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Design of Spin Coater for Thin Film Growth

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Dedications

Praise be to ALLAH at the beginning and at the end

To **my parents**, whose unwavering love, encouragement, and sacrifices have been the cornerstone of my journey. Your belief in me has been my guiding light through every challenge and triumph.

To my beloved brother **Abdelghafour**, whose constant support and encouragement have strengthened my resolve. Your wisdom, companionship, and unwavering faith in me have been a source of comfort and inspiration.

*This dissertation is dedicated to all of you,
as a token of my deepest gratitude for your
endless support and love.*

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ABSTRACT

This dissertation presents the design, fabrication, and characterization of a cost-effective, Arduino-based spin coater for thin film deposition. The system utilizes commercially available components, 3D-printed parts, and open-source software to achieve precise control over spin speed and deposition time. The performance of the spin coater was validated through the deposition of tin oxide (SnO_2) thin films. X-ray diffraction (XRD) analysis confirmed the formation of crystalline SnO_2 with a tetragonal rutile structure. Ultraviolet-visible (UV-Vis) spectroscopy revealed high optical transparency in the visible region and a band gap of approximately 3.88 eV. The results demonstrate the capability of the developed spin coater to produce high-quality SnO_2 thin films suitable for various applications, providing a viable and accessible alternative to expensive commercial systems, particularly for resource-constrained research and educational settings. This work contributes to the dissemination of thin film technology, fostering innovation and experimental inquiry in materials science.

Keywords: Spin coating; Thin film deposition; Materials characterization; Low-cost fabrication; Educational technology

ملخص

تقدم هذه المذكرة تصميم وتصنيع وتوصيف جهاز طلاء دوار منخفض التكلفة يعتمد على أردوينو (Arduino) لترسيب الأغشية الرقيقة. يستخدم النظام مكونات متاحة تجارياً، وأجزاء مطبوعة بتقنية الطباعة ثلاثية الأبعاد، وبرمجيات مفتوحة المصدر لتحقيق تحكم دقيق في سرعة الدوران ووقت الترسيب. تم التحقق من أداء جهاز الطلاء الدوار من خلال ترسيب أغشية رقيقة من أكسيد القصدير. أكد تحليل حيود الأشعة السينية (XRD) تكون أكسيد القصدير البلوري ذو البنية الروتيلية رباعية الأضلاع. كشف التحليل الطيفي للأشعة فوق البنفسجية-المرئية (UV-Vis) عن شفافية بصرية عالية في المنطقة المرئية وفجوة طاقة تبلغ حوالي ٨٨.٣ إلكترون فولت. تُظهر النتائج قدرة جهاز الطلاء الدوار المطور على إنتاج أغشية رقيقة عالية الجودة من أكسيد القصدير مناسبة لتطبيقات متنوعة، مما يوفر بديلاً مجدياً ويسهل الوصول إليه للأنظمة التجارية باهظة الثمن، خاصة للبيئات البحثية والتعليمية محدودة الموارد. يساهم هذا العمل في نشر تقنية الأغشية الرقيقة، مما يعزز الابتكار والاستقصاء التجريبي في علوم المواد.

الكلمات المفتاحية: الطلاء الدوار؛ ترسيب الأغشية الرقيقة؛ توصيف المواد؛ تصنيع منخفض التكلفة؛ التكنولوجيا التعليمية

