RAMAIAH
Institute of Technology

Department of Electrical & Electronics Engineering

A Project Report on

IoT Enabled Successive Ionic Layer Adsorption and Reaction Coating Device

Submitted in partial fulfillment of the requirements for the award of the degree of

Bachelor of Engineering in Electrical and Electronics Engineering

By

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Department of Electrical &
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CERTIFICATE

Certified that the project work entitled **IoT Enabled Successive Ionic Layer Adsorption and Reaction Coating Device** is carried out by Harsh Vardhan 1MS19EE021, Prayushi Doshi 1MS19EE038, Ravuri Sai Chaitra 1MS19EE044 and Rounit Verma Anand 1MS19EE046, bonafide students of **M S Ramaiah Institute Of Technology, Bengaluru** in partial fulfillment for the award of **Bachelor of Engineering in Electrical and Electronics Engineering** of Visvesvaraya Technological University, Belagavi during the year **2022-23**. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the department library. The project report has been approved as it satisfies the academic requirements in respect of project work prescribed for the said degree.

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DECLARATION

We, hereby, declare that the entire work embodied in this project report has been carried out by us at M S Ramaiah Institute of Technology, Bengaluru, under the supervision of **Mr. Ramakrishna Murthy K.** This report has not been submitted in part or full for the award of any diploma or degree of this or any other University.

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ABSTRACT

Thin film deposition is a widely used technique in various fields such as optics, electronic semiconductor devices, and aerospace. One of the popular techniques for thin film deposition is the successive ionic layer adsorption and reaction (SILAR), which involves sequential immersion of a substrate into separate precursor solutions, resulting in the deposition of thin film on the substrate.

SILAR coating can be done manually, but it can be time-consuming, hazardous, and non-uniform but since the automation of this process, it has become easier to perform this technique. However, these existing devices are very expensive and hence, unaffordable for many industries and researchers.

This work has been aimed to design and develop an inexpensive but effective SILAR coating device that can be easily utilized by end-users without requiring cutting-edge hardware abilities. The device is incorporated with an ESP-32 microcontroller as the main core and an IoT platform to enable remote monitoring of the coating process in real-time. The objective has been to reduce the cost and design complexity of the machine while ensuring efficient and precise thin film deposition.

The developed device provides a simple setup for holding the substrate and dipping it into different solutions by customizing the number of beakers, cycles, dip, and drip duration to get thin and uniform coating on the substrate. The incorporation of IoT technology allows remote control and monitoring of the coating process in real-time, providing greater convenience and flexibility for the user. Due to its low cost and ease of use, this machine can be advantageous to educational institutions, keen researchers, and industries for demonstration and industrial purposes. The SILAR coating device has been developed to offer an affordable and efficient solution for thin film deposition, making it a valuable tool for material science and engineering applications.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Thin film coating is a process of depositing a layer of material on a substrate to modify its properties or enhance its performance. Thin films are typically in the range of a few nano meters to several micrometers thick, and the materials used for thin film coatings can vary widely, including metals, ceramics, polymers, and organic compounds. The deposition of thin films can be achieved through several techniques, such as physical vapor deposition (PVD), chemical vapor deposition (CVD), atomic layer deposition (ALD), and spray coating. Each technique has its advantages and disadvantages, and the choice of method depends on the desired properties of the coating, the substrate material, and the application requirements.

SILAR (Successive Ionic Layer Adsorption and Reaction) coating is a thin film deposition technique that involves the sequential immersion of a substrate in a solution containing precursor materials, followed by rinsing and drying steps. Each immersion cycle forms a new layer of the material on the substrate, resulting in a conformal and uniform coating.

The SILAR technique is simple, low-cost, and can be applied to a wide range of substrates, including glass, metals, and polymers. The method is versatile and allows for the deposition of various materials, including metals, oxides, and chalcogenides.

SILAR coating has numerous applications in various fields, including solar cells, sensors, catalysis, and corrosion protection. In solar cells, SILAR coating has been used to deposit layers of photoactive materials to enhance the absorption of sunlight and improve energy conversion efficiency. In sensors, SILAR coatings have been used to modify surface properties and enhance sensitivity to analytes. In corrosion protection, SILAR coatings have been used to create protective layers on metal surfaces, reducing their susceptibility to corrosion.

1.2 Literature Survey

In [1] various thin-film coating methods and how they combine high-quality performance with cost-effectiveness is discussed. This article provides an overview of different methods used for thin-film coatings and emphasizes the importance of achieving both high-quality performance and cost-effectiveness in the coatings industry. Crucial role of thin film on applications such as optical coatings, corrosion protection, electronic devices, etc., are highlighted.

The paper also discusses different thin-film coating methods such as physical vapor deposition (PVD), chemical vapor deposition (CVD), and sol-gel coating. The author elaborates on the advantages and limitations of each method, as well as their applications and potential cost-effectiveness.

In [2], a detailed overview of the design and control of an automatic dipping system used in coating production processes is presented. The authors emphasize the importance of automation in coating production to improve efficiency, productivity, and quality of coated products. The article presents a comprehensive control scheme for the automatic dipping system, which includes feedback and feedforward control strategies to regulate the dipping process. The authors describe the use of sensors and actuators to monitor and adjust the dipping parameters in real-time, ensuring accurate and consistent coating results.

An open-source equipment for thin film fabrication using three different methods such as electrodeposition, dip coating, and SILAR (Successive Ionic Layer Adsorption and Reaction) is discussed in [3]. The article provides detailed information on the design and construction of the open-source equipment, including the materials, components, and fabrication process. The paper also discusses the control and automation aspects of the equipment, including the use of microcontrollers and open-source software for precise and reliable operation. The experimental results demonstrating the performance and versatility of the open-source equipment for thin film fabrication in presented to showcase the successful deposition of thin films using electrodeposition, dip coating, and SILAR methods.

[4] provides an overview of the working principles of the ESP32 microcontroller module and presents an analytical comparison of using low-cost microcontroller modules in embedded systems design. This paper begins by introducing the ESP32 microcontroller module, which is a popular and affordable choice for embedded systems development. The authors provide an overview of the key features and functionalities of the ESP32, including its dual-core processor, built-in Wi-Fi and Bluetooth capabilities, and support for various communication protocols.

The article then discusses the working principles of the ESP32 microcontroller module, including its architecture, memory organization, and peripheral interfaces. The authors highlight the versatility and flexibility of the ESP32 in supporting a wide range of applications, from simple sensor-based systems to complex IoT solutions. Furthermore, the article presents an analytical comparison of using low-cost microcontroller modules, including the ESP32, in embedded systems design. The authors compare the performance, power consumption, ease of programming, and cost factors of the ESP32 with other popular microcontroller modules, such as Arduino and Raspberry Pi. The article also discusses the advantages and limitations of using low-cost microcontroller modules in embedded systems design, including considerations such as scalability, reliability, and development tools. The authors provide insights into the challenges and opportunities of using low-cost microcontroller modules in various application domains, including industrial automation, smart agriculture, and wearable devices.

In [5], an in-depth review of the control methods for stepper motors is discussed. Various techniques for controlling stepper motors, including open-loop and closed-loop control methods, as well as micro stepping techniques are also discussed. The article also covers advanced control techniques, such as sensor less control, predictive control, and adaptive control, that are used in high-performance stepper motor applications.

Furthermore, the article discusses the applications of stepper motors in various industries, such as automotive, aerospace, robotics, medical, and manufacturing. The authors provide examples of how stepper motors are used in different applications, such as CNC machines, 3D printers, surveillance systems, and positioning systems. The article also highlights the advantages of using stepper motors in specific applications, such as their precise motion control, high torque at low speeds, and ease of integration with digital control systems.

[6] presents a detailed discussion on the modeling of linear actuators. The mathematical models used for linear actuator analysis and control, including electrical, mechanical, and electromechanical models are discussed. The article also discusses the dynamic behavior of linear actuators, such as the influence of friction, load, and inertia, on their performance. It also presents various approaches for modeling linear actuators, including lumped-parameter models, distributed-parameter models, and empirical models. The advantages and limitations of each approach and highlight their applications in different scenarios.

[7] introduces the concept of IoT and its potential applications in manufacturing. It highlights the importance of real-time monitoring of machine and system performance in modern manufacturing environments to ensure efficient operations and timely decision-making. The article then presents a comprehensive review of the state-of-the-art techniques and technologies for real-time performance monitoring in manufacturing. Various approaches, including data-driven methods, model-based methods, and hybrid methods, for monitoring machine and system performance are discussed. Different types of sensors, data acquisition techniques, and communication protocols used in IoT-based performance monitoring are also reviewed.

Furthermore, the article presents a detailed discussion on the challenges and opportunities associated with implementing IoT-based performance monitoring in manufacturing. It discusses issues such as data accuracy, data integration, scalability, security, and privacy, and provide insights on how to address these challenges. The article also includes a case study that demonstrates the application of IoT-based performance monitoring in a manufacturing setting. The design and implementation of a real-time monitoring system for a multi-stage manufacturing process, including the selection of sensors, data acquisition, data analysis, and visualization is discussed.

In conclusion, the article provides a detailed overview of the use of IoT for real-time monitoring of machine and system performance in manufacturing. It covers various techniques, technologies, challenges, and opportunities associated with implementing IoT-based performance monitoring. The article can be a valuable resource for researchers, engineers, and practitioners working in the field of manufacturing automation, IoT, and industrial data analytics.

1.3 Summary of literature survey

- Dip coating is one of the most cost-effective and provides high quality results.
- SILAR coating is a type of thin-film deposition technique that involves the deposition of a metal or metal oxide coating onto a substrate surface.
- The thickness of the coating can be controlled by varying the concentration of the precursor solution, the immersion time, and the number of coating cycles.
- The control scheme of a dip coating device involves integrating sensors, actuators, and a microcontroller to precisely control the dipping process, ensuring accurate and consistent coating results.
- The control system uses feedforward control strategies to precisely adjust the motion of the substrate.

- ESP32 is a versatile and flexible microcontroller, which supports a wide range of applications, from simple sensor-based systems to complex IoT solutions.
- Key features and functionalities of the ESP32 include its dual-core processor, built-in Wi-Fi, and Bluetooth capabilities.
- Stepper motors are commonly used for dip coating automation because of their ability to precisely control the movement and position of the substrate. Various techniques for controlling stepper motors, including open-loop and closed-loop control methods have been discussed.
- For remote and real-time monitoring of the device, IoT should be enabled with the to ensure data accuracy, data integration, scalability, security, and privacy, and provide insights on how to address these challenges.

1.4 Problem Statement

Removal of cost barrier in thin film coating based education and research through an affordable IoT Enabled SILAR coating device.

1.5 Objective

The objectives of the work are as follows:

1. To develop a cost-effective SILAR coating device.
2. To integrate IoT for data monitoring purposes.
3. To test the developed prototype for its functionality.

1.6 Organization of Chapter

The project report discusses about the Successive Layer Ionic Adsorption and Reactance coating device and its characteristics. The focus is on eliminating the financial obstacle that researchers and educational institutions encounter in thin film coating process. The report has been broadly divided into five chapters as follows.

Chapter 1 deals with the brief introduction to the entire project and the literature survey undertaken to get familiarized to this field of research.

Chapter 2 focuses on the introduction to successive ionic layer adsorption and reaction and different thin film coating techniques

Chapter 3 concentrates on methodology and implementation of the whole project

Chapter 4 focusses on discussion of results on characterization

Chapter 5 conclusion and future scope.

CHAPTER 2

INTRODUCTION TO SUCCESSIVE IONIC LAYER ADSORPTION AND REACTION

2.1 Thin Film Coating Techniques

Thin film technology is a versatile and widely used process that helps improve the properties of bulk materials in various industries. By depositing a thin layer of material onto a substrate, thin film coating can alter the surface properties of the substrate to enhance its mechanical, physical, and chemical characteristics.

It is widely used in various industries, including electronics, aerospace, medical, nanotechnology and automotive, among others.

