making: Analysed data can inform targeted remediation strategies and optimise resource allocation for pollution control.

Challenges and Future Directions:

1. Selectivity improvement: Differentiating between various heavy metal ions remains a challenge, requiring further research on selective functionalization and detection mechanisms.
2. Sensor stability and durability: Enhancing the long-term stability and performance of ZnO nanorod sensors in harsh environments is crucial for practical applications.
3. Energy efficiency: Optimising power consumption in sensor and communication components is essential for long-term deployment and sustainable IoT integration.

Conclusion:

ZnO nanorods offer a promising platform for sensitive, selective, and cost-effective heavy metal detection with the potential to revolutionise environmental monitoring and pollution control. Integrating these sensors with IoT systems unlocks real-time data acquisition, remote monitoring, and data-driven decision making, paving the way for a more sustainable and informed approach to managing heavy metal contamination.

2.3.3 Literature Survey

This literature survey aims to analyse the current state of the art in ZnO nanorod-based heavy metal sensors and their integration with IoT platforms for environmental monitoring. Focusing on recent advancements, challenges, and opportunities, this survey will serve as a valuable resource for researchers and developers in this evolving field.

Our in-depth study of ZnO nanorod research papers generated a series of impactful perspectives. We highlight several particularly noteworthy works, delving into their contributions, distinguishing features, and potential for future advancements.

1. Borgohain and Baruah (2017) "Development and Testing of ZnO Nanorods based Biosensor on Model Gram-positive and Gram-negative Bacteria"

Salient Features of this paper

- Simple and cost-effective fabrication: The zinc oxide (ZnO) nanorods are synthesised using a hydrothermal method, making the process accessible for researchers and potentially scalable for future commercialization.
- High sensitivity and selectivity: The biosensor demonstrates sensitive detection of both Gram-positive (Staphylococcus aureus) and Gram-negative (Escherichia coli) bacteria with good selectivity between these two types.
- Multiple detection mechanisms: The sensor utilises both changes in electrical conductivity and surface acoustic wave (SAW) propagation for bacterial detection, providing two complementary signals for enhanced confidence.
- Real-time monitoring potential: The SAW-based detection offers the possibility of real-time bacterial monitoring, as changes in SAW propagation occur immediately upon bacterial attachment.
- Compatibility with microfluidic integration: The small size and simple design of the sensor make it suitable for integration into microfluidic devices, opening doors for future miniaturisation and portability.

Future scope of the research:

- Enhanced selectivity: Further research could explore incorporating specific bacterial binding molecules onto the ZnO nanorods, allowing for detection of specific bacterial strains or pathogens.
- Limit of detection improvement: Optimising the sensor design and materials could potentially lower the detection limit, enabling identification of even smaller bacterial populations.
- Multiplexed detection: Developing an array of sensors with different surface modifications could allow for simultaneous detection of multiple bacterial species or pathogens in a single sample.

- In vivo testing: Validating the sensor's performance in real-world settings, such as food or water samples, or even directly testing for bacterial infections in vivo, would be crucial for practical applications.
- Integration with microfluidics and IoT: Combining the sensor with microfluidic devices and IoT platforms could enable portable, real-time bacterial monitoring in various environments, from food production to healthcare settings.

Overall, Borgohain and Baruah's work provides a promising foundation for developing ZnO nanorod-based biosensors for rapid and accurate bacterial detection. Future research should focus on improving selectivity, sensitivity, and practical implementation to fully realise the potential of this technology in various fields.

2. V. V. Daigavane and M. A. Gaikwad, "Water Quality Monitoring System Based on IoT," in IEEE Internet of Things Journal, vol. 4, no. 6, pp. 2088-2095, Dec. 2017.
   Salient Features of the Research:
   - IoT Integration: The paper likely discusses the integration of Internet of Things (IoT) technologies in the context of water quality monitoring. This involves the use of sensors and communication devices to collect and transmit data.
   - Sensor Deployment: Details on the types of sensors used for water quality measurements. This could include sensors for parameters like pH, turbidity, dissolved oxygen, and other relevant indicators.
   - Communication Protocols: Information on the communication protocols employed to transmit data from the sensors to a central monitoring system. This may involve wireless technologies such as Wi-Fi, Bluetooth, or other IoT-specific protocols.
   - Data Analysis: Discussion on how the collected data is analyzed and processed. This might include the use of algorithms or machine learning techniques to derive meaningful insights from the raw sensor data.
   - Real-Time Monitoring: Emphasis on the real-time monitoring capability of the system, enabling prompt detection of water quality issues.

- User Interface: Description of the user interface or dashboard used to visualize the water quality data. This could be accessible through web applications or mobile apps.

Future scope of the research:

- Scalability: Expanding the system to monitor a larger area or multiple water bodies.
- Energy Efficiency: Improvements in the energy efficiency of sensors and communication devices, ensuring long-term sustainability.
- Integration with Smart Cities: Integration with broader smart city initiatives, allowing for a more comprehensive approach to urban environmental monitoring.
- Enhanced Sensor Technologies: Utilising advancements in sensor technologies for more accurate and diverse water quality measurements.
- Security and Privacy: Addressing concerns related to the security of data transmission and storage, as well as ensuring user privacy.
- Community Engagement: Involving local communities in the monitoring process, potentially through citizen science initiatives or educational programs.

3. M. Mukta, M. E. Miea, S. Islam, S. D. Barman, A. W. Reza, and M. S. H. Khan, "IoT-based Smart Water Quality Monitoring System," in IEEE Sensors Journal, vol. 19, no. 23, pp. 10725-10732, Dec. 2019. salient feature and future scope

   Salient Feature of the research paper

- Real-time data acquisition and analysis: The system utilises various sensors to measure key water quality parameters like pH, temperature, conductivity, and turbidity, providing real-time data access through an IoT platform.
- Cost-effective and scalable: The design employs readily available sensors and open-source software, making it accessible for implementation in a wide range of settings.
- Remote monitoring and alerts: Users can remotely access water quality data and receive alerts in case of parameter deviations beyond set thresholds, facilitating timely intervention.

- Data visualisation and historical analysis: The system provides tools for visualising real-time and historical data, enabling comprehensive water quality trends analysis.
- Integration with existing infrastructure: The design allows for easy integration with existing water supply systems and infrastructure, minimising implementation complexities.

Future Scope of the Research paper:

- Improved sensor accuracy and selectivity: Advancements in sensor technology could provide even more accurate and specific water quality measurements, facilitating better prediction and mitigation of potential problems.
- Advanced data analysis and predictive models: Utilising machine learning and AI algorithms could extract further insights from collected data, enabling predictive analysis of water quality changes and proactive interventions.

R. Borgohain, "Heavy-metal ion sensor using chitosan capped ZnS quantum dots," IEEE Sensors Journal, vol. 11, no. 20, pp. 2011-2015, 2011.

The salient feature of the research paper:

- Highly sensitive detection: The chitosan-capped ZnS quantum dots exhibited high sensitivity towards lead (Pb2+) ions, with a detection limit of 0.1 µM. This sensitivity is significantly higher compared to many conventional heavy metal sensors.
- Selective detection: The sensor demonstrates good selectivity towards Pb2+ ions, with minimal interference from other common metal ions, making it suitable for real-world applications where mixed metal contamination exists.
- Fluorescence quenching mechanism: The detection principle relies on the quenching of ZnS quantum dot fluorescence upon binding with Pb2+ ions. This offers a simple and reliable readout method for the sensor.
- Biocompatible and eco-friendly: Chitosan, a natural polymer used for capping the quantum dots, enhances biocompatibility and reduces the potential environmental impact of the sensor.

- Cost-effective synthesis: The fabrication of the sensor utilises readily available materials and simple synthesis techniques, making it potentially cost-effective for large-scale production.