Résumé

Ce mémoire présente la conception, la fabrication et la caractérisation d'un dispositif de dépôt par centrifugation (spin coater) économique basé sur Arduino pour le dépôt de couches minces. Le système utilise des composants disponibles dans le commerce, des pièces imprimées en 3D et des logiciels open-source pour obtenir un contrôle précis de la vitesse de rotation et du temps de dépôt. La performance du dispositif de dépôt par centrifugation a été validée par le dépôt de couches minces d'oxyde d'étain (SnO_2). L'analyse par diffraction des rayons X (DRX) a confirmé la formation d'oxyde d'étain cristallin avec une structure rutile tétragonale. La spectroscopie ultraviolet-visible (UV-Vis) a révélé une haute transparence optique dans la région visible et une bande interdite d'environ 3,88 eV. Les résultats démontrent la capacité du dispositif développé à produire des couches minces de SnO_2 de haute qualité adaptées à diverses applications, offrant une alternative viable et accessible aux systèmes commerciaux coûteux, particulièrement pour les environnements de recherche et d'enseignement à ressources limitées. Ce travail contribue à la diffusion de la technologie des couches minces, favorisant l'innovation et la recherche expérimentale en science des matériaux.

Mots-clés : Dépôt par centrifugation ; Dépôt de couches minces ; Caractérisation des matériaux ; Fabrication à faible coût ; Technologie éducative

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List of Abbreviations

Abbreviation	Description
<i>Deposition Methods</i>	
APCVD	Atmospheric Pressure Chemical Vapor Deposition
CBD	Chemical Bath Deposition
CVD	Chemical Vapor Deposition
LCVD	Laser Chemical Vapor Deposition
LPCVD	Low-Pressure Chemical Vapor Deposition
MOCVD	Metal-Organic Chemical Vapor Deposition
PCVD	Photochemical Vapor Deposition
PVD	Physical Vapor Deposition
<i>Materials and Chemical Compounds</i>	
ATO	Antimony-Doped Tin Oxide
CdS	Cadmium Sulfide
CH ₃ CH ₂ OH	Ethanol (C ₂ H ₅ OH)
CO	Carbon Monoxide
Cu K _α	Copper K-alpha (X-ray Radiation Source at 1.5418 Å)
H ₂	Hydrogen
HCl	Hydrochloric Acid
NO ₂	Nitrogen Dioxide
PLA+	Polylactic Acid Plus (Enhanced 3D Printing Material)
SnO ₂	Tin Oxide
TCOs	Transparent Conductive Oxides
ZnO	Zinc Oxide
<i>Electronic Components and Technology</i>	
AC	Alternating Current
BLDC	Brushless Direct Current (Motor)
DC	Direct Current
ESC	Electronic Speed Controller

Table .1 (continued): List of Abbreviations and Descriptions

Abbreviation	Description
GND	Ground (Electrical Reference Point)
IoT	Internet of Things
LCDs	Liquid Crystal Displays
LEDs	Light-Emitting Diodes
OLEDs	Organic Light-Emitting Diodes
PWM	Pulse Width Modulation
SCL	Serial Clock Line
SDA	Serial Data Line
USB	Universal Serial Bus
VCC	Voltage Common Collector (Positive Supply Voltage)
IDE	Integrated Development Environment
<i>Analysis and Characterization Techniques</i>	
FWHM	Full Width at Half Maximum
JCPDS	Joint Committee on Powder Diffraction Standards
UV-Vis	Ultraviolet–Visible Spectroscopy
XRD	X-Ray Diffraction
<i>Mathematical and Physical Parameters</i>	
2θ	Two Theta (Diffraction Angle in XRD)
D_{moy}	Average Crystallite Size
E_g	Optical Band Gap Energy
$h\nu$	Photon Energy (where h is Planck's constant and ν is frequency)
hkl	Miller Indices (Representing Crystallographic Planes)
ϵ	Lattice Strain
ϵ_{moy}	Average Lattice Strain
<i>Units and Measures</i>	
$\text{\AA}$	Ångström ($1 \text{ \AA} = 10^{-10} \text{ m}$)
cm^{-1}	Per Centimeter (Unit of Wavenumber in Spectroscopy)
DZD	Algerian Dinar (Currency)
eV	Electronvolt (Energy Unit, $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$)
ml	Milliliter (10^{-3} L)
mm	Millimeter (10^{-3} m)
nm	Nanometer (10^{-9} m)
rad	Radian (Angular Measure)
RPM	Revolutions Per Minute
s	Second (SI Unit of Time)