There are several types of thin film coating techniques as shown in Fig. 2.1 :

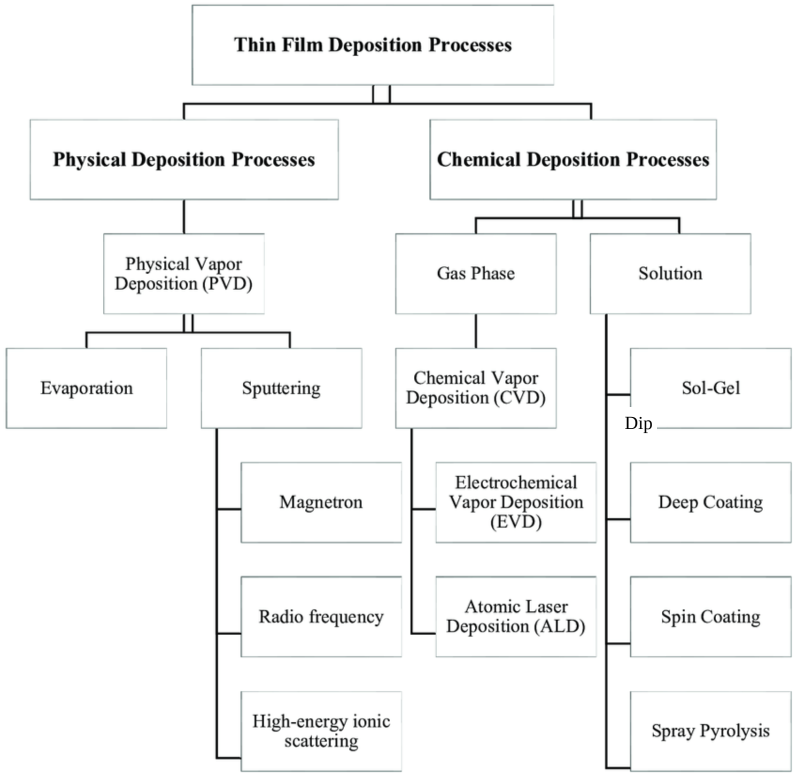

Fig.2.1 Classification of Thin Film Coating techniques

Physical Deposition Processes: Physical deposition processes are techniques used to create thin films of materials on a substrate by depositing atoms, molecules, or ions through physical methods. There are several types of physical deposition processes, including:

1. Physical Vapor Deposition: A process of depositing a thin film of material onto a substrate by evaporating the material in a vacuum and then condensing it onto the substrate surface. The advantages of PVD include high purity, good adhesion, and precise thickness control. However, the disadvantages of PVD are that it can be

expensive, limited to certain types of materials, and require high vacuum conditions and specialized equipment. The different types of PVD are discussed below:

a. Evaporation: A material is heated to a high temperature, causing it to evaporate and form a vapor that is directed towards the substrate. The vaporized material then condenses onto the substrate surface, forming a thin film. It is a relatively simple process that can produce high-purity films with good control of thickness and composition, but it is limited to materials with relatively low melting points and can be prone to thermal stress and poor adhesion.

b. Sputtering: a target material is bombarded with high-energy ions in a vacuum chamber, causing atoms from the target material to be ejected and deposited on a substrate. The ejected atoms form a plasma, which is then directed towards the substrate. It can deposit a wider range of materials and can produce films with good adhesion and uniformity, but it can be more complex, costly, and prone to film defects such as particulate contamination. There are three ways of bombarding the target material:

    i. Magnetron: The magnetron is used to generate a plasma of ionized gas that bombards the target material with high-energy ions.

    ii. Radio frequency: In RF sputtering, the target material is bombarded with high-energy ions generated by a plasma of ionized gas that is created by applying a high-frequency electromagnetic field.

    iii. High energy ionic scattering: As the ion beam interacts with the surface atoms, some of the ions will be scattered back in the direction of the detector. The scattered ions can provide information about the positions and bonding of surface atoms, as well as the presence of impurities or defects.

Chemical Deposition Processes: These processes involve the use of a chemical precursor, which is a volatile compound that is thermally or photochemically decomposed to form a solid film on the substrate, for deposition of thin film coating on the substrate. The classification is as follows:

1) Gas Phase: A process that involve the deposition of thin films from the gas phase. In this process, a precursor gas is introduced into a reactor chamber, where it reacts with another gas or with the substrate to form a solid film.
    a) Chemical Vapor Deposition: In CVD, the precursor gas is introduced into a reactor chamber, where it reacts with the substrate or with another gas to form a solid film. This reaction is typically initiated by heating the substrate or by introducing energy in the form of plasma or light. Advantages of CVD include high-quality films, precise control, large area coverage, and high deposition rates. Disadvantages include complexity, high cost, and limited material compatibility.
        i) Electrochemical Vapor Deposition: A process that involves the transport of species in a vapor phase generated from an electrolyte solution to a substrate under the influence of an electrical field.
        ii) Atomic Layer Deposition: A thin-film deposition technique that utilizes self-limiting surface reactions to deposit films one atomic layer at a time.

2) Solution: Solution-based chemical deposition processes involve the use of solutions containing dissolved precursors that react to deposit thin films onto a substrate. These processes are cost-effective and can be used to deposit a wide range of materials.

   a) Sol-Gel: Sol-gel coating is a solution-based chemical deposition process that involves the conversion of a liquid solution into a solid film by a series of chemical reactions.

   b) Dip Coating: Dip coating is a wet chemical deposition process that involves immersing a substrate in a solution of the desired coating material, followed by withdrawal at a controlled rate to form a thin film. Advantages of dip coating include simplicity, cost-effectiveness, and versatility. Disadvantages include limited control over film thickness and the potential for uneven coating.

   c) Spin Coating: Spin coating is a thin film deposition technique that involves applying a liquid coating material onto a rotating substrate, resulting in a uniform and controlled coating thickness.

   d) Spray Pyrolysis: A chemical deposition process that involves the atomization of a precursor solution into fine droplets, which are then heated to form a thin film.

2.2 Market Survey

The global market for thin film materials is projected to grow from $ 9.8 billion in 2020 to $11.8 billion by 2025 at a CAGR of 3.7% as shown in Fig.2.2. The global solar photovoltaic (PV) market grew by 22% in 2020, reaching a record 142 GW of new installations. SILAR coatings have shown up to a 10% increase in conversion efficiency in the solar industry as shown in Fig. 2.4. The global lithium-ion battery market is projected to grow from USD 36.7 billion in 2020 to USD 129.3 billion by 2027 at a CAGR of 18.0% as shown in Fig. 2.3. SILAR coatings improve the capacity and lifespan of lithium-ion batteries. The global catalyst market is projected to grow from USD 30.1 billion in 2020 to USD 40.5 billion by 2027 at a CAGR of 4.0%. SILAR coatings improve the performance of catalysts used in various chemical reactions.

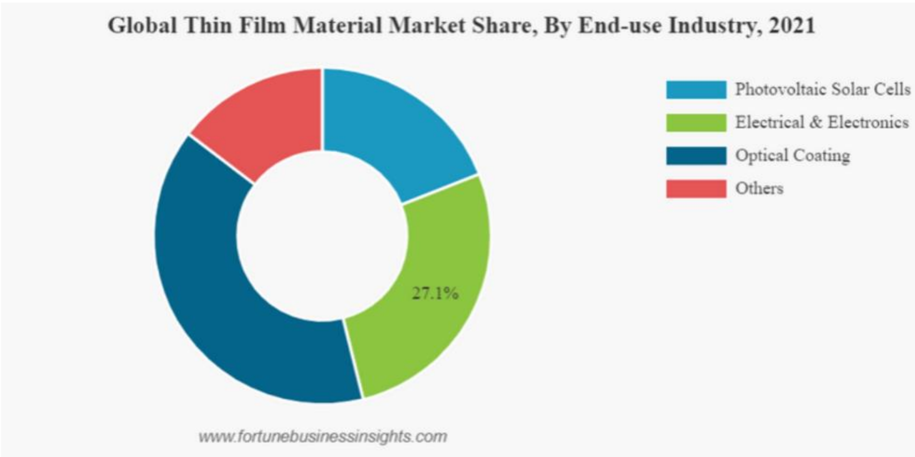

Fig.2.2 Global Solar PV market [16]

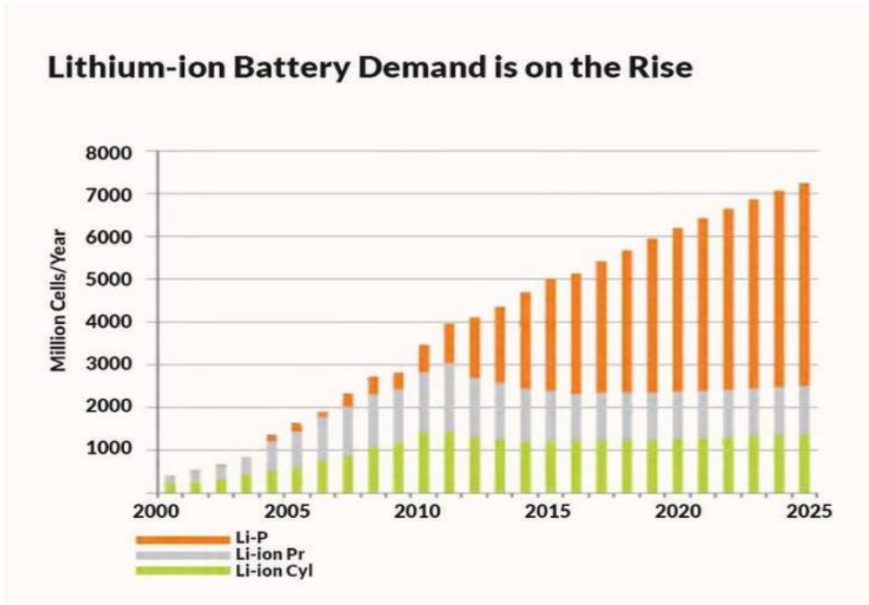

Fig.2.3 Global Lithium-ion battery market [16]

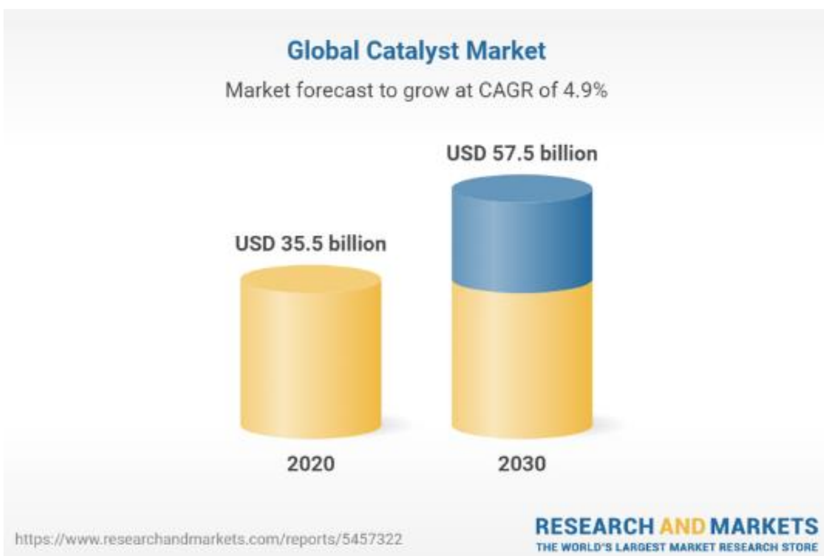

Fig.2.4 Global catalyst market [17]

2.3 Successive Ionic Layer Adsorption and Reaction (SILAR) Coating

SILAR (Successive Ionic Layer Adsorption and Reaction) coating is a type of chemical bath deposition (CBD) method used to deposit thin films on a substrate. It involves the alternate immersion of a substrate into two or more solutions containing ions of the desired coating material, followed by a reaction step to form a thin film.