Future Scope of the research paper:

- Enhancement of detection limit: Further research could explore strategies to improve the sensitivity of the sensor, potentially pushing the detection limit even lower for sensitive environmental monitoring or medical applications.
- Specificity improvement: While the sensor shows good selectivity for Pb2+, further studies could investigate specific functionalization techniques to achieve even higher selectivity and differentiate between even more closely related metal ions.
- Sensor stability and reusability: Improving the long-term stability of the chitosan-capped ZnS quantum dots and developing strategies for sensor regeneration could enhance the practical applicability and cost-effectiveness of the technology.
- Real-world deployment and integration: Testing the sensor performance in real-world environments like contaminated water or soil samples would be crucial for validating its practical effectiveness. Additionally, exploring integration with microfluidic devices or portable instrumentation could facilitate on-site and real-time heavy metal detection.
- Toxicity and environmental considerations: Further investigation into the potential environmental and biological impacts of chitosan-capped ZnS quantum dots should be conducted to ensure their safe and sustainable application in various settings.
- Overall, Borgohain's work presents a promising approach for developing highly sensitive and selective heavy metal sensors using biocompatible and eco-friendly materials. Future research focused on improving detection limits, selectivity, stability, and real-world implementation can pave the way for broader adoption of this technology in environmental monitoring, industrial applications, and even medical diagnostics.

2.4 Summarised outcome of the literature review

2.4.1 ZnO nanorods for heavy metal detection:

- Offer high sensitivity, selectivity, and cost-effectiveness for heavy metal detection.
- Recent advancements include doping, functionalization, heterostructures, and novel detection mechanisms for improved performance.
- Key challenges remain in enhancing selectivity between different metals, long-term stability, and addressing potential toxicity concerns.

2.4.2 IoT integration for heavy metal monitoring:

- Enables real-time data acquisition, remote access and control, and data-driven decision making for environmental monitoring.
- Microfluidic devices and wireless communication technologies are key advancements for on-site and remote monitoring.
- Energy efficiency of sensors and communication modules, data security and privacy, and robust network infrastructure are critical challenges.

2.4.3 Promising directions and future research:

- Focus on achieving highly selective ZnO nanorod sensors for differentiating between various heavy metals.
- Investigate novel detection mechanisms for faster response times and improved sensitivity.
- Enhance sensor stability and durability for long-term operation in harsh environments.
- Optimise energy efficiency of sensors and communication modules for sustainable IoT implementation.
- Develop secure and reliable data transmission and analysis platforms for robust environmental monitoring systems.

Overall:

ZnO nanorods offer a promising technology for sensitive, selective, and cost-effective heavy metal detection, with substantial potential for revolutionising environmental monitoring. Integrating these sensors with IoT platforms unlocks real-time data acquisition and analysis, paving the way for effective management of heavy metal pollution. Addressing current challenges and focusing on future research directions will be crucial for maximising the impact of this technology on a global scale.

2.5 Theoretical discussions

2.5.1 ZnO nanorods for heavy metal detection:

Detection Mechanisms:

- Adsorption: Heavy metal ions bind to the large surface area of ZnO nanorods, resulting in changes in electrical conductivity, mass, or optical properties (colour, reflectance).
- Charge transfer: Electrons transfer between the metal ions and ZnO, altering its conductivity or luminescence.

Factors Affecting Detection Performance:

- Structure and Size: Doping, functionalization, and heterostructures can enhance selectivity and sensitivity towards specific metals.
- Surface properties: Higher surface area leads to increased adsorption and detection sensitivity.
- Detection mechanism: Different mechanisms have varying responses and selectivities to different metals.

Advantages of ZnO Nanorods:

- High surface area and small size for enhanced interactions with metal ions.
- Tailorable properties through doping and functionalization.
- Multiple detection mechanisms offering flexibility.
- Relatively low cost and readily available materials.

Challenges:

- Distinguishing between different heavy metal ions can be challenging.
- Long-term stability and durability in harsh environments need improvement.
- Potential toxicity concerns need to be addressed, especially for environmental applications.

2.6 Conclusions

ZnO nanorods hold significant promise for sensitive and selective heavy metal detection, thanks to their large surface area, tailorable properties, and multiple detection mechanisms. Recent advancements in doping, functionalization, and heterostructures further enhance their performance.

Integrating ZnO nanorods with IoT platforms unlocks real-time data acquisition and analysis for environmental monitoring. This capability enables early detection of heavy metal contamination, facilitates data-driven decision making, and improves water quality management.

Key challenges remain in maximising the practical application of this technology:

- Selectivity: Differentiating between various heavy metals requires further research on targeted functionalization and innovative detection mechanisms.
- Long-term stability and durability: Enhancing the resistance of ZnO nanorods to harsh environments is crucial for real-world deployment.
- Energy efficiency and data security: Optimising sensor and communication energy consumption and ensuring robust data transmission and analysis are essential for sustainable and secure monitoring systems.

Future research directions should focus on:

- Developing highly selective ZnO nanorods for specific heavy metals.
- Investigating novel detection mechanisms for faster response times and improved sensitivity.
- Optimizing sensor stability and durability for long-term operation.
- Developing strategies for sustainable energy usage and secure data management.

By addressing these challenges and continuing research efforts, ZnO nanorod-based heavy metal detection integrated with IoT technology has the potential to revolutionize environmental monitoring, pollution control, and water quality management, contributing to a cleaner and healthier future.

CHAPTER-3
METHODOLOGY

3.1 Introduction

This chapter deals with the methodologies adopted in this project. This chapter contains information about the fabrication and designing of the sensor, testing of the sensor software used, hardware used and the device parameters adopted for the formation of the structure and the types of analyses done.

3.2 Fabrication of ZnO nanorod sensor

Zinc oxide (ZnO) nanorod sensors represent a class of gas sensing devices predicated upon the utilization of one-dimensional nanostructures characterised by a rod-like morphology. Renowned for their heightened sensitivity, these sensors discern diverse gases by quantifying alterations in electrical conductivity ensuing from the interaction between gas molecules and the ZnO nanorods. Noteworthy attributes encompass an elevated surface-to-volume ratio, expeditious response and recuperation intervals, and the prospect of achieving selectivity through the implementation of surface functionalization. ZnO nanorod sensors find application in realms such as environmental surveillance, industrial safety, and healthcare. The manufacturing methodologies encompass chemical vapor deposition and hydrothermal synthesis. On the frontier of research lies the imperative to augment selectivity, stability, and pragmatic amalgamation for ubiquitous deployment.

The steps for the fabrication process are discussed below.

3.2.1 Fabrication of electrode

The fabrication of copper electrodes has the following steps :

- The PCB was designed by creating the circuit layout using PCB design software like Diptrace.
- The design was then printed onto photo paper using a laser printer.
- A copper plate was prepared by cutting it to match the PCB size and cleaning its surface with isopropyl alcohol.

- The design was transferred by placing the photo paper onto the copper plate with the toner side facing down.
- The paper was ironed onto the copper plate using high heat for 2-3 minutes.
- The copper plate was immersed in ferric chloride etchant for 10-15 minutes until the exposed copper was etched away.

- The plate was removed from the etchant, rinsed thoroughly with water, and the photo paper was peeled off.

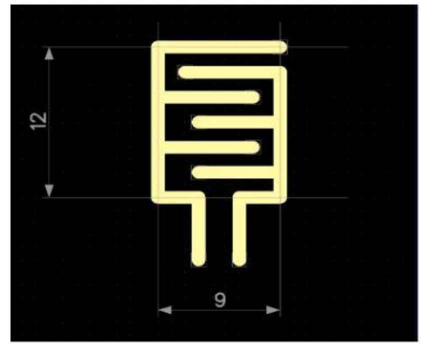

Fig 3.1 Design of PCB layout

3.2.2 Synthesis of ZnO nanoparticles

The steps for the synthesis of Zno nanoparticles are:

- *Preparation of Zinc Acetate Solution:* 20 mL of 4mM zinc acetate dihydrate [$Zn(CH_3COO)_2.2H_2O$] was prepared using ethanol (C_2H_5OH) and subjected to rigorous stirring at 50°C for an hour
    (a) Calculation of weight zinc acetate dihydrate in 20 ml ethanol**:**

    Weight = (Number of Moles).(Molar mass of Zinc Acetate Dihydrate)
    = (Molarity x volume).**(**Molar mass of Zinc Acetate Dihydrate)
    = (4mM X 20 mmol) X 219.49g/mol
    = 0.0175g

    (b) Chemical Reaction

$$Zn(CH_3COO)_2.2H_2O \xrightarrow{\text{(Ethanol)}} Zn_2^{+} + 2CH_3COO^{-} + 2H_2O$$