Table .1 (continued): List of Abbreviations and Descriptions

Abbreviation	Description
V	Volt (Unit of Electric Potential)
\$	United States Dollar (Currency)
°C	Degrees Celsius (Temperature Unit)
%	Percent

General Introduction

Thin film technology represents an important part of modern materials science, enabling significant advancements across diverse fields including electronics, optics, energy harvesting, and sensing applications. Among the various thin film deposition methodologies, spin coating stands out for its simplicity, cost-effectiveness, and capability to produce uniform coatings on planar substrates. This technique involves depositing a liquid precursor onto a substrate, which is subsequently rotated at high angular velocities, leveraging centrifugal forces to distribute the material evenly. The result is a film characterized by precisely controlled thickness, exceptional homogeneity and properties that are essential for numerous applications in optoelectronics and sensor technology [1, 2].

Despite the precision and reliability offered by commercial spin coating systems, their substantial cost often renders them inaccessible to small-scale research laboratories and educational institutions, thereby limiting the widespread adoption of this essential technology. The financial barriers associated with acquiring such specialized equipment can inhibit innovation and experimental research, particularly in resource-constrained environments. Consequently, there exists a compelling need to make access to thin film deposition technologies widely available, enabling a broader spectrum of researchers to engage in experimental investigations without the limitations imposed by prohibitive capital investments [3, 4].

Research Objectives

The impetus for this dissertation stems from the necessity to bridge the gap between affordability and functionality in thin film research. This work aims to design and fabricate a low-cost, customizable spin coater capable of producing high-quality films suitable for rigorous experimental investigations. By leveraging open-source hardware and software frameworks, this project seeks to empower researchers to explore various deposition parameters, such as spin speed and time, without reliance on expensive proprietary systems. The integration of accessible technology not only enhances the research capabilities of smaller institutions, but also fosters a culture of innovation and experimental inquiry [4].

This dissertation focuses on the design, construction, and application of an Arduino-based spin coater that incorporates available electronic components and 3D-printed structural parts. The user interface consists of a keypad and screen, facilitating precise control over critical

process parameters such as rotational velocity and deposition duration. These parameters are fundamental in determining the resulting film's thickness, uniformity, and material properties. To validate the performance of the developed spin coater, tin oxide (SnO_2) thin films, which are widely employed in gas sensors, transparent conductive oxides and photovoltaic devices, were deposited under varying spin speeds. The relationship between deposition parameters and film characteristics, including structural and optical properties, was systematically investigated [1, 3].

Specific Aims

The objectives of this study are threefold:

1. **Design and Fabrication:** Develop a functional spin coater using commercially available components, additive manufacturing techniques, and Arduino programming to achieve precise control over deposition parameters.
2. **System Validation:** Characterize the spin coater's performance through reproducibility tests and comparison with commercial models.
3. **Application to SnO_2 Thin Films:** Investigate the influence of spin speed on SnO_2 film quality, including structural and optical behavior, to establish guidelines for optimal deposition conditions [3].

Significance and Innovation

This research not only demonstrates the feasibility of constructing low-cost laboratory equipment but also contributes to a comprehensive understanding of spin coating dynamics for metal oxide thin films. The integration of open-source hardware (Arduino) and additive manufacturing (3D printing) exemplifies the potential of interdisciplinary approaches in advancing materials science research. By providing detailed schematics and control system architecture, this project serves as a replicable blueprint for researchers seeking affordable, customizable solutions for thin film deposition [4]. The successful deposition and characterization of SnO_2 thin films using the homemade spin coater validates its capability to produce high-quality materials comparable to those obtained with commercial systems, but at a significantly reduced cost.

Dissertation Structure

The structure of this dissertation is organized as follows:

Chapter I : Reviews the fundamental principles of thin film technology, spin coating, components of commercial systems, and properties and applications of SnO_2 thin films.