The SILAR coating process involves the following steps:

1. The substrate is immersed in a solution containing a precursor ion of the coating material.

2. After a predetermined time, the substrate is removed and rinsed with a solvent to remove excess solution.

3. The substrate is then immersed in a second solution containing a counter-ion that reacts with the precursor ions adsorbed on the substrate surface.

4. After a predetermined time, the substrate is removed and rinsed with a solvent to remove excess solution.

5. The process is repeated by alternating between the precursor and counter-ion solutions until the desired coating thickness is achieved. Fig. 2.5 shows the procedure of SILAR coating technique.

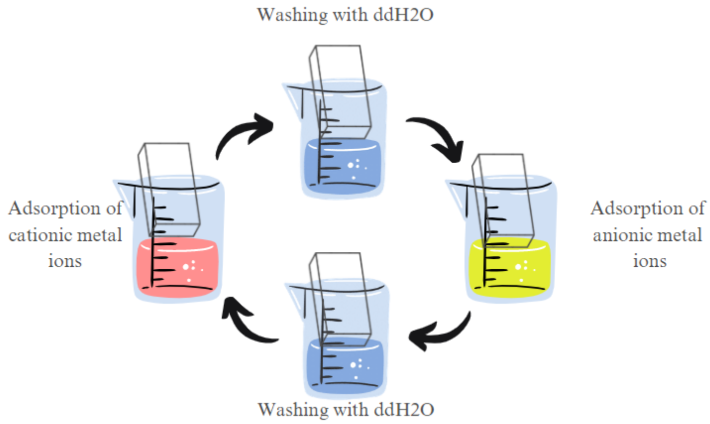

Fig.2.5 Procedure to perform SILAR coating technique

There are several existing devices which make this process happen automatically like, Holmarc's SILAR Coating System with Stirrer, SILAR Coating System with Magnetic Stirrer, SILAR System without heater and Stirrer, SILAR Coating System with Overhead Stirrer.

Fig 2.6 Holmarc's SILAR Coating System with Stirrer [18]

Fig.2.6 shows Holmarc's SILAR Coating System with Stirrer. The driving mechanism is stepper motor. It weighs around 48 Kg, can accommodate maximum of six beakers and runs at power of 230V, 50 Hz. Here, five samples at a time can be loaded. It costs around 4 lakhs.

Fig 2.7 Holmarc's SILAR Coating System with Magnetic Stirrer [18]

Fig.2.7 shows SILAR Coating System with Magnetic Stirrer which drives using lead screw. The maximum number of samples loaded at one time is five with maximum number of beakers as four. The rated power input is 230V, 50Hz. It costs around 7 lakhs.

Fig 2.8 Holmarc's SILAR System without heater and Stirrer [18]

Fig.2.8 shows Holmarc's SILAR System without heater and stirrer. This device is almost like the device in Fig.2.6. It runs at 230V, 50Hz with maximum accommodation of beaker as six. This also weighs around 50 Kg, but it costs around 5 lakhs.

Fig 2.9 Holmarc's SILAR Coating System with Overhead Stirrer [18]

SILAR Coating System with Overhead Stirrer is shown in Fig.2.9. It weighs 130 Kg. The stirrer speed here ranges from 0-999 rpm, depending on the need of the user. It has hot plate as an additional feature, ambient to temperature 200℃. As it is heavier, and has more features, it costs around 9 lakhs.

2.4 IoT- Enabled Successive Ionic Layer Adsorption and Reaction Device

The high cost of existing machines, which typically range from 2 to 7 lakhs, as mentioned in section 2.3, presents a significant challenge for educational and research institutions that wish to acquire them. This cost barrier can make it difficult for these institutions to invest in the necessary equipment to conduct research or teach students about the technology.

The work deals with design and development of inexpensive but effective IoT enabled SILAR coating device. The objective of work is to reduce cost and design complexity and enable the end-users to utilize the device without employing cutting-edge hardware abilities. It incorporates microcontroller as the main core and an IoT platform to enable remote monitoring and control of the coating process in real-time. The device provides a simple setup for holding the substrate and dipping it into different solutions by customizing the number of beakers, cycles, dip and drip duration to get thin and uniform coating on the substrate. It can be of immense use to educational institutions, keen researchers and industries for demonstration and industrial purposes as it is affordable and easy to use.

2.5 Advantages of inhouse developed IoT-Enabled SILAR Coating Device:

The advantages of a SILAR (Successive Ionic Layer Adsorption and Reaction) coating device include:

1. Simple and cost-effective: SILAR coating devices are relatively simple and low-cost to manufacture and operate compared to other coating methods, making them accessible to a wider range of users.
2. Precise control: SILAR coating allows for precise control over the thickness and uniformity of the coating layer, enabling the user to achieve the desired coating properties.
3. Versatile: SILAR coating can be applied to a wide range of substrates and materials, including semiconductors, metals, and ceramics, making it a versatile coating technique.
4. Conformal coating: SILAR coating can provide conformal coating, meaning the coating material conforms to the shape of the substrate and covers the surface uniformly and completely.
5. High surface area coverage: SILAR coating can cover large surface areas, making it ideal for coating thin films and nanostructures.
6. Environmentally friendly: SILAR coating typically involves the use of water-based solutions and is less harmful to the environment compared to other coating methods that use organic solvents or toxic chemicals.

CHAPTER 3

METHODOLOGY AND IMPLEMENTATION

In the present work, IoT based Successive Layer Ionic Adsorption and Reaction device has been developed and tested, featuring remote monitoring and user interactivity. The device incorporates an IoT system that allows for real-time monitoring of the deposition process, making it possible to optimize the coating parameters for improved performance. The device has demonstrated its ability to coat various substrates with excellent uniformity, adhesion, and thickness. The remote monitoring capability and user interactivity make this device an attractive solution for a wide range of industrial applications. Its selection, preparation and characterization are explained in below section.

3.1 Components Selection

The components used for the construction of the device were selected based on their quality, reliability, and compatibility with the design. The key components used included a NEMA 17 bipolar stepper motor, ESP32 Microcontroller, L298N motor driver, A4988 motor driver, DC motor, LCD, I2C module, keypad and Teflon rod.

3.1.1 NEMA 17 bipolar stepper motor (17HS4401S)

The NEMA 17 bipolar stepper motor is a popular choice for SILAR coating devices due to its compact size, high torque output, and precise control.

Firstly, the compact size of the NEMA 17 stepper motor makes it an ideal choice for small-scale SILAR coating devices. Its small form factor allows it to be easily integrated into the design of the device, without taking up too much space.

Secondly, the NEMA 17 stepper motor offers high torque output, which is important in SILAR coating devices since it needs to move the dipping mechanism smoothly and at a consistent speed, even under varying loads. The high torque output also helps to ensure that the substrate is immersed in the chemical solutions at a consistent rate, which is critical for the uniformity and reproducibility of the coating.

3.1.1.1Stepper motor torque calculation

$$\mu = 0.05.$$

$$g = 9.81\ m/s^2$$

$$i = 1$$

$$d = 20\ cm$$

$$F = 0$$

m = 0.4 kg

$$T = \frac{(\mu F + mg)d}{2i}\ N - cm$$

$$T = 39.24\ N - cm$$

where:

μ is frictional coefficient

g is acceleration due to gravity in m/s^2

i is gear ratio

d is diameter in cm

T is torque in $N - cm$

m is mass of circular plate in kg

NEMA17 bipolar stepper motor has a high torque output of 43 N-cm, requires a rated current of 1.7A to operate, has a small step angle of 1.8 degrees, and a holding torque of 1.2 N-m, which makes this stepper motor ideal choice for this project.

3.1.2 ESP32 Microcontroller

ESP32 is a microcontroller that is well-suited for IoT applications, and it has several features that make it a good choice for use in SILAR coating devices. ESP32 has built-in Wi-Fi and Bluetooth connectivity, which allows it to communicate with other devices over the internet or Bluetooth without requiring additional hardware. This can be helpful for monitoring the SILAR coating device remotely. The ESP32 has a current consumption of

70mA and an operating voltage range of 2.2-3.6V. ESP32 has 39 GPIO (General Purpose Input/Output) pins. ESP32 microcontroller is used to control speed and direction of movement of DC and stepper motors in SILAR coating devices which will improve the precision and accuracy of the coating process, leading to higher-quality and more uniform coatings.

3.1.3 L298N Motor driver

The L298N is a popular motor driver IC that is often used in SILAR coating devices for controlling the DC motors that are used for agitation and mixing of the ionic solutions during the coating process. The L298N motor driver typically has a maximum operating voltage of 46V and a maximum current rating of 2A per channel. This driver is used extensively because of its high current capability, dual H-bridge configuration, protection features, and ease of use. It allows for precise control of the agitation and mixing of the ionic solutions, which is important for achieving uniform coating thickness and properties. The L298N motor driver can amplify the current supplied to the DC motor, allowing it to drive motors with higher current requirements. This is important in SILAR coating devices, where the DC motor may need to be powerful enough to agitate and mix the ionic solutions used in the deposition process. The L298N motor driver can control the direction of rotation of the DC motor, allowing it to be used for both agitation and mixing of the solutions during the coating process. The L298N motor driver includes protection features such as thermal shutdown and overcurrent protection, which help to prevent damage to the motor and the motor driver in case of a fault or malfunction. The L298N motor driver is a low-cost solution for controlling DC motors, making it an attractive choice for SILAR coating devices that need to be cost-effective.

3.1.4 A4988 Motor driver

The A4988 motor driver is a popular stepper motor driver used in many applications, including SILAR coating devices. The A4988 motor driver typically has a maximum current rating of 2A per phase and a maximum voltage rating of 35V. The A4988 motor driver is a popular choice for controlling stepper motors in SILAR coating devices because of its high precision, high torque, support for micro stepping, ease of use, and low cost. The A4988 motor driver supports micro stepping, which allows for even finer control of the motor movement. This can help to achieve even higher precision in the coating process. The A4988 motor driver can provide very precise control of the stepper motor, allowing for accurate positioning of the substrate during the coating process. This can help to achieve a uniform coating thickness and properties. Stepper motors require high torque to move the substrate precisely, especially when dealing with heavier loads. The A4988 motor driver can provide high torque to the stepper motor, ensuring that the substrate moves smoothly and accurately. The A4988 motor driver is easy to use and requires only a few external components, making it a popular choice for DIY projects and prototyping. The A4988 motor driver is relatively inexpensive, making it a cost-effective solution for controlling stepper motors in SILAR coating devices.

3.1.5 DC Motor

DC motors are used in SILAR coating device for the agitation and mixing of the ionic solutions during the coating process and for linear movement for the substrate to dip in the solution. Agitation of the ionic solutions is important in the SILAR coating process as it helps to promote the diffusion of ions and the nucleation of particles on the substrate. The geared DC motor has voltage rating of 12v with no-load current of 200mA and torque range of 1.5 to 6 kg-cm. DC motors can be controlled to provide precise and consistent agitation speed, which is important for the reproducibility and uniformity of the coating process. DC motors can provide high torque, which is important for applications that require high agitation forces, such as mixing viscous solutions. DC motors are generally quieter than other types of motors, such as AC motors, which can be important in laboratory environments where noise can be a disturbance. The SILAR coating device employs two DC motors: one for linear motion with a rated speed of 500 rpm, and another for stirring with a rated speed of 200 rpm. The linear motor is responsible for driving the linear motion of the system, while the stirrer motor is used to agitate and mix the contents of the system.

3.1.6 LCD

An LCD can display real-time information about the coating process, such as the number of beakers, Dip duration in seconds, drip duration in seconds, number of cycles and Speed of the mechanical stirrer in rpm. This can help the operator monitor the coating process and make any necessary adjustments in real-time. An LCD can be used to display the status of the SILAR coating process, such as the number of cycles left. This can help the operator keep track of the progress of the coating process and ensure that it is proceeding as expected. An LCD can be used as a user interface for the SILAR coating device, allowing the operator to input commands and parameters for the coating process. This can help simplify the operation of the device and make it more user-friendly.