- *Dilution of Zinc Acetate Solution:* An additional 20 mL of fresh ethanol was added to the previously prepared ZincAcetate solution to dilute it.
- *Addition of Sodium Hydroxide solution:* At room temperature, 20 ml of 4mM Sodium hydroxide solution, also utilizing ethanol as the solvent was added to the dilute Zinc Acetate solution under mild stirring for approximately 30 minutes
    a) Calculation of weight Zinc Acetate Dihydrate in 20 mL ethanol :

Weight = Number of Moles X Molar mass of Zinc Acetate Dihydrate

= (Molarity X Volume) X Molar mass of Zinc Acetate Dihydrate

= (4mM X 20 ml) X 39.997g/mo = 0.0032g

b) Chemical Reaction : $Zn^{2+} + 2OH^{-} \rightarrow Zn(OH)_2$

- *Formation of ZnO :* The above mixture was then placed in a water bath at 60·C for an hour. The mixture was then cooled to room temperature.

a) Chemical Reaction :

$$Zn(OH)_2 \xrightarrow{\text{(Heat)}} ZnO + H_2$$

3.2.3 Seeding of ZnO nanoparticles

The steps for seeding of ZnO nanoparticles are:

- We take the PCB where the designis made for the seeding process.
- We have to clean the substrate using deionized water before starting the Hydrothermal process.
- After this we dry the substrate for 15 mins at temperature of 60 degrees Celsius.
- After drying we dip it in a solution containing the ZnO nanoparticles for 15 mins.
- Again we have to dry it for 15 mins at 90 degrees Celsius.
- We have to again perform step 4 and step 5 two more times.
- After completing these steps a good fixation of seeded ZnO nanoparticles on the substrate takes place.

3.2.4 Growth of ZnO nanorod

The following steps are performed for the growth of the ZnO nanorod:

- The seeded substrate is placed inverted in a petri dish such that its surface is in contact with the above solution.
- After the completion, the substrate is washed thoroughly with deionized water to remove any existing solution.
- An equimolar solution of zinc nitrate hexahydrate [Zn(NO3)2.6H2O] and hexamine [C6H12N4] is prepared.

- The setup is then kept in the oven for 15 hours. After every 5 hours, the solution mixture is changed.
- The growth of ZnO nanorods on the seeded substrate is carried out in a hot air oven maintained at 90°C.

Fig 3.2 Fabricated ZnO nanorod sensor

3.3 Working Principle of Zno nanorod sensor

Zinc oxide (ZnO) nanorods are used as sensitive elements in detecting heavy metals. These nanorods possess unique electrical properties that are influenced by the presence of heavy metal ions in the surrounding environment.

When exposed to a solution containing heavy metal ions, such as iron, copper, or chromium, these ions adhere to the surface of the ZnO nanorods. This interaction alters the distribution of charge carriers within the nanorods, affecting their conductivity.

As a result, the resistance of the ZnO nanorod sensor increases or decreases depending on the type and concentration of the detected heavy metal ions. This change in resistance serves as a measurable indicator of the presence and quantity of heavy metals in the sample.

3.4 System set up for ZnO nanorod sensor for detecting heavy metals

3.4.1 Hardware circuit

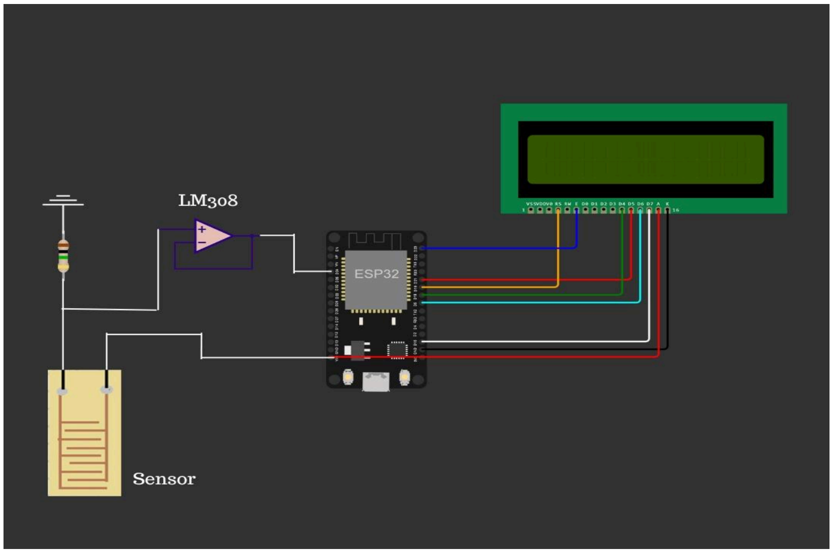

Fig 3.3 Hardware Circuit

1. ZnO Nanorod Sensor:

The sensor is used to measure the resistance, which changes based on the concentration of heavy metals in water. It is shown on the left side of the circuit.

2. Voltage Divider:

The sensor is connected in series with a resistor, forming a voltage divider. This configuration allows the voltage across the sensor to vary with its resistance.3.Operational Amplifier (LM308):The voltage from the divider is fed into an LM308 operational amplifier. The op-amp is configured as a buffer used for stabilizing the signal for accurate reading.

4. ESP32 Microcontroller:

The stabilized voltage is then input to the ESP32 microcontroller, which reads the voltage corresponding to the sensor's resistance.

5. LCD Display:

The ESP32 processes this data and sends it to an LCD display, where the resistance value is shown.

3.4.2 Functional Block Diagram

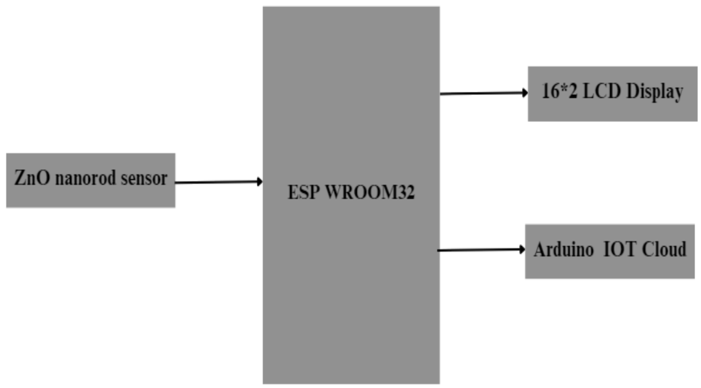

Fig 3.4 Functional Block Diagram

The block diagram shows the integration of a ZnO nanorod sensor with an ESP32 (ESP WROOM32) microcontroller. The sensor detects resistance changes based on the concentration of heavy metals in water. This resistance data is sent to the ESP32 for processing. The processed data is displayed on a 16*2 LCD screen for real-time monitoring. Additionally, the ESP32 connects to the Arduino IoT Cloud, enabling remote monitoring and data logging of the sensor readings online. This setup provides a thorough system for detecting and monitoring heavy metal concentrations in water, both locally on the LCD and remotely via the IoT cloud.

3.5Preparation of test solution

3.5.1 Preparation of Fecl$_3$ solution

A 40ppm (0.2466 mM)master solution was made in 100 ml of deionized water. After that, it was diluted to 0.001 ppm, 0.005 ppm, 0.1 ppm, 0.2 ppm, 0.3 ppm, and 0.4 ppm.

weight of the solute = (Number of moles) X(Molar mass of FeCl3)

= Molarity×Volume (L)×Molar mass (g/mol)

=0.0002466M×0.1L×162.2g/mol=0.004g

3.5.2 Preparation of CrO_3 solution

A 40ppm (0.4 mM)master solution was made in 100 ml of deionized water. After that, it was diluted to 0.001 ppm, 0.01, 0.02 ppm, 0.03 ppm, and 0.04 ppm.

weight of the solute = (Number of moles) X(Molar mass of FeCl3)

= Molarity×Volume (L)×Molar mass (g/mol)

=0.0004M×0.1L×99.99g/mol=0.0039g

3.5.3 Preparation of $CuSO_4$ solution

A 40ppm (0.25 mM)master solution was made in 100 ml of deionized water. After that, it was diluted to 0.01 ppm, 0.1 ppm, 0.5 ppm, 1 ppm, 1.5 ppm, and 2 ppm.

weight of the solute = (Number of moles) X(Molar mass of FeCl3)

= Molarity×Volume (L)×Molar mass (g/mo

=0.00025M×0.1L×159.609g/mol=0.004g

CHAPTER 4

CHARACTERISATION AND RESULTS DISCUSSION

4.1 Introduction

We synthesized ZnO nanorods using a hydrothermal method and thoroughly characterized them using several advanced techniques. Scanning electron microscopy (SEM), transmission electron microscopy (TEM), selected area electron diffraction (SAED), and UV-Vis spectroscopy were employed to analyze their morphology, structure, and optical properties. We then fabricated a sensor using these ZnO nanorods and tested it with various solutions to evaluate its performance.