Chapter II : Details the design methodology, assembly procedures, and programming implementation of the Arduino-based spin coater.

Chapter III : Presents experimental results on SnO₂ film deposition, structural and optical characterization, and the correlation between spin speed and resultant film properties.

This research underscores the value of open-source innovation in scientific instrumentation and establishes a foundation for further exploration of deposition techniques for functional nanomaterials. The findings of this work have implications not only for the academic community but also for industries that rely on thin film technologies, thereby contributing to the advancement of both fundamental science and practical applications [3].

Chapter I

Theoretical Background and Literature Review

I.1 Introduction

This chapter reviews the theoretical background of thin films technology, including deposition methods, with specific focus on spin coating technique, and then tin oxide (SnO_2) thin films and their properties and applications.

I.2 Thin Films Technology

I.2.1 Definition of Thin Films

Thin films are defined as layers of material ranging in thickness from fractions of a nanometer to several micrometers. They are characterized by their unique physical, chemical, mechanical, and optical properties, which can vary significantly from their bulk counterparts due to quantum confinement effects and surface interactions [5].

Thin films can be composed of a variety of materials, including metals, insulators, and semiconductors. Their applications span numerous fields, from electronics to optics, and even biomedicine. The ability to produce thin films with desired characteristics makes them indispensable in advanced technological applications [6].

The fundamental understanding of thin films entails examining their structure and properties, which can be influenced significantly by factors such as substrate type, deposition parameters, and post-deposition treatments. Post-deposition processing, often involving thermal annealing, can alter crystallinity, optical transmittance, and electrical conductivity [7, 8]. This level of control allows researchers and engineers to optimize thin films to meet the performance criteria of specific applications.

I.2.2 Thin Films Deposition Techniques

Thin film deposition methods are critical in material sciences field. These methods can be broadly categorized based on their operational mechanisms and material characteristics. The most prominent techniques include Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD), and solution-based methods such as sol-gel techniques, which encompass spin, dip, and spray coating.