3.1.7 I2C module

The I2C (Inter-Integrated Circuit) module is often used in SILAR coating devices for communication between the microcontroller and Display.I2C requires only two wires (SCL and SDA) for communication, which can simplify the wiring and reduce the number of pins required on the microcontroller. This can help to reduce the overall size and complexity of the SILAR coating device.I2C is a low-power protocol that uses a synchronous, serial communication protocol. This can help to reduce the power consumption of the device, which can be important in battery-powered or portable SILAR coating devices.I2C is a widely used communication protocol with a well-established standard, making it a reliable and robust option for SILAR coating devices.

3.1.8 Keypad

A keypad can provide a user interface for the operator to interact with the SILAR coating device. The keypad can be used to input parameters such as the number of beakers, Dip duration in seconds, drip duration in seconds, number of cycles and Speed of the mechanical stirrer in rpm.

3.1.9 Teflon Rod

Teflon (polytetrafluoroethylene, PTFE) rod is used in SILAR coating device as a stirrer for the solution the beaker. Teflon is highly resistant to chemical attack and is non-reactive with most solvents and chemicals used in the SILAR coating process. This makes it an ideal material for the stirrer. Teflon has a non-stick surface. Teflon has a high melting point and can withstand high temperatures without degrading, which is important in the SILAR coating process where elevated temperatures may be required. Teflon has a low coefficient of friction.

3.2 Assembly of the Model

Assembly of the model started by preparing the 2D and 3D model using software named Fusion 360.

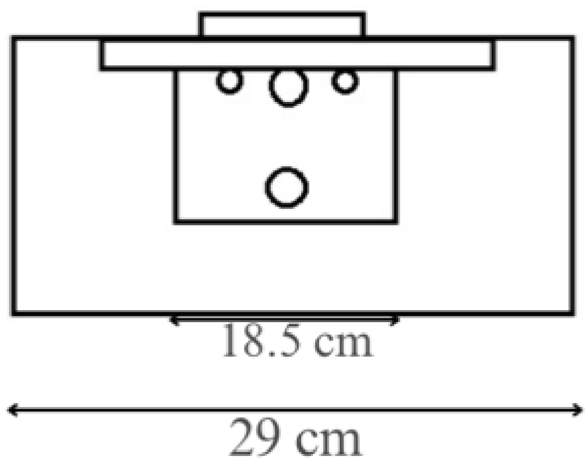

Fig.3.1 Top view of the model

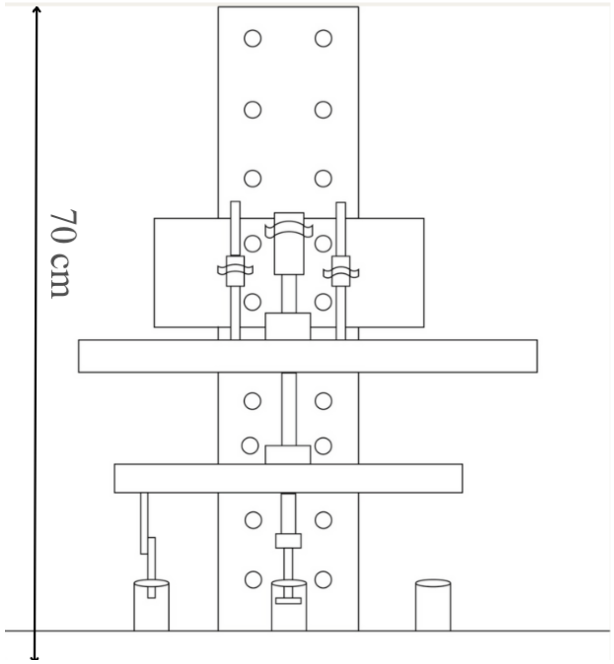

Fig.3.2 Front view of the Model

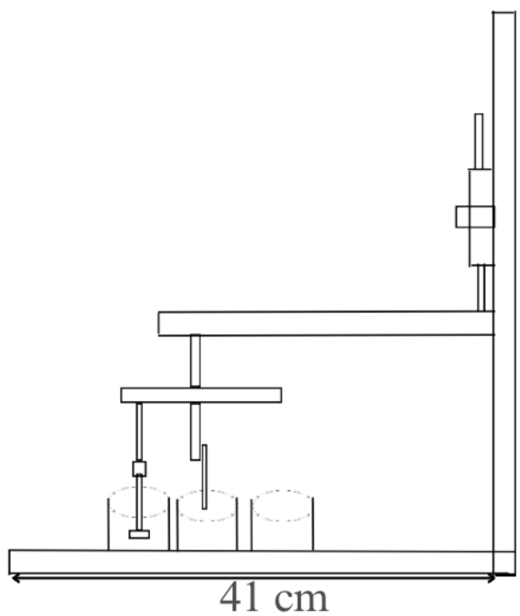

Fig.3.3 Side view of Model

Fig. 3.1, Fig.3.2 and Fig.3.3 show the 2D design of the setup in top view, front view and side view respectively, which include the base, substrate holder, an assembly for dipping the substrate and a support at the back to hold the assembly. The total height of the instrument should be 70 cm and the total width should be 41 cm. The bigger plate of the assembly is 29 cm, and the smaller plate is kept as 18.5 cm. The length and width kept for the all the parts of the devices are fixed by keeping in the mind the weight each part has to carry.

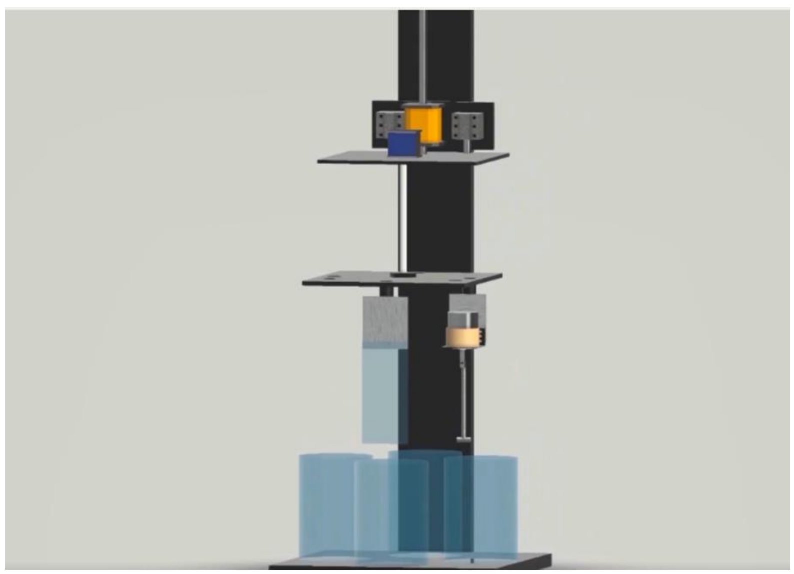

Fig.3.4 3D Model of SILAR Coating Device

Fig.3.4 is 3D model of the instrument which gives a clearer picture of what it exactly looks like.

The components with specific design aspects are selected after making 2D and 3D model of the SILAR coating device. Then went on with installing motors and other components to the model. Nema17 Bipolar stepper motor is used for angular circular rotation at desired angle based on the number of beakers. DC motor is used for the linear movement of the system for substrate to dip in the solution and come back to its original position with the help of lead screw and nut. Another DC motor is employed to rotate a stirrer within a beaker to ensure a uniform solution, and the user can regulate the speed of the stirrer by providing an input through a keypad and monitoring it on an LCD screen. All these motors are controlled by ESP32 Microcontroller. The programming language used to code the ESP32 microcontroller is Arduino C, and this is done through the Arduino IDE software.

3.2.1 Code Flow Chart

Firstly, inputs, such as number of beakers, dip duration in seconds, drip duration in seconds, number of cycles and speed of stirrer in rpm, are taken from the user using keypad and LCD. Then, these inputs are displayed to the user using LCD. If the number of cycles is greater than 0, then the linear actuator will move down for substrate to dip inside the solution. Then, the substrate will wait inside the solution for dip duration and linear actuator will move up. Then, it will wait for drip duration and rotates clockwise to repeat the same steps for the next beaker as well. Once the cycle is complete, the number of cycles will be reduced, and cycles left will displayed to the user using LCD. When the number of cycles reaches to zero, then the controller comes out of the while loop and A message is displayed to user that the process is complete is using LCD.

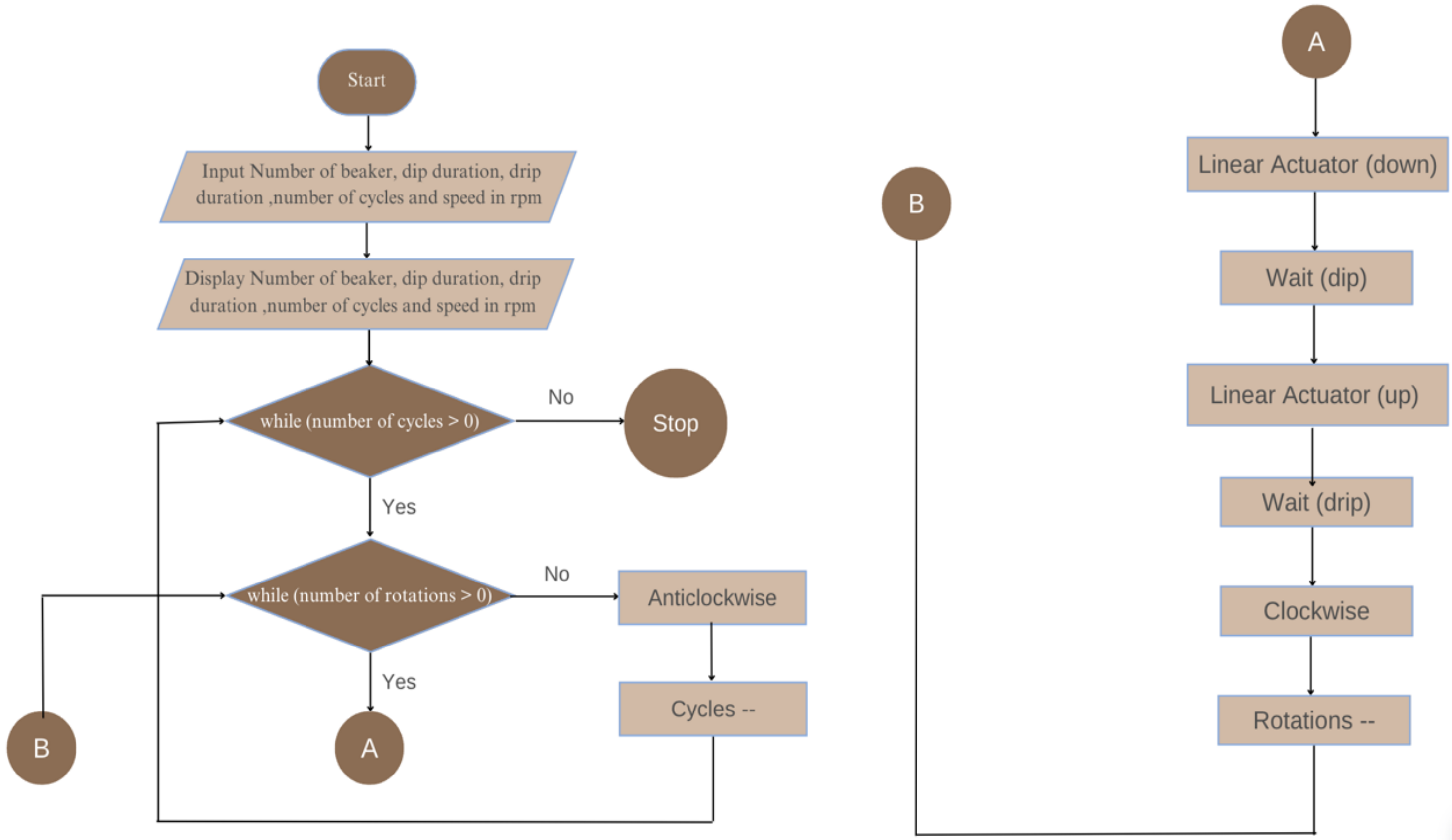

Fig.3.5 Flow Chart of algorithm used in SILAR coating device

3.2.2 Blynk

Blynk is a mobile app-based platform that allows users to control and monitor their hardware projects remotely. For SILAR coating devices, Blynk can be used to monitor various parameters of the device such as number of beakers, dip duration in seconds, drip duration in seconds, number of cycles and speed of stirrer in rpm. This can be done through a smartphone or tablet by connecting to the device through Wi-Fi or Bluetooth. Blynk also provides real-time data visualization, allowing users to monitor the progress of the coating process remotely. Blynk is a powerful tool for building connected devices and applications and is widely used by developers. Overall, Blynk can enhance the functionality and user experience of SILAR coating devices by providing a user-friendly interface and remote access to monitor the device.