4.2 Chracterisation Result

4..2.1 TEM, SEM and SAED image of ZnO nanorod

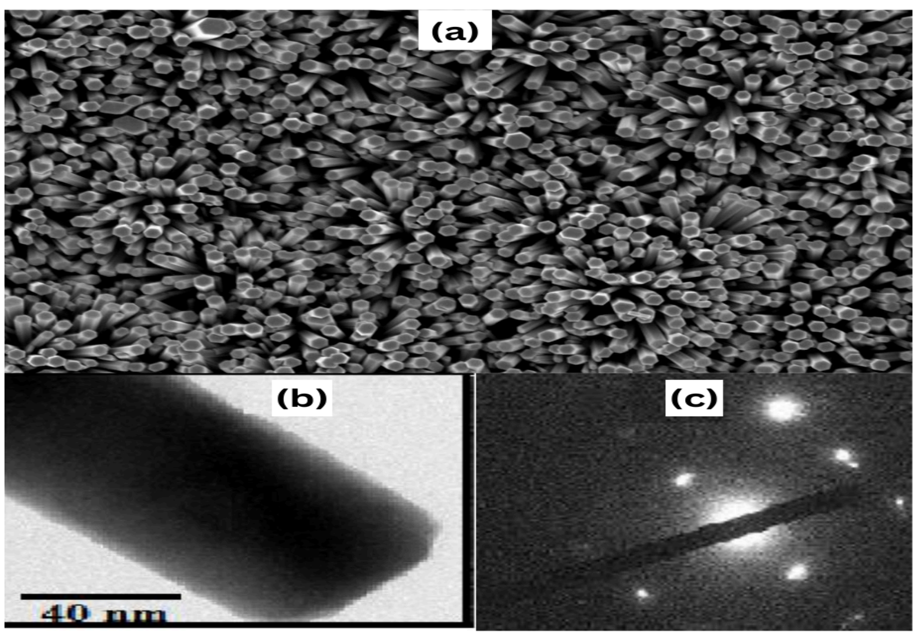

Fig. 4.1 (a) SEM image of ZnO nanorod (b) TEM image of ZnO nanorod (c) SAED pattern of ZnO nanorod

Fig. 4.1 (a) shows the SEM image of ZnO nanorod. It provides insights into their surface morphology which plays a crucial role in determining the nanorods' properties and interactions with their environment. The backscattered electrons in SEM imaging are sensitive to variations in surface topography and composition, allowing for the visualization of surface roughness and texture. The observed surface roughness of the nanorods impact their mechanical, optical and catalytic properties. The above image shows a dense array of uniformly distributed ZnO nanorods, indicating successful synthesis with consistent diameter and alignment, ideal for applications requiring high surface area and uniformity.

Fig. 4.1 (b) show the TEM image of the nanorods. The TEM image displays a single, smooth, and straight ZnO nanorod with a width of approximately 40 nm, confirming its high crystallinity and structural integrity.

Also, the TEM image allows for the observation of surface features and defects at the atomic scale, which can influence the nanorods' properties, including their chemical reactivity and electronic behavior.

Fig. 4.1 (c) show the selected area diffraction pattern (SAED) of the nanorods. The SAED pattern shows distinct diffraction spots, confirming the crystalline nature of the ZnO nanorods and hexagonal wurtzite structure of the ZnO nanorod, indicating high-quality crystal formation.

4.2.2 UV-VIS spectroscopy and Tauc Plot

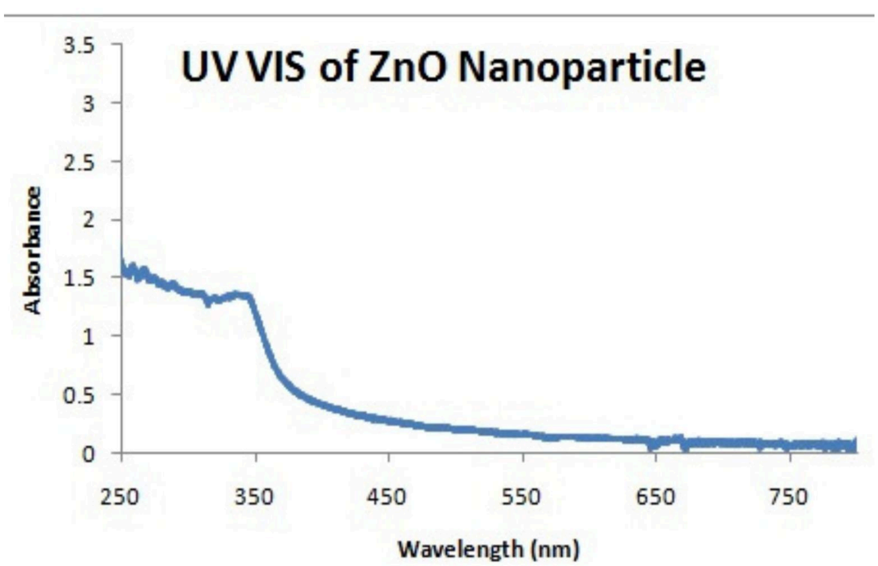

Fig 4.2 UV-VIS spectroscopy

UV-Vis spectroscopy is a critical analytical technique used to determine the optical properties of materials, such as ZnO nanorods. It measures the absorbance of UV and visible light, providing information about the electronic transitions within thig 4.2 UV-VIS spectroscopy of ZnO nanoparticlese material

In this graph of ZnO nanoparticle we can see that the ZnO particle absorbs UV light at a wavelength of 350 nm .

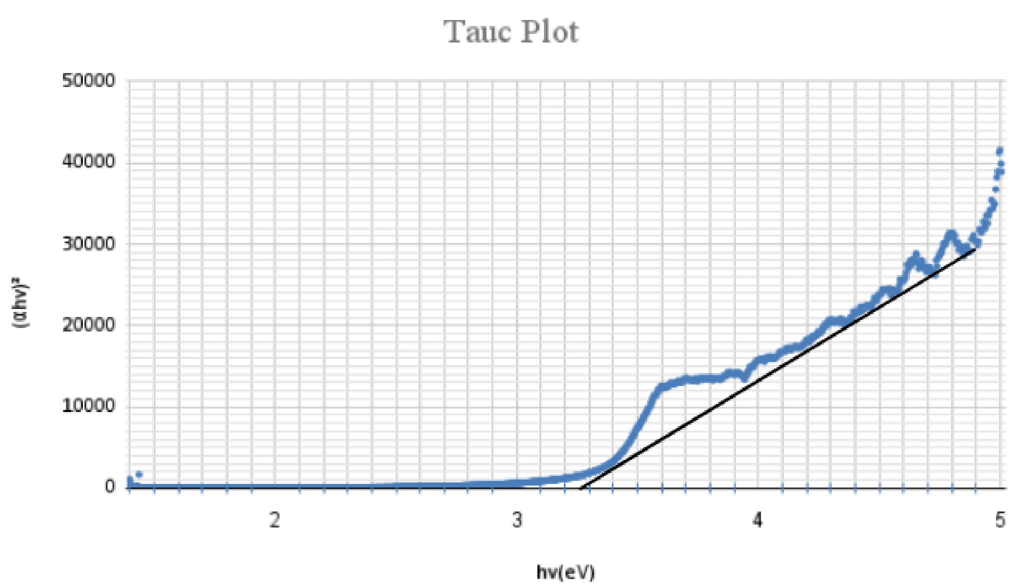

Fig4.3 Tauc Plot

On the other hand Tauc plot is a method derived from the UV-Vis absorbance data to determine the optical band gap ZnO particle accurately . It involves plotting $(\alpha h\nu)^2$ versus the photon energy hν, where α is the absorbance coefficient and hν is the photon energy. The absorbance coefficient can be calculated using the formula given below.