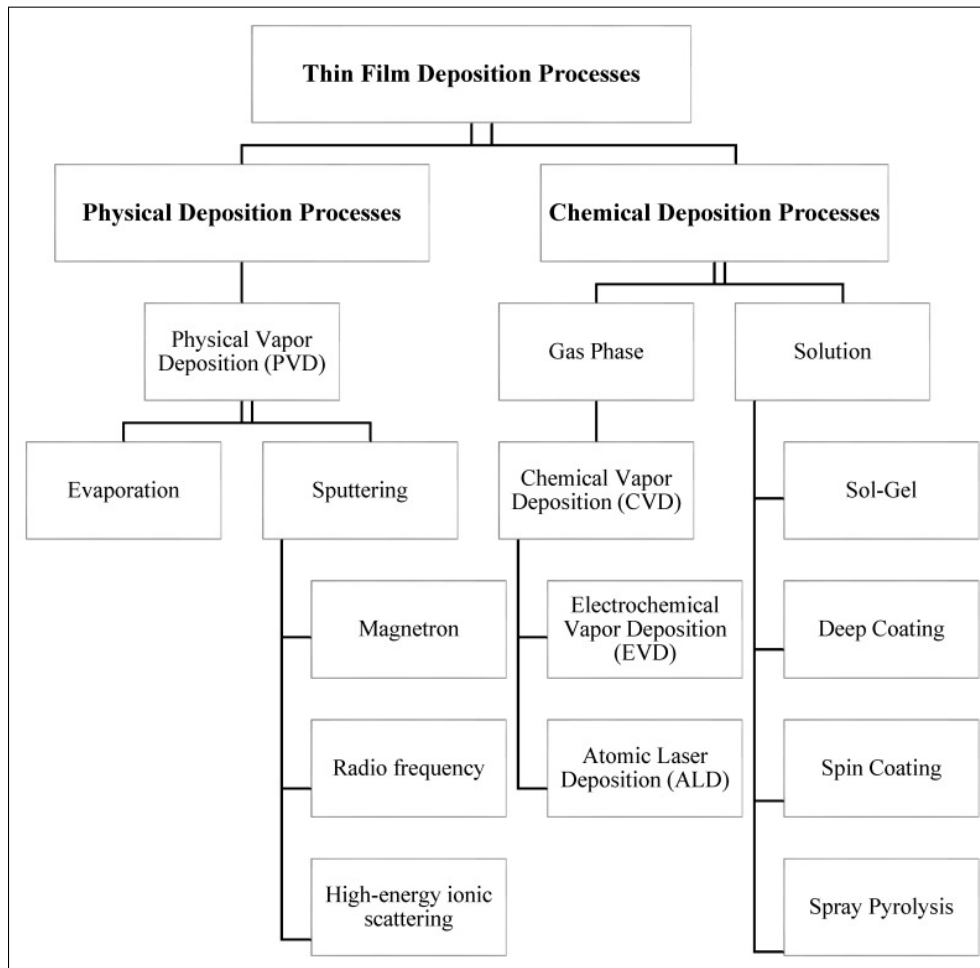


Figure I.1: Thin film deposition techniques categorized

• Physical Vapor Deposition

Physical vapor deposition (PVD) is an elegant atomistic process where material transforms from solid or liquid into vapor, travels through vacuum or low-pressure environments, and ultimately condenses onto a substrate surface. This sophisticated technique allows for precise control over coating thickness, ranging from just a few nanometers to several thousand nanometers, making it versatile for applications requiring graded compositions, multilayer structures, thick deposits, or even freestanding components.

The process typically deposits material at a rate of 1-10 nanometers per second, allowing for

careful buildup of the desired coating. This controlled atom-by-atom approach enables extraordinary precision in material engineering. PVD encompasses several important variations, each with distinctive characteristics:

- **Evaporation (vacuum deposition):** Material is thermally energized until it vaporizes and then condenses on the cooler substrate.
- **Arc vapor deposition:** A high-current, low-voltage arc strikes the source material, causing rapid evaporation and ionization.
- **Sputter deposition:** Ions bombard a target, ejecting atoms that then deposit onto the substrate.
- **Ion plating:** Combines aspects of both evaporation and sputtering, where the vapor passes through a plasma before reaching the substrate.

PVD can be further categorized based on specific technical configurations: vacuum evaporation (a), sputter deposition (which can occur in either plasma environments (b,c) or vacuum (d)), and various forms of ion plating (with thermal evaporation (e), sputtering (f), or arc vaporization sources (g)), ion-assisted deposition (h) as shown in Figure I.2 [9].