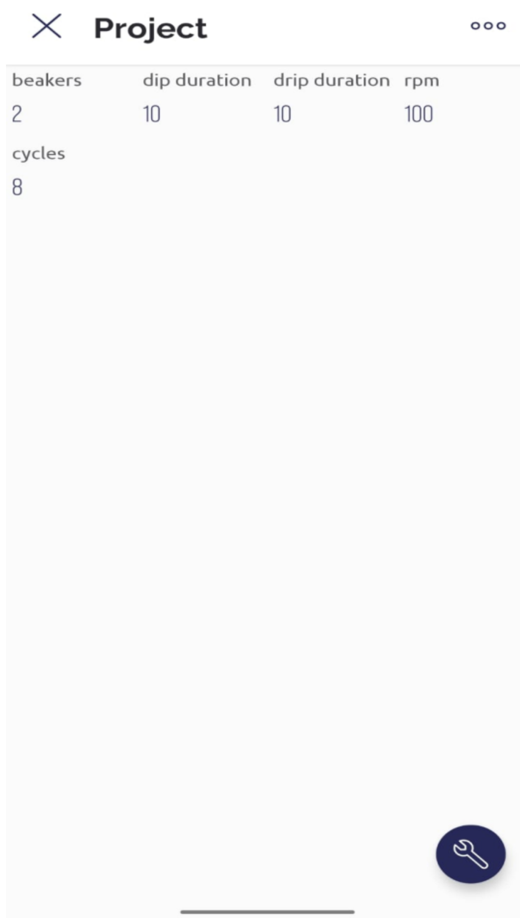

Fig.3.5 Blynk app to track progress of the process

3.2.3 PCB designing and schematics

For designing PCB, schematics is designed using a software called KiCAD. KiCAD is an open-source software suite used for electronic design automation (EDA) and is commonly used for printed circuit board (PCB) design. With KiCAD, designers can create and test their electronic designs before manufacturing, allowing for greater precision and reliability in the final product. Fig.3.6 shows the schematics designed using KiCAD software. Fig.3.6 shows schematics of the PCB.

After designing schematics, connections are made according to the schematics and its proper working is tested. Then, PCB is designed using the same software KiCAD and it is printed. All the components like ESP32 microcontroller, A4988 motor driver, L298 N motor, drivers are mounted on the PCB for secure connections and less wiring.

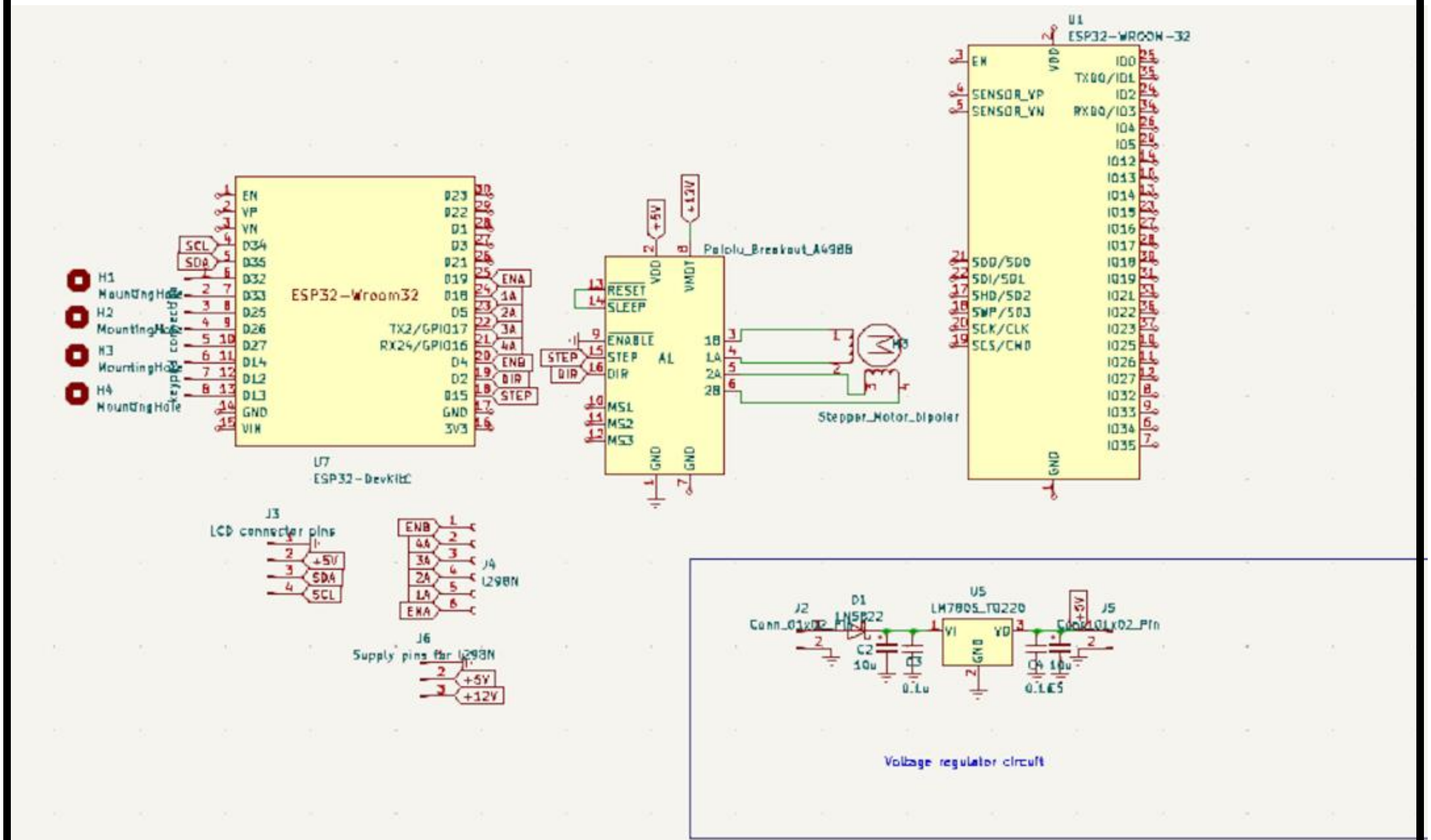

Fig.3.7 Schematics of PCB using KiCAD

A printed circuit board (PCB) is a critical component in the design and manufacture of electronic devices. In this circuit, the PCB has the following functions: In Fig.3.7, the design is PCB is shown.

Power Supply: The 220V AC supply is used by a Switched-Mode Power Supply (SMPS) to generate a regulated 12V DC output of 2A. The output of the SMPS is fed to the 12V terminals (J2) on the PCB.

Motor Drivers: The internal tracks on the PCB provide the 12V supply to the Vmot pin of the A4988 driver, which is used to run the bipolar stepper motor. Additionally, the tracks supply 12V to the L298N driver (J6) for running both the driver itself and the DC motors (J4).

Voltage Regulation: The 12V supply is also fed to a 7805 voltage regulator IC (U5) which produces a fixed regulated output voltage of 5V DC (J5). The 5V supply is then fed to both the ESP32 Devkit V1 board and A4988 driver for running the IC.

Display and Input: The 16x2 LCD is connected (J3) via SCL and SDA pins (GPIOs 34 and 35 respectively, which are shorted externally with GPIOs 22 and 21) to the microcontroller. Additionally, the 4*3 keypad is connected to the microcontroller via the J1 pin section on the PCB.

Stepper Motor: The bipolar stepper motor is connected to the A4988 driver via the M3 pin section on the PCB.

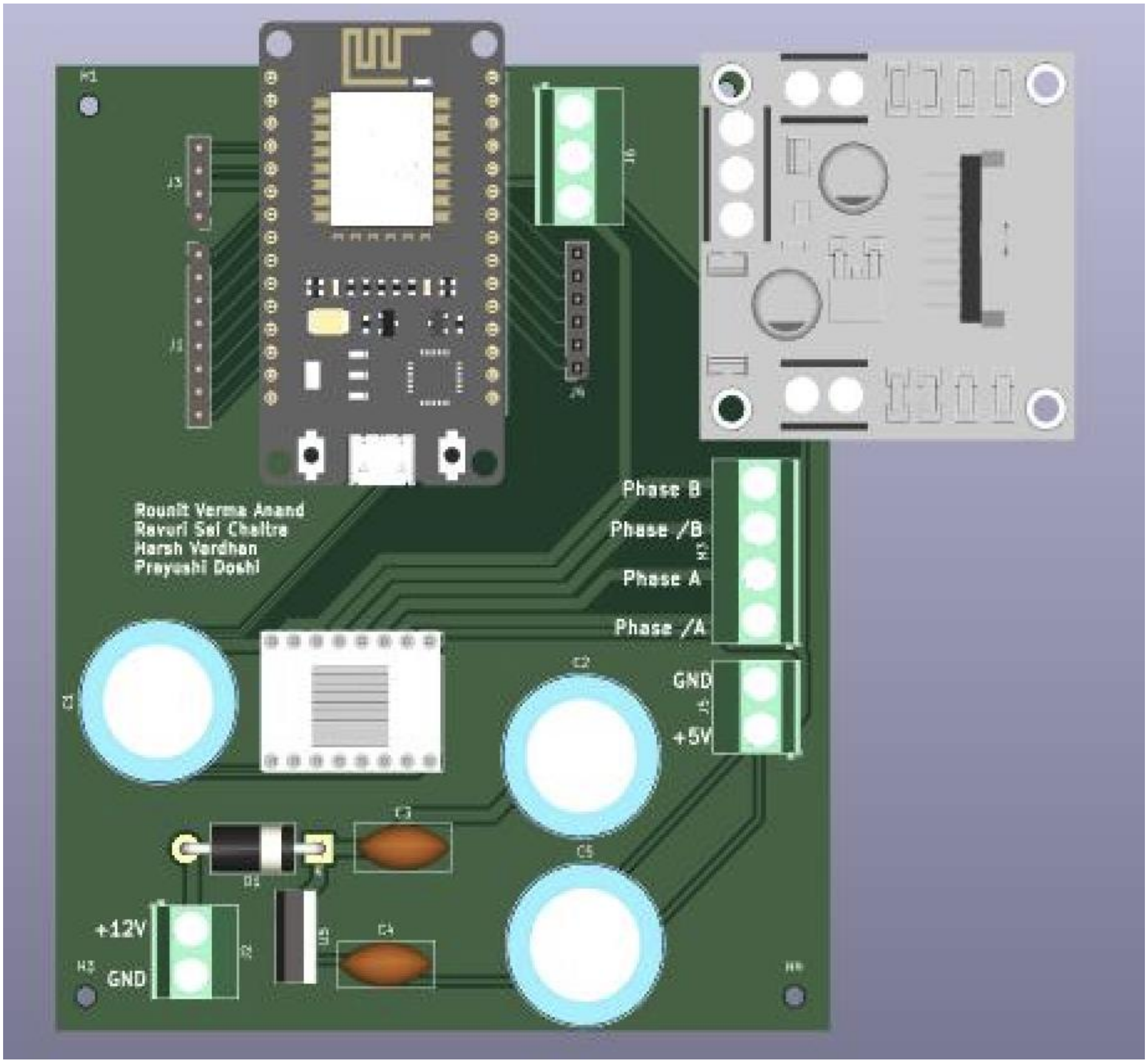

Fig.3.8 Design of PCB used in SILAR Coating Device

3.3 Project Expenses

Table 3.1: Details of project expenses

S.No.	Components Used	Cost in Rs.
1.	ESP32 Devkit V1 Module	₹ 300
2.	DC motors (geared motors)	₹ 480 x 2 = 960
3.	Nema17 Bipolar Stepper motor	₹ 480
4.	A4988 Driver	₹ 75
5.	L298N Driver	₹ 125
6.	LCD display	₹ 125
7.	I2C module	₹ 75
8.	Keypad	₹ 90
9.	Teflon rod	₹ 500 for 1 meter
10.	Lead Screw and Nut	₹450
11.	PCB	₹2500
12.	Substrate holder	₹400
13.	7805 regulator	₹10
14.	Miscellaneous costs	₹3000
15.	**Total cost**	**₹9210**

3.4 Product description

Product Name: IoT Enabled SILAR Coating Device

Description: The IoT Enabled SILAR Coating Device is a microcontroller-based device that enables the SILAR (Successive Ionic Layer Adsorption and Reaction) coating process to deposit material onto a substrate. The device is designed to be used in research and development laboratories and allows for precise control of deposition cycles. The device includes an ESP32 microcontroller, an SMPS power supply, a voltage regulator, driver for two DC motors, a bipolar stepper motor driver, an LCD display, and a keypad.