α= (2.303*A)/d , where A is absorbance and d is the thickness of the sample (=1cm)

After plotting the Tauc plot a tangent is drawn in at point the graphs start to linearly increase. The tangent cuts the x axis at approximately in 3.3eV which is the bandgap of ZnO.

4.3 Testing with test solutions

The resistance of the sensor in presence of air and deionsied water are found to be 7.71 MΩ and the 6.17 MΩ respectively. Taking deionised water as reference the future testing is done with the test solutions.The response and sensitivity is calculated using the formulas given below:

Response = $\{[R_{DI}-R]/R_{DI})\}x100\%$

Where, $R_{DI\,=}$ Resistance of deionised water

R= Resistance of the heavy metal at given concentration

Sensitivity=[Change in Resistance /Change in concentration] (MΩ/PPM)

4.3.1 Testing with Fe^{3+} ion

Concentration (in ppm)	**Resistance (MΩ)**	**Sensitivity (MΩ/ppm)**	**Response (%)**
0.1	2.8	3.03	54.57
0.2	2.5		59.52
0.3	2.26		63.42
0.4	1.89		69.38

Table 4.1 - Concentration, Resistance, Sensitivity and Response Data for Iron

Limit of detection = 0.01ppm (resistance found to be 6.07 MΩ)

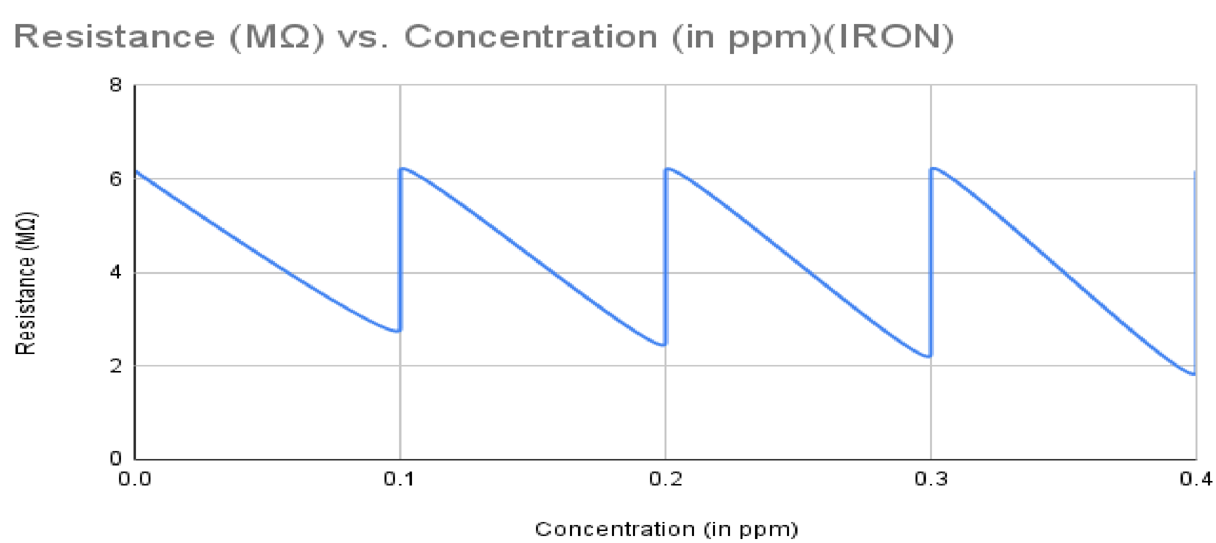

Fig 4.4 Resistance vs Concentration graph of Iron

From the table 4.1 we can see that with Iron the sensors resistance decreased with increase in concentration as the conductivity increases. The sensitivity with Iron is found to be 3.03 (MΩ/ppm). The response of the sensor increases slightly increases with concentration but approximately remains same. From the Fig 4.4 we can see that the sensor shows repeatability as when we washed the sensor with deionised water after each reading the sensor goes back to its the resistance of deionised water which is 6.17 MΩ. The limit of detection for Iron is found to be at 0.01ppm which is 6.07MΩ.

4.3.2 Testing with Cr^{6+} *ion*

Concentration (in ppm)	**Resistance (MΩ)**	**Sensitivity (MΩ/ppm)**	**Response (%)**
0.01	2.85	38.33	53.77
0.02	2.55		58.75
0.03	2.45		60.17
0.04	1.7		72.54

Table 4.2 - Concentration, Resistance, Sensitivity and Response Data for Chromium

Limit of detection = 0.001ppm (resistance found to be 5.85 MΩ)

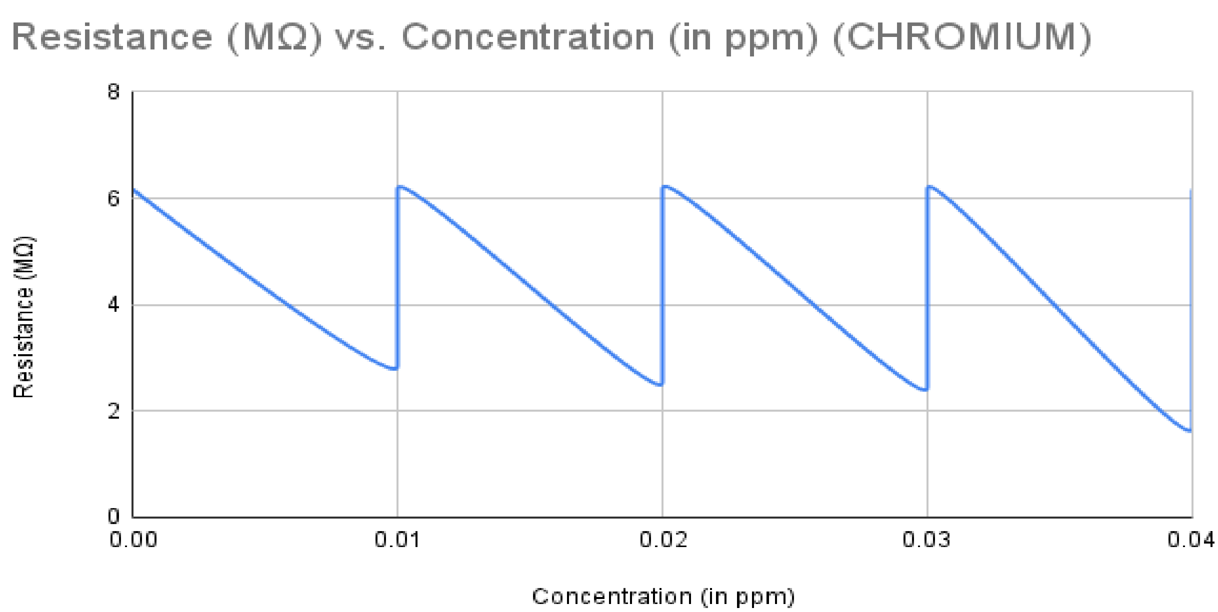

Fig 4.5 Resistance vs Concentration graph of Chromium

From the table 4.2 we can see that with Chromium the sensors resistance decreased with increase in concentration as the conductivity increases. The sensitivity with Chromium is found to be 38.33 (MΩ/ppm). The response of the sensor increases slightly increases with concentration but approximately remains same. From the Fig 4.4 we can see that the sensor shows repeatability as when we washed the sensor with deionised water after each reading the sensor goes back to its the resistance of deionised water which is 6.17 MΩ. The limit of detection for Iron is found to be at 0.001ppm which is 5.85MΩ.