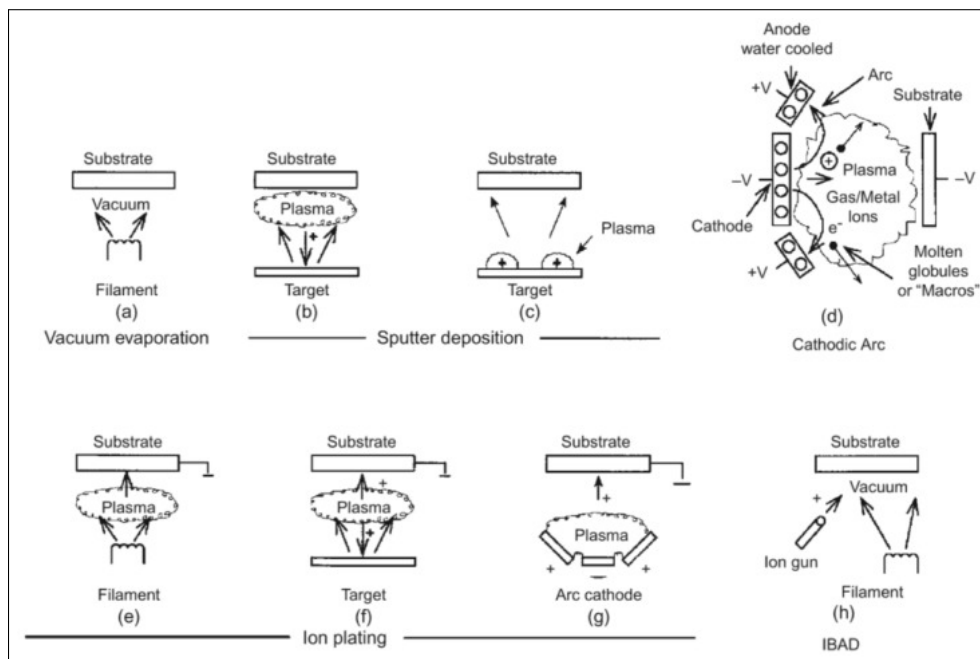


Figure I.2: Physical Vapor Deposition Processing Techniques [9].

• Chemical Vapor Deposition

Chemical vapor deposition (CVD) is a sophisticated materials synthesis technique wherein gaseous precursors are transported to a reaction chamber containing one or more heated substrates. Upon contact with these substrates, the precursors undergo chemical reactions that result

in the deposition of a solid film. Concurrent with this deposition process, chemical byproducts and unreacted precursor gases are evacuated from the chamber through an exhaust system. Conventional CVD methodologies necessitate elevated temperatures (typically 600–900°C) to facilitate the requisite chemical reactions. This thermal requirement constitutes a significant limitation, restricting the technique's applicability to substrates with sufficient thermal stability and thus limiting the scope of application of these methods. The fundamental process architecture is illustrated in Figure I.3, which provides a schematic representation of the chemical vapor deposition mechanism.

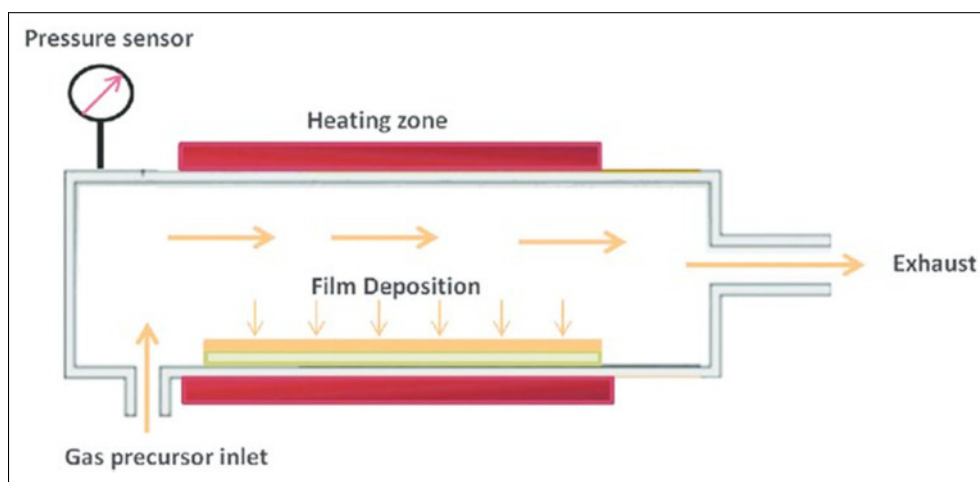


Figure I.3: Schematic representation of the Chemical Vapor Deposition mechanism [9].

The CVD technology encompasses several process variants, each optimized for specific applications:

- **Low-pressure chemical vapor deposition (LPCVD)**, which operates under reduced atmospheric conditions
- **Atmospheric pressure chemical vapor deposition (APCVD)**, which functions at standard atmospheric pressure
- **Metal-organic chemical vapor deposition (MOCVD)**, which utilizes organometallic precursors
- **Laser chemical vapor deposition (LCVD) or photochemical vapor deposition (PCVD)**, which employ directed energy sources to initiate localized reactions.