Key Features:

- Precise control of deposition cycles
- Supports a linear actuator DC motor and a stirrer DC motor with adjustable speed up to 200 RPM
- Easy-to-use 16*2 LCD display and 4*3 keypad for taking user inputs
- Can be used with 2, 3, or 4 beakers
- Supports Blynk app integration for real-time tracking of deposition cycles

Technical Specifications:

- Input Voltage: 220V AC
- Output Voltage: 12V DC
- Maximum Output Current: 2A
- Microcontroller: ESP32

- Voltage Regulator: 7805
- Linear Actuator DC Motor Driver: L298N
- Stirrer DC Motor Driver: L298N
- Bipolar Stepper Motor Driver: A4988
- LCD Display: 16*2
- Keypad: 4*3
- Rated Speed of Linear Actuator DC Motor: 500 RPM
- Rated Speed of Stirrer DC Motor: Adjustable up to 200 RPM
- Rated Current of Bipolar Stepper Motor: 1.5A
- Magnetic clip for substrate holder position adjustment
- Stroke length: 16 cm

Physical Specifications:

- Weight: 10 kg

Material: The structure is designed using mild steel plates of required dimension

Number of PCB Layers: 2

CHAPTER 4

RESULTS AND DISCUSSIONS

The IoT- Enabled SILAR Coating Device developed has been successfully designed, built, and tested, resulting in a functional and effective device for depositing thin films of materials onto substrates. In this section, the results of the tests conducted on the device, including its ability to rotate at different angles of 90°, 120° and 180° to deposit thin films of materials onto substrates, and be operated remotely using Wi-Fi or Bluetooth are discussed. The advantages and limitations of the device are discussed and compared with existing coating devices. Overall, the results demonstrate that the SILAR coating device is a promising device for formation of thin film coating around the substrates which can be used by education and research institutes.

The SILAR coating device was assembled using various mechanical components, including a linear actuator, motors, and a rotational mechanism. These components were integrated with the ESP-32 module, which served as the microcontroller for the device. The code for the device was developed using the Arduino Integrated Development Environment (IDE) and uploaded to the ESP-32 module.

As shown in Fig.4.1, The SILAR coating device so developed features, as proposed, a keypad and an LCD display that enable the user to input the desired parameters for the coating process and monitor the progress in real-time. The keypad allows the user to input the rotation angle, the number of beakers to be used, the dip and drip durations, and the number of cycles. The LCD display then shows the input values and displays the progress of the coating process.

The dip and drip durations for the cationic and anionic solutions were taken in seconds, and the device can perform any number of cycles as specified by the user. The dipping in cationic solution and then in anionic solution completes one cycle, and the device repeats this process until the desired number of cycles is completed.

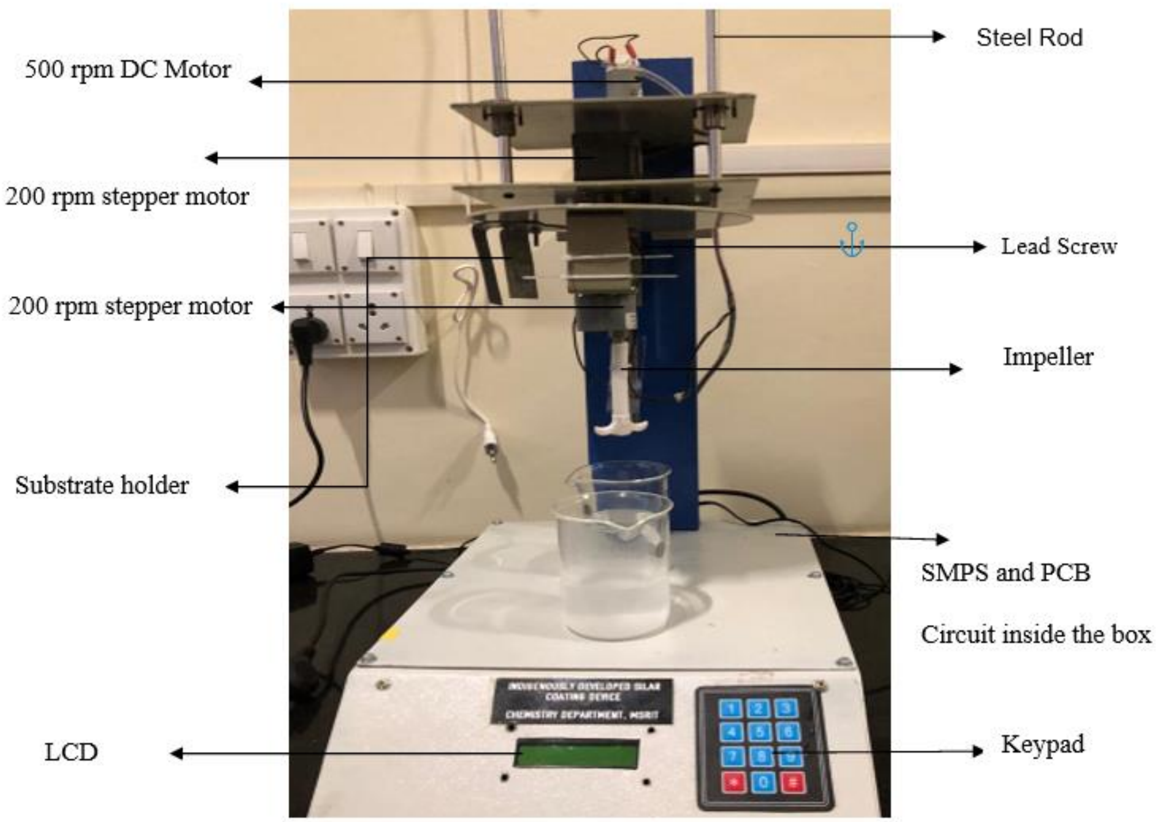

Fig 4.1 IoT enabled SILAR Coating Device

4.1 Testing of the device using Zinc ammonia complex

The device was tested by performing dip coating of $[Zn(NH_3)_4]^{2+}$ on the glass slide was 100 cycles.

Fig 4.2 Clean glass substrate before testing

Zinc ammonia complex was prepared in one beaker by adding 2.5 gm of $ZnSO_4$ in 150 mL distilled water, followed by addition of 30 mL NH_3 in the solution. This was 180 mL of cationic solution. The other beaker had distilled water, 200 mL which was heated upto 90℃.

Fig.4.2 shows the glass slide used for testing. It was cleaned first. It was then put into the substrate holder, preferably the back side of the slide should be covered as coating is not required at the back.

Inputs were provided. Number of beakers were taken as 2, followed by dip and drip duration of 10 seconds. The speed of the motor was kept as 100 rpm. Here, as the solution was of low viscosity, speed did not play a major role. Lastly, the number of cycles were fed as 25. The complete process was repeated four times, to achieve the goal of completing 100 cycles.

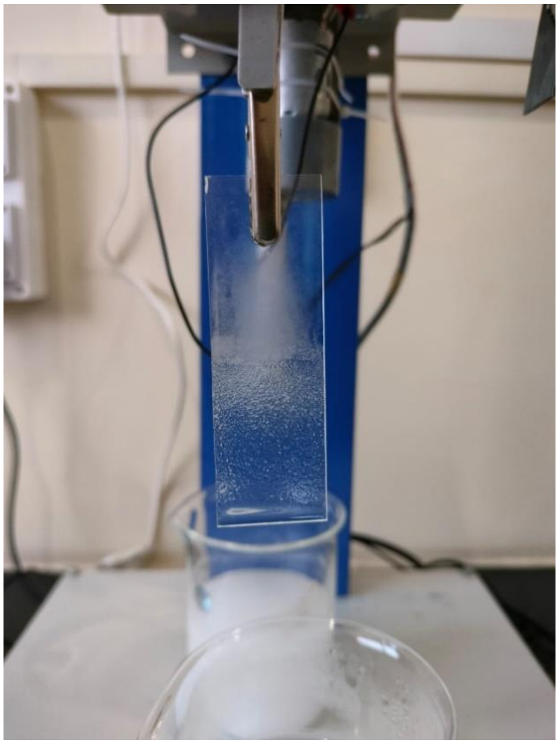

Fig 4.3 glass substrate after 25 cycles

First, the substrate was dipped into the complex, with simultaneous stirring in the second beaker, followed by dipping of the substrate in the next beaker filled with hot distilled water and stirring the complex solution. This completed one cycle.

To maintain the temperature of distilled water, the beaker was refilled with heated upto 90℃ after every 25 cycles.

Fig.4.3 shows how the substrate looks after 25 cycles. The particles of the solution can be seen on it.

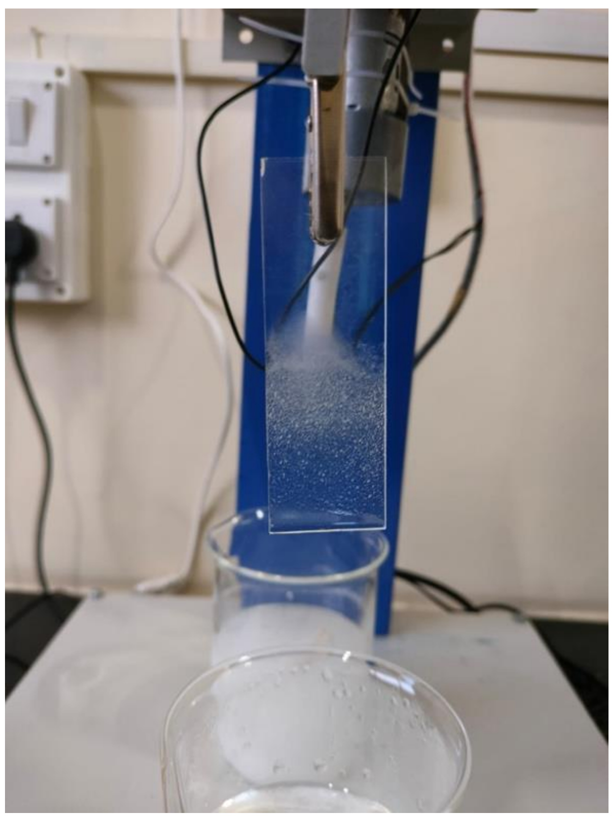

Fig 4.4 glass substrate after 50 cycles

Fig.4.4 and Fig.4.5 also show the coating completed after 50 and 75 cycles respectively. Here, the coating has become thicker and looked uniform.