4.3.3 Testing with Cu^{2+} ion

Concentration (in ppm)	**Resistance (MΩ)**	**Sensitivity (MΩ/ppm)**	**Response (%)**
0.1	3.62	0.785	41.32
0.5	3.06		50.4
1	2.82		54.29
1.5	2.51		59.32
2	2.19		64.5

Table 4.3 - Concentration, Resistance, Sensitivity and Response Data for Copper

Limit of detection = 0.01ppm (resistance found to be 6.04 MΩ)

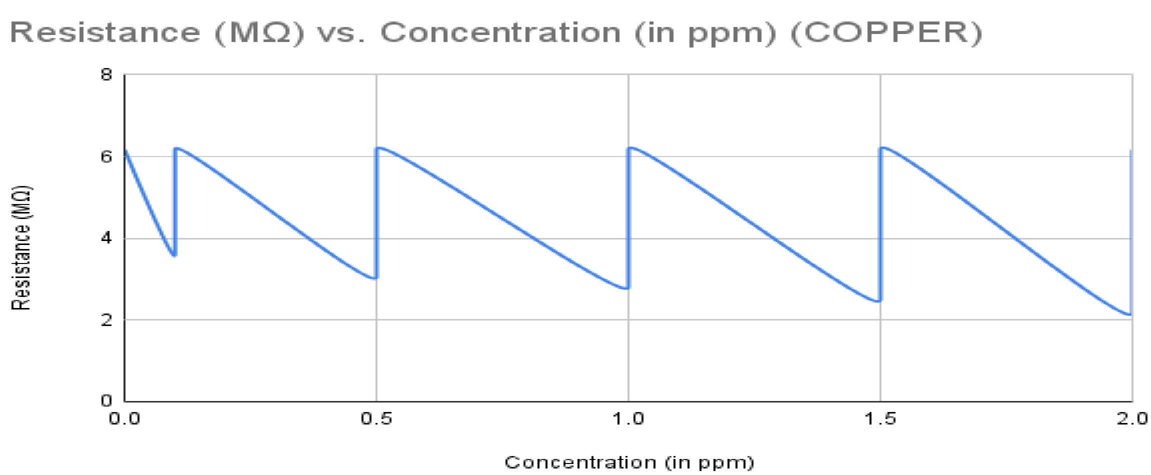

Fig 4.6 Resistance vs Concentration graph of Copper

From the table 4.3 we can see that with Copper the sensors resistance decreased with increase in concentration as the conductivity increases. The sensitivity with Chromium is found to be 0.785(MΩ/ppm). The response of the sensor increases slightly increases with concentration but approximately remains same. From the Fig 4.4 we can see that the sensor shows repeatability as when we washed the sensor with deionised water after each reading the sensor goes back to its the resistance of deionised water which is 6.17 MΩ. The limit of detection for Copper is found to be at 0.001ppm which is 6.04M

4.3.4 Sensitivity vs Heavy metal

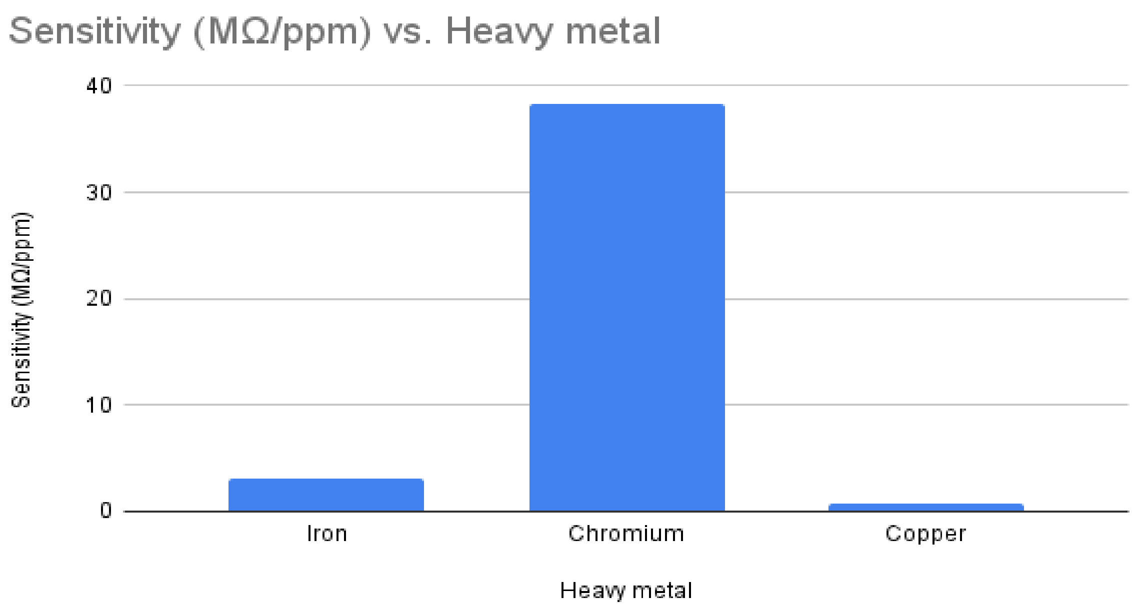

Fig 4.7 Sensitivity vs Heavy metal graph

From the graph it can be seen that for different metal the overall sensitivity is different .From the graph it can see that for Iron sensitivity is 3.03 MΩ/ppm and for Chromium it is found to be 38.33 MΩ/ppm and has sensitivity value of 0.785MΩ/ppm. for Copper .Thus, form the graph we can infer that the sensor has moderate response to change in the concentration of Iron and very strong response in detecting the change in Chromium . Meanwhile, Copper exhibits lowest sensitivity indicating lower response to change in detecting copper. Therefore from the graph it can be inferred that the sensor is highly selective towards Chromium.

4.3.5 Concentration vs Response

4.3.5.1 Concentration vs Response of Iron

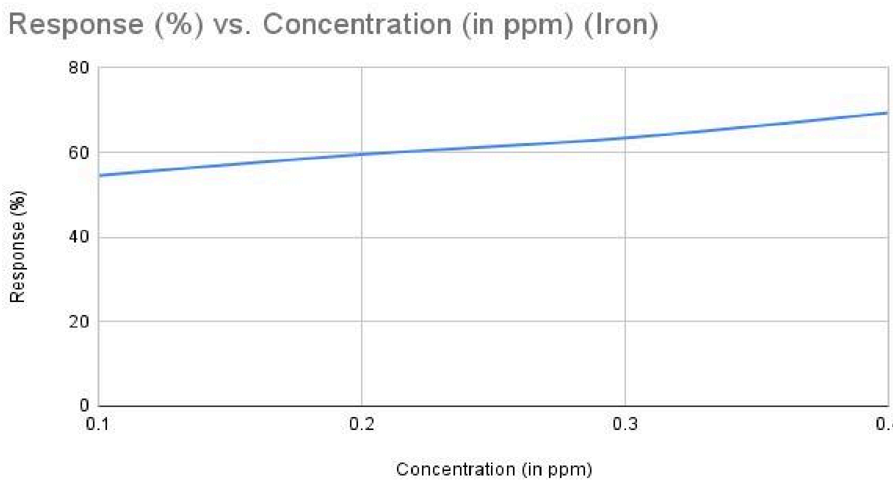

Fig 4.8 Response vs Concentration graph of Iron

From the fig 4.8 and table 4.1 we can see that as we increase the concentration of iron the response also increases . Which indicates that the sensor is sensitive to change in iron concentration.

4.3.5.2 Concentration vs Response of Chromium

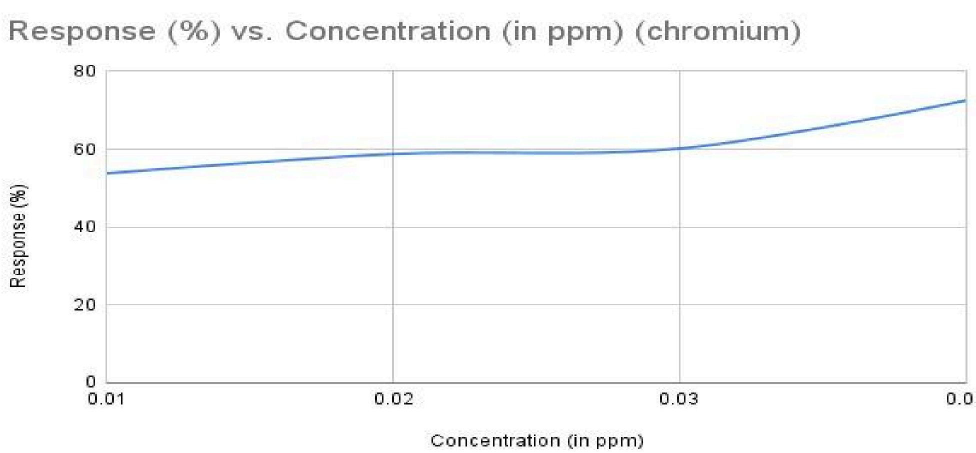

Fig 4.9 Response vs Concentration graph of Chromium

From the fig 4.9 and table 4.2 we can see that as we increase the concentration of chromium the response also increases.Which indicates that the sensor is sensitive to change in chromium concentration.

4.3.5.3 Concentration vs Response of Copper

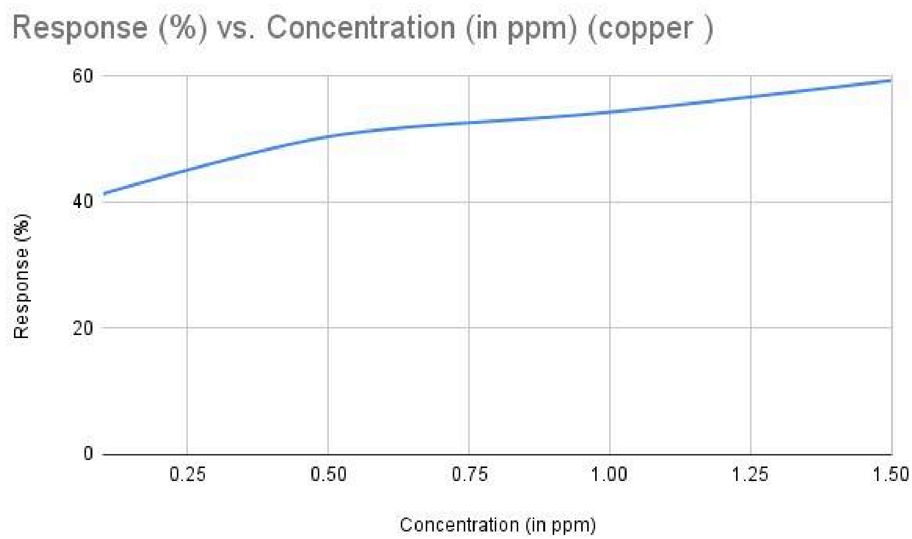

Fig 4.10 Response vs Concentration graph of Copper

From the fig 4.10 and table 4.3 we can see that as we increase the concentration of copper the response also increases.Which indicates that the sensor is sensitive to change in copper concentration.

4.3.6 Response time of the sensor with different heavy metal ions

4.3.6.1 Response time of Iron

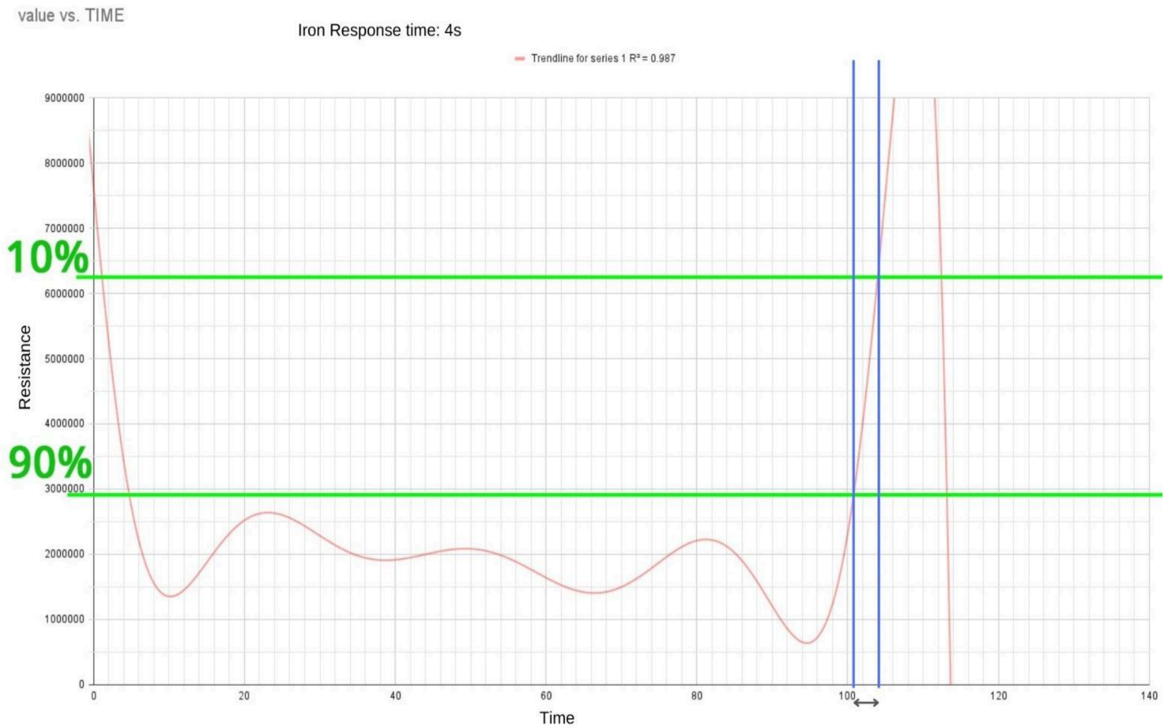

Fig 4.11 Response Time of Iron

From the figure we can see that the response time of sensor with respect to Iron is 4 seconds.

4.3.6.2 Response time of Chromium

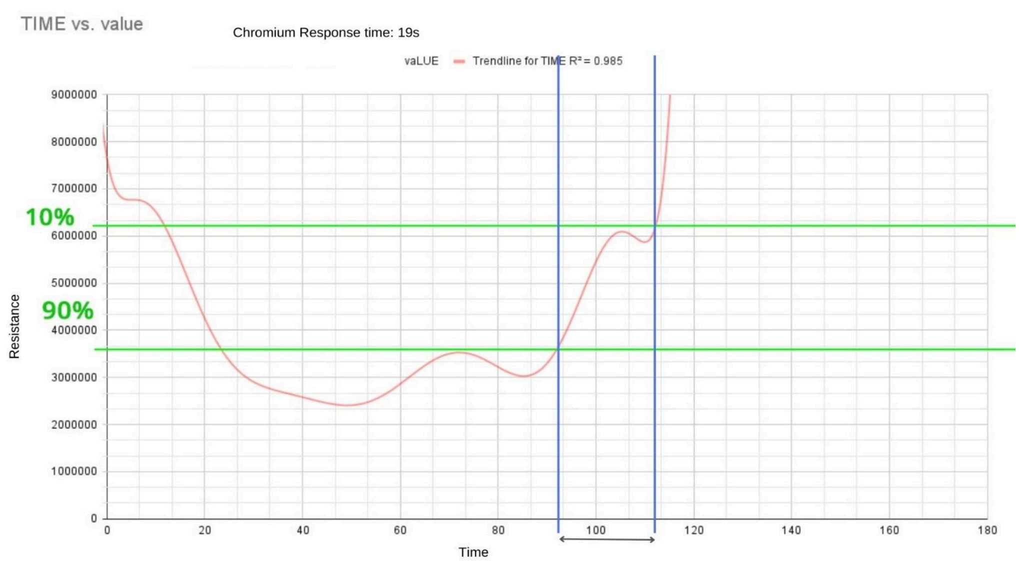

Fig 4.12 Response Time of Chromium

From the figure we can see that the response time of sensor with respect to Chromium is 19 seconds.