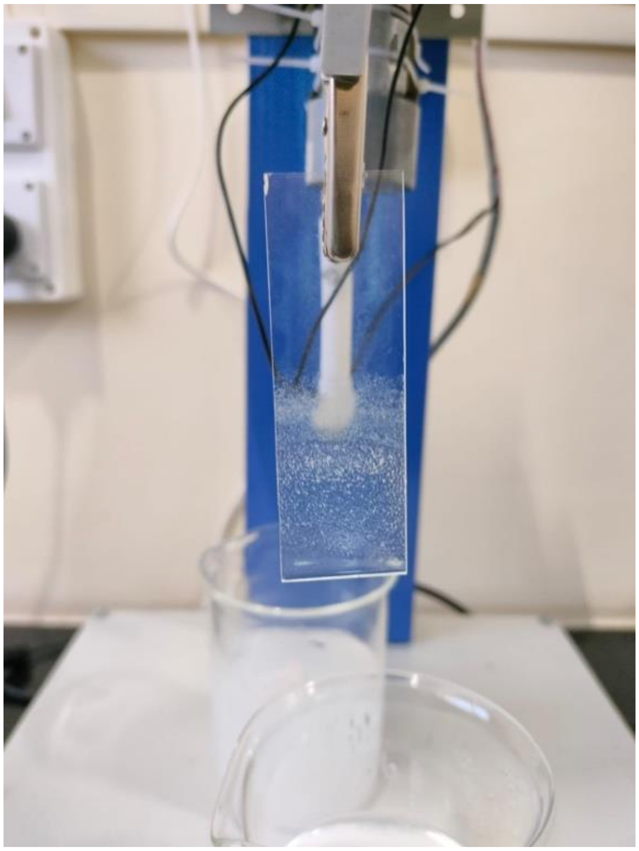

Fig 4.5 glass substrate after 75 cycles

Fig 4.6 glass substrate after 100 cycles and slow heating

Fig.4.6 shows the final coating of *ZnO* on the substrate. After the completion of 100 cycles, $Zn(OH)_2$ got coated on the substrate which was followed by slow heating at 100℃ to get *ZnO* on the slide.

4.1.1 Deposition of ZnO thin films

ZnO thin films were deposited onto the glass substrates using the SILAR technique. The cationic solution was prepared by dissolving 0.1 M of zinc sulphate heptahydrate in 150 ml of distilled water under constant stirring for 10 min. A quantity of 30 ml of 25% ammonia was added to the cationic solution to make the zinc–ammonium complex. Hot distilled water maintained at 98C was taken as an anionic solution. Glass substrates were immersed in the ammonium complex solution for 10 s. It was then immersed in the anionic solution for 10 s to remove excessive OH^- ions and dried in air for 10 s. This forms one SILAR deposition cycle. Deposition cycles were varied from 25 to 100 four times. All the prepared samples were annealed at 100°C for 6 hours for the complete transformation of zinc hydroxide to zinc oxide.

4.1.2 Growth mechanism

When manufacturing a coating using a process called dip coating, zinc ammonium complex is used, which contains both Zn2+ cations and hydroxyl groups. These components react with each other to form a stable zinc hydroxide complex, which then acts as a seed for the growth of ZnO.

During the formation of ZnO, the hydroxyl groups on the surface of the complex can either accept or release a proton, which can act as an acid or a base. The Zn cations in the complex act as a Lewis acid, while the $O_2{}^-$anions act as a Lewis base, and the interaction between their respective acid and base orbitals is responsible for the formation of ZnO upon annealing. However, when the dip coating process is carried out for 75 deposition cycles, the excess presence of H+ ions in the solution causes a change in the acidity level after 50 cycles which leads to deformation of ZnO. The whole process is explained in Fig.4.7.

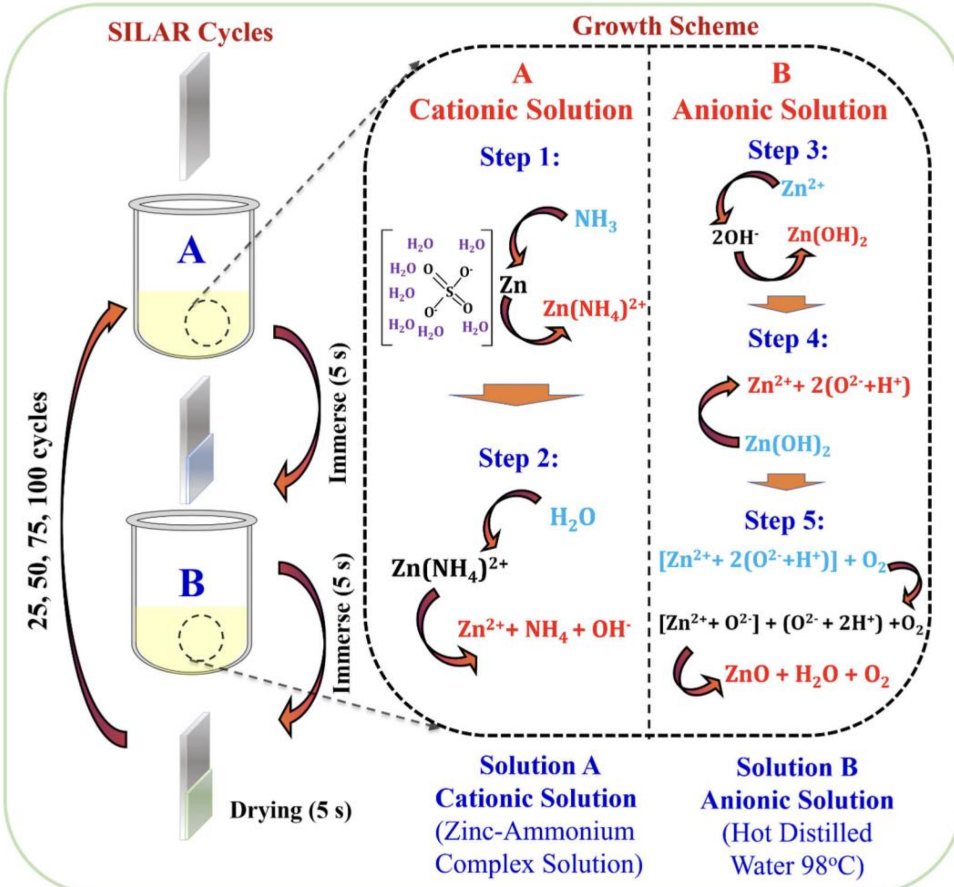

Fig 4.7 Growth mechanism of ZnO thin film deposited using SILAR technique [19]

4.1.3 FTIR (Fourier transform infrared) spectra

FTIR (Fourier Transform Infrared Spectroscopy) is a technique used to analyze the chemical composition and structure of a material by measuring the absorption of infrared light. In the case of a zinc ammonia complex coating, FTIR test has been done after an interval of 25 cycles, four times.

The above Fig. 4.7 shows the graph so obtained for the substrates given for testing after 25, 50, 75 and 100 cycles respectively. The x-axis shows wavenumber of the infrared light whereas y-axis is the transmittance. Transmittance represents the fraction of the incident infrared light that passes through the sample and reaches the detector.

The transmittance value indicates the amount of light absorbed by the sample at different wavelengths. A higher transmittance value indicates that more light is transmitted through the sample, suggesting low absorption or transparency. Conversely, a lower transmittance value indicates higher absorption of infrared light by the sample.

Wavenumber is a unit of measurement used to describe the frequency or energy of the infrared light used in FTIR spectroscopy.

The wavenumber scale in an FTIR spectrum represents the range of frequencies at which the infrared light is absorbed by the sample. It provides information about the molecular vibrations and functional groups present in the material.

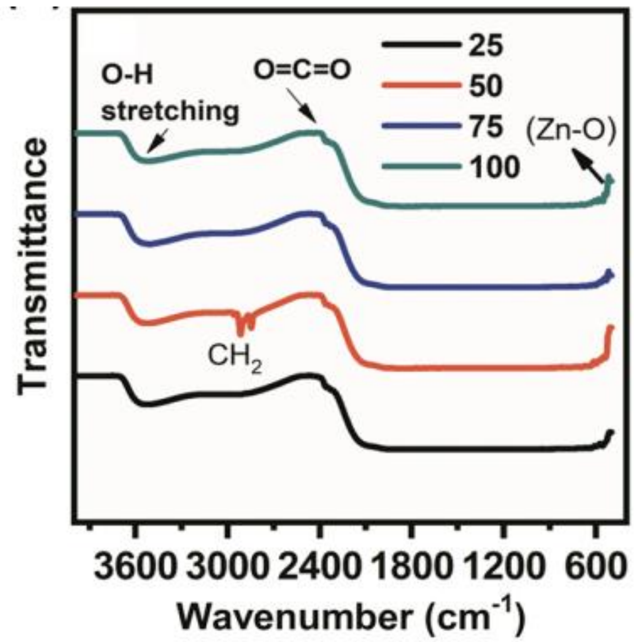

Fig 4.8 FTIR spectra of ZnO thin film

Black, red, blue and green curves in the graph show results corresponding to 25, 50, 75 and 100 cycles respectively. Presence of C-H-H bond was detected after 50 cycles at 2800 cm^{-1}.

Presence of atmospheric C=O=O was detected after 100 cycles at 2400 cm^{-1}. Zn-O bond was detected after 100 cycles at 50 cm^{-1}. This confirmed that ZnO is coated on the glass slide.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

In conclusion, the SILAR coating device is a highly versatile and adaptable tool for depositing thin films on various substrates. The device utilises a simple and cost-effective technique for depositing thin films with high precision and control. With the incorporation of sensors, and a microcontroller, the deposition process can be monitored in real-time, ensuring a consistent and high-quality final product.

The device can be easily modified to suit different shapes, sizes, and applications, making it a versatile tool for researchers, engineers, and manufacturers. The modular design and adjustable parameters allow for greater flexibility and adaptability, enabling the device to be used for a wide range of applications.

In conclusion, the SILAR coating device is a highly effective and practical tool for depositing thin films on a range of substrates. Its simplicity, versatility, and precision make it an excellent choice for researchers and manufacturers looking to produce high-quality thin films for various applications. The construction of a SILAR coating device requires careful consideration and attention to detail. The device must be designed to meet the specific requirements of the application, incorporating sensors, control systems, and other components as necessary. The use of open-source software, such as KiCAD, can aid in the design and testing of the device before manufacturing, resulting in a more precise and reliable product. The SILAR coating technique has many advantages over other deposition methods, such as low-cost, simple operation, and the ability to coat a variety of substrates.

However, the construction of a SILAR coating device is not without its challenges. One such challenge is the need for precise control of the deposition parameters, such as the number of cycles, dip duration, and solution concentration. These parameters must be carefully controlled to ensure that the coating is uniform and consistent.

To achieve this level of control, a microcontroller can be used to regulate the deposition process. The microcontroller can be programmed to adjust the deposition parameters based on real-time feedback from sensors monitoring the solution and the substrate. For example, the microcontroller can adjust the dip duration based on the thickness of the coating already deposited or the temperature of the solution. This allows for a highly controlled and optimised deposition process, resulting in high-quality coatings.

The design of the device must also take into account the safety of the operators and the environment. The device should be designed to contain any hazardous chemicals used in the deposition process and to prevent any spills or leaks. Additionally, proper ventilation and fume hoods should be used to ensure the safe operation of the device.

In summary, the construction of a SILAR coating device requires careful consideration of many factors, including electronic design, control systems, and safety. By carefully designing and constructing the device, it is possible to achieve a high level of control and precision in the deposition process, resulting in high-quality and consistent coatings for a variety of applications.