4.3.6.3Response time of Copper

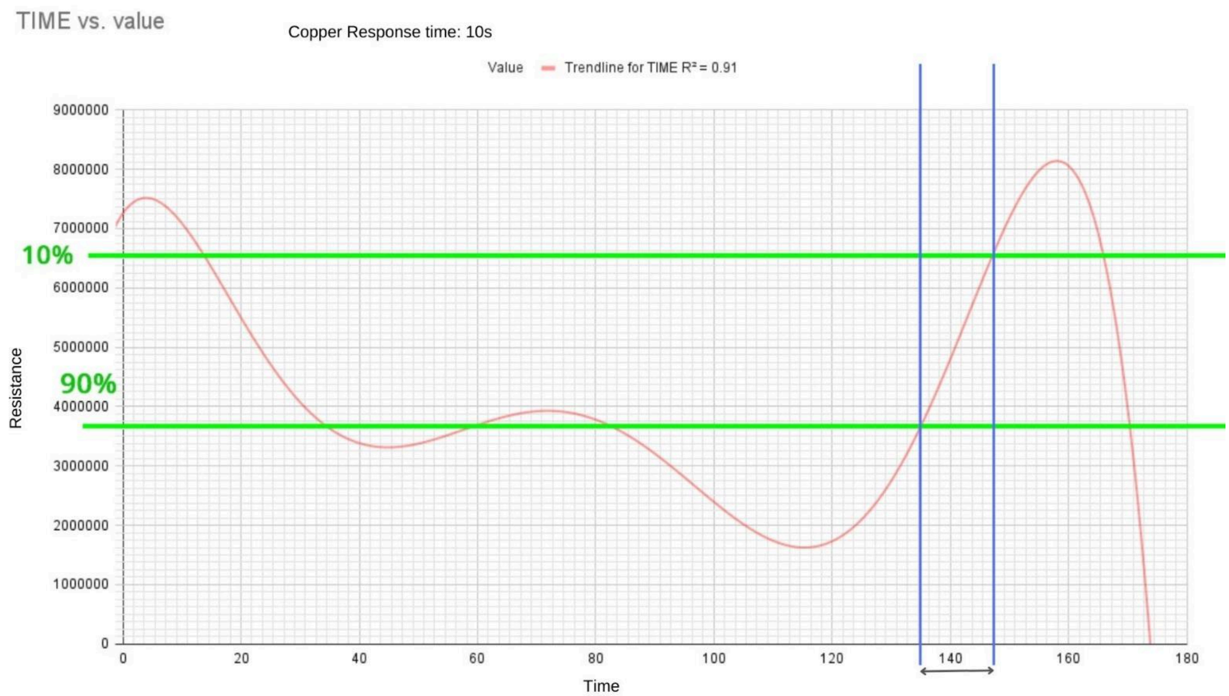

Fig 4.13 Response Time of Copper

From the figure we can see that the response time of sensor with Copper is 10 seconds.

4.3.6.4 Response Time vs Heavy metals

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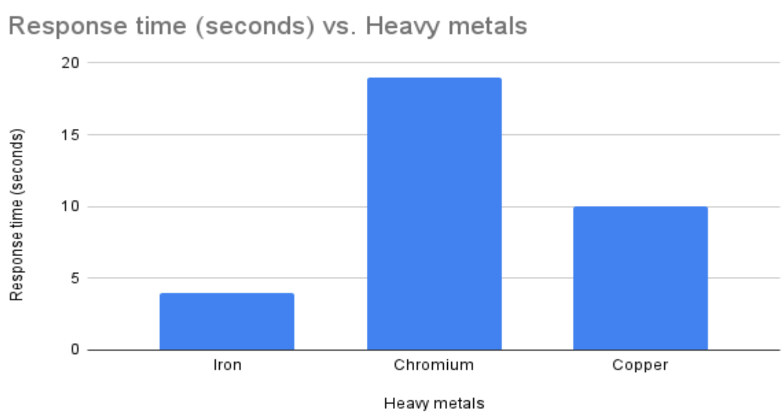

Fig 4.14 Response Time vs Heavy metals

From the Fig 4.14, we can see that the sensor exhibits the shortest response time for Iron, suggesting high efficiency in detecting Iron quickly**.** In contrast, the sensor takes longer to stabilize for Copper and Chromium, indicating medium and lower efficiency in detecting those ions .

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Brief summary of the work

5.1.1 Problem statement and objective

The project titled "Development of a ZnO Nanorod-Based IoT-Integrated Sensor for Real-Time Detection of Heavy Metal Ions in Water" involves developing a ZnO nanorod sensor to detect the presence of heavy metal .

The main objectives of this project is to

- Develop a ZnO nanorod sensor to detect the presence of heavy metals.
- To integrate the sensor using IoT technology for real-time data collection, transmission, and remote monitoring.

5.1.2 Work Methodology

A proper methodology was followed throughout the project, beginning with the selection of components such as the ESP32 module, LM308 operational amplifier and a 16x2 LCD display. The ZnO nanorod sensor was fabricated in the Nanolab with precision. Software tools, specifically the Arduino IDE, were chosen for programming the circuit. Following this, the hardware components were meticulously assembled, integrating the ZnO nanorod sensor, LM308 and LCD display with the ESP32 module. The system was then connected to the IoT using Arduino Cloud, enabling remote and real-time monitoring. Successive testing of heavy metals was conducted to ensure the sensor's functionality and accuracy in detecting heavy metal ions with successful IoT integration ensuring effective real-time data transmission . Successful tests validated the sensor's performance, leading to the accomplishment of the project objectives .

5.2 Conclusion

The following are the conclusion of the project

- *Resistance Decrease*: With rising heavy metal ion levels, the sensor consistently showed decreased resistance as the conductivity increases.

- *Specific Sensitivity:* Each metal exhibited unique sensitivity values: 3.03 MΩ/ppm for iron, 38.33 MΩ/ppm for chromium, and 0.785 MΩ/ppm for copper, ensuring accurate quantification of contaminants.
- *Response :* As we increase the concentration of heavy metal the sensor's response also increases which indicates that at higher concentration the sensor is more sensitive to the change in detecting the change.
- *Response time:*The response time of Iron is very less which indicates that the sensor is able to detect the Iron quickly . Copper has moderate response time and Chromium has the longest response time.
- *Repeatability:* After each reading, washing the sensor with deionized water restored resistance to a consistent baseline of 6.17 MΩ, affirming its repeatability and reliability for continuous usage.

5.3 Future scope of work

In the realm of future work, there exists a multitude of avenues to explore for the enhancement and expansion of the project's scope. Firstly, efforts can be directed towards refining the sensor's capabilities, aiming to improve sensitivity and selectivity towards a broader spectrum of heavy metal ions. This could involve delving into novel nanomaterials or innovative surface functionalization techniques to augment detection efficiency. Additionally, integrating advanced IoT platforms and data analytics methodologies could empower the sensor for real-time monitoring and predictive analysis, offering insights into water quality trends and facilitating early detection of contamination events. Field testing in diverse environmental settings, such as industrial sites or natural water bodies, would further validate the sensor's robustness and practical utility. Moreover, streamlining the sensor's design and fabrication processes to enable mass production and commercialization could significantly broaden its accessibility and deployment potential. Furthermore, exploring the integration of multi-parameter monitoring capabilities and user-friendly mobile applications could provide a more comprehensive understanding of water quality dynamics while enhancing stakeholder engagement and usability. By embarking on these future endeavours, the project stands poised to continue its impactful contributions towards addressing the complex challenges of heavy metal contamination in water resources and advancing the landscape of environmental monitoring.

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ANNEXURES

```
#include <LiquidCrystal.h>
#define inputPin 34

#include "thingProperties.h"
LiquidCrystal lcd(19, 23, 18, 17, 16, 15);

void setup() {
  // Initialize serial and wait for port to open:
  Serial.begin(115200);
  int resistance = 0;

  // This delay gives the chance to wait for a Serial Monitor without blocking if none is found
  delay(1500);
  pinMode(inputPin, INPUT);
  lcd.begin(16, 2);
  lcd.print("Final Year");
  lcd.clear();

  // Defined in thingProperties.h
  initProperties();

  // Connect to Arduino IoT Cloud
  ArduinoCloud.begin(ArduinoIoTPreferredConnection);
  setDebugMessageLevel(2);
  ArduinoCloud.printDebugInfo();
}

void loop() {
  ArduinoCloud.update();
```

```
  float value = analogRead(inputPin);
  float voltage = (3.3 / 4095) * value;
  float intermediatevalue = (3.3 * 1000000) / voltage;
  int resistance = intermediatevalue - 1000000;

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("resistance");
  lcd.setCursor(0, 1);
  lcd.print(resistance);
  delay(3000);

  lcd.clear();
  Serial.print("Resistance = ");
  Serial.print(resistance);
  Serial.println(" ohms");
}

void onResistanceChange() {
  // Handle changes in resistance
}
```