5.2 FUTURE SCOPE

In a SILAR coating device, it is essential to monitor the health of each solution present in different beakers to ensure a consistent and homogeneous deposition process. This can be achieved by incorporating sensors that can measure various parameters such as pH, temperature, and concentration of the solutions. The data obtained from these sensors can be used to adjust the deposition process in real-time, ensuring that the final product meets the desired specifications.

Another important aspect of a SILAR coating device is maintaining the solution at the desired temperature. This can be achieved by incorporating hot plates that can heat the solution to the required temperature. The temperature can be monitored using sensors and controlled using a microcontroller. This ensures that the deposition process occurs at the optimal temperature, resulting in a high-quality and consistent product.

Increasing the dip duration to minutes and hours can also be beneficial in some cases. For example, when coating thicker films or depositing multiple layers, longer dip durations may be required. This can be achieved by modifying the control system to increase the dip duration as required. This requires careful monitoring of the deposition process and adjusting the parameters accordingly.

Scaling the existing prototype for different shapes and sizes can be a challenging task. However, it is necessary to ensure that the device can be used for a variety of applications. This can be achieved by designing the device in a modular fashion, with interchangeable parts that can be easily swapped out for different shapes and sizes. Additionally, the device can be designed with adjustable parameters that can be modified to suit different requirements. This approach allows for greater flexibility and adaptability, making the device more versatile and useful in a range of applications.

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Appendix: Code Details

Setup:

1. Relevant libraries are imported.
2. Rows and columns for the LCD are set as global variables.
3. A 4*3 keypad matrix is formed to take input from the user.
4. GPIO pins on the ESP32 devkit board are assigned to the LCD, keypad, A4988 driver, and L298N driver.
5. The number of beakers (in seconds), dip duration (in seconds), drip duration (in seconds), number of cycles, and stirrer motor speed are taken as inputs from the user using the LCD display and keypad, and stored in global variables.
6. If any of the given inputs are incorrect, the user can immediately re-enter the values by pressing the '*' button.
7. The '#' button is used to enter values and proceed with entering the rest of the inputs

Loop Flow:

1. The linear actuator (500 RPM motor, lead screw, and nut) pulls the entire assembly upwards at the start position and waits for the user to give inputs for performing SILAR coating.
2. Once the inputs are given, the ESP32 connects to the internet using the built-in WiFi module, and the inputs can be seen on the Blynk mobile app.
3. The remaining number of cycles can be monitored both on the LCD screen and the Blynk mobile application.

4. Once the inputs are given, the linear actuator moves the assembly downward and the substrate gets dipped in the solution for the specified dip duration. For the same dip duration, the mechanical stirrer (rotated by a 200 RPM DC motor) rotates the solution in the next beaker where the substrate has to be dipped next.
5. After the dip duration, the linear actuator pulls the system upwards and stays in position for the drip duration.
6. The stepper motor rotates the substrate and stirrer in a clockwise direction and stops above the next solution where dipping has to be done (90 degrees if 4 beakers, 120 degrees if 3 beakers, 180 degrees if 2 beakers).
7. Steps 4-6 are repeated until the first cycle is completed. (For one cycle, it repeats thrice for 4 beakers, twice for 3 beakers, and once for 2 beakers)
8. Once the first cycle is completed, the stepper motor brings the substrate and stirrer back to its original starting position by rotating in the anti-clockwise direction.
9. Steps 3-8 are repeated until the number of cycles entered is completely exhausted.
10. Once the SILAR coating has been performed, a "Cycles Completed" message is displayed on the screen, and the device resets itself to start from step 1.

Arduino C code

```
#include<Stepper.h>

#include <LiquidCrystal_I2C.h>

#include <Keypad.h>

#include <WiFi.h>

#include <WiFiClient.h>

#include <BlynkSimpleEsp32.h>

#define BLYNK_PRINT Serial

char auth[] = "KxRpGCuOKZSon_OKW_SJKqRQfyUodNLh";

char ssid[] = "Harsh's Galaxy F14 5G";

char pass[] = "qaereh25bbsa4s2";

// set the LCD number of columns and rows

int lcdColumns = 16;

int lcdRows = 2;

#define ROW_NUM     4 // four rows

#define COLUMN_NUM  3 // three columns
```

```
char keys[ROW_NUM][COLUMN_NUM] = {
  {'1', '2', '3'},
  {'4', '5', '6'},
  {'7', '8', '9'},
  {'*', '0', '#'}
};
byte pin_rows[ROW_NUM] = {32, 33, 25, 26}; // GIOP32, GIOP33, GIOP25, GIOP26 connect to the row pins
byte pin_column[COLUMN_NUM] = {27, 14, 12};  // GIOP27, GIOP14, GIOP12 connect to the column pins
Keypad keypad = Keypad( makeKeymap(keys), pin_rows, pin_column, ROW_NUM, COLUMN_NUM );
// set LCD address, number of columns and rows
// if you don't know your display address, run an I2C scanner sketch
LiquidCrystal_I2C lcd(0x27, lcdColumns, lcdRows);
int no_of_beakers; //2, 3, 4
int dip_duration;
```

```
int drip_duration;

int no_of_cycles;

int RPM;

int rpm;

//Stepper Motor

const int dirPin = 2;

const int stepPin = 15;

int stepsPerRevolution;

int stepsPerRevolution_2;

int stepDelay;

//Motor

const int MotorPin1 = 18;

const int MotorPin2 = 5;

const int MotorPin3 = 17;

const int MotorPin4 = 16;

int getKeypadInput(String label) {
```

```
  String input = "";
  char key = NO_KEY;
  lcd.setCursor(0, 0);
  lcd.print(label); // display the label on the first row of the LCD
while (key != '#') {
    key = keypad.getKey(); // read the next key from the keypad
    if (key == '*') {
      ESP.restart();
    }
    if (key != NO_KEY) { // if a key was pressed
        input += key; // add the key to the input string
        lcd.setCursor(input.length(), 1);
       lcd.print(key); // display the key on the second row of the LCD
    }
  }
  int result = input.toInt(); // convert the input string to an integer
```

```
 lcd.clear();
return result; // return the result
}
void setup() {
  Serial.begin(9600);
if (WiFi.status() == WL_CONNECTED) {
    Blynk.begin(auth, WiFi, "blynk.cloud", 80);
  }
  pinMode(stepPin, OUTPUT);
  pinMode(dirPin, OUTPUT);
  pinMode(MotorPin1, OUTPUT);
  pinMode(MotorPin2, OUTPUT);
  pinMode(MotorPin3, OUTPUT);
  pinMode(MotorPin4, OUTPUT);
  pinMode(19, OUTPUT);
  pinMode(4, OUTPUT);
```

```
digitalWrite(19, HIGH);

//500 rpm motor pulls the assembly upwards

digitalWrite(MotorPin1, HIGH);

digitalWrite(MotorPin2, LOW);

delay(4000);

digitalWrite(19, LOW);

 lcd.begin();

lcd.backlight();

no_of_beakers = getKeypadInput("Beakers:");

dip_duration = getKeypadInput("Dip Duration:");

drip_duration = getKeypadInput("Drip Duration:");

no_of_cycles = getKeypadInput("Cycles:");

RPM = getKeypadInput("Speed in RPM: ");

stepsPerRevolution = 200 / no_of_beakers;

stepsPerRevolution_2 = (no_of_beakers - 1) * stepsPerRevolution;

stepDelay = 10;
```

```
rpm = RPM * (255 / 200);
lcd.setCursor(0, 0);
lcd.print("Inputs given: ");
delay(1000);
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Beakers: ");
lcd.print(no_of_beakers);
lcd.setCursor(0, 1);
lcd.print("Dip Duration: ");
lcd.print(dip_duration);
delay(2000);
lcd.clear();
delay(800);
lcd.setCursor(0, 0);
lcd.print("Drip Duration: ");
```

```
lcd.print(drip_duration);

lcd.setCursor(0, 1);

lcd.print("Cycles: ");

lcd.print(no_of_cycles);

delay(2000);

lcd.clear();

delay(800);

lcd.setCursor(0, 0);

lcd.print("Speed in RPM: ");

lcd.setCursor(0, 1);

lcd.print(rpm);

delay(2000);

lcd.clear();

Blynk.virtualWrite(V1, no_of_beakers);

Blynk.virtualWrite(V2, dip_duration);

Blynk.virtualWrite(V3, drip_duration);
```

```
  Blynk.virtualWrite(V4, rpm);

}

void loop() {

  digitalWrite(19, HIGH);

  Blynk.virtualWrite(V5, no_of_cycles);

  lcd.clear();

  delay(500);

  lcd.setCursor(0, 0);

lcd.print("Cycles left: ");

  lcd.setCursor(0, 1);

  lcd.print(no_of_cycles);

 // main code here, to run repeatedly:

  if (no_of_cycles--) {

     //Turn 500 rpm Motor for 1962.5 millisecond

    for (int i = 0; i < no_of_beakers - 1; i++) {

      digitalWrite(MotorPin1, LOW);
```

```
digitalWrite(MotorPin2, HIGH);

digitalWrite(MotorPin3, LOW);

digitalWrite(MotorPin4, LOW);

delay(1962.5);

//Turn 200 rpm motor for Dip Duration

digitalWrite(MotorPin1, LOW);

digitalWrite(MotorPin2, LOW);

digitalWrite(MotorPin3, HIGH);

digitalWrite(MotorPin4, LOW);

analogWrite(4, rpm);

delay(dip_duration * 1000);

//Turn 500 rpm Motor in opposite direction for 4500 ms

digitalWrite(MotorPin1, HIGH);

digitalWrite(MotorPin2, LOW);

digitalWrite(MotorPin3, LOW);

digitalWrite(MotorPin4, LOW);
```

```
  delay(4500);
  //Drip Duration
  digitalWrite(MotorPin1, LOW);
  digitalWrite(MotorPin2, LOW);
  digitalWrite(MotorPin3, LOW);
  digitalWrite(MotorPin4, LOW);
  delay(drip_duration * 1000);
 //Rotate Stepper motor clockwise
  anticlockwise();
}
digitalWrite(MotorPin1, LOW);
digitalWrite(MotorPin2, HIGH);
digitalWrite(MotorPin3, LOW);
digitalWrite(MotorPin4, LOW);
delay(1962.5);
//Turn 200 rpm motor in clockwise for Dip Duration
```

```
digitalWrite(MotorPin1, LOW);

digitalWrite(MotorPin2, LOW);

digitalWrite(MotorPin3, HIGH);

digitalWrite(MotorPin4, LOW);

analogWrite(4, rpm);

delay(dip_duration * 1000);

//Turn 500 rpm Motor in opposite direction for 4500 ms

digitalWrite(MotorPin1, HIGH);

digitalWrite(MotorPin2, LOW);

digitalWrite(MotorPin3, LOW);

digitalWrite(MotorPin4, LOW);

delay(4500);

//Drip Duration

digitalWrite(MotorPin1, LOW);

digitalWrite(MotorPin2, LOW);

digitalWrite(MotorPin3, LOW);
```

```
    digitalWrite(MotorPin4, LOW);
    delay(drip_duration * 1000);
    clockwise();
}
else {
    lcd.clear();
    delay(500);
    lcd.setCursor(0, 0);
    lcd.print("Cycles");
    lcd.setCursor(0, 1);
    lcd.print("Completed");
    exit(0);
  }
}
void clockwise() {
  digitalWrite(dirPin, HIGH);
```

```
  // Spin motor
  for (int x = 0; x < stepsPerRevolution_2; x++)
  {
    digitalWrite(stepPin, HIGH);
    delay(stepDelay);
    digitalWrite(stepPin, LOW);
    delay(stepDelay);
  }
  delay(1000); // Wait a second
}
void anticlockwise()
{
  //counterclockwise
  digitalWrite(dirPin, LOW);
  // Spin motor
  for (int x = 0; x < stepsPerRevolution; x++)
```

```
 {
  digitalWrite(stepPin, HIGH);
   delay(stepDelay);
   digitalWrite(stepPin, LOW);
   delay(stepDelay);
 }
 delay(1000); // Wait a second
}
```