CVD methodologies offer several distinct advantages in materials engineering. Foremost among these is the conformal nature of the resulting films, characterized by uniform thickness distribution across topographical features, including both planar surfaces and vertical sidewalls. Additional benefits include high deposition rates, compatibility with an extensive range of materials systems, and the capacity to produce films of exceptional purity.

A CVD process mechanism can be illustrated in several steps as shown in Figure I.4:

1. Forced flow of reactant gases into the system.
2. Diffusion and flow of reactant gases through the gaseous boundary layer to the substrate.
3. Adsorption of gases onto the substrate.
4. Chemical reactions of the adsorbed species, or of adsorbed and gaseous species.
5. Desorption of adsorbed species from the substrate.
6. Diffusion and flow of product gases through the boundary layer to the bulk gas.
7. Forced exit of gases from the system.

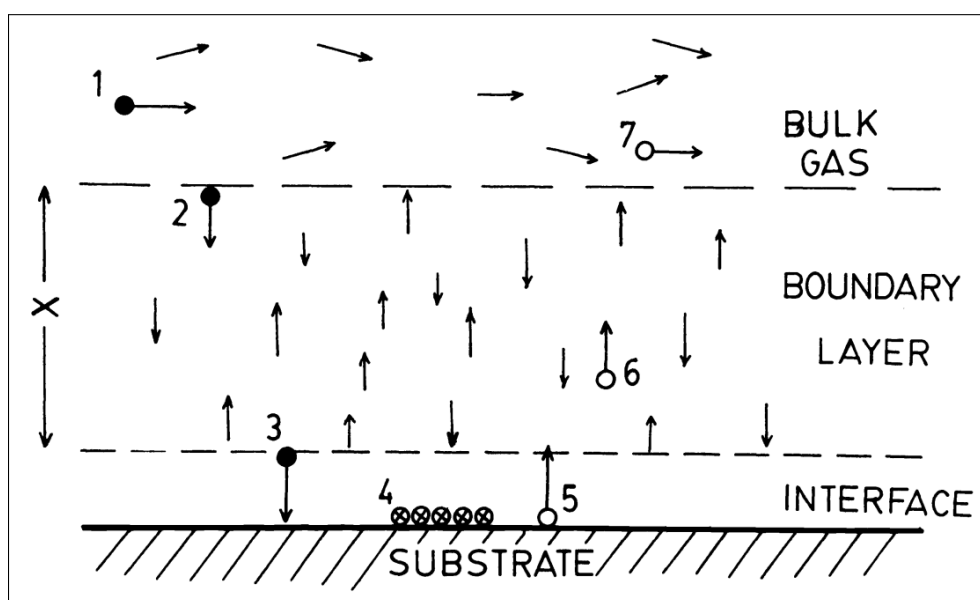


Figure I.4: Schematic representation of the Chemical Vapor Deposition mechanism steps [10].

Despite these advantages, CVD techniques present several notable limitations. The precursor materials must possess sufficient volatility at ambient temperatures to enable gas-phase transport. Furthermore, many precursor compounds exhibit problematic characteristics, including toxicity, chemical reactivity, explosive potential, and corrosive properties. These factors contribute to operational hazards and elevated process costs, as documented in previous research [9].

• Sol-Gel

The sol-gel process represents a versatile technique for synthesizing ceramic and glass materials, beginning with precursor solutions that undergo hydrolysis and polymerization reactions to form a colloidal suspension (sol), followed by condensation to create a three-dimensional

network encapsulating liquid (gel).

From this foundation, several fabrication routes are possible:

- **Spin-coating:** where sol is deposited onto a rotating substrate allowing centrifugal forces to create uniform thin films while excess solution is ejected and remaining solvent evaporates to form xerogel films (this technique will be discussed in greater detail in the next section);
- **Dip-coating:** involving substrate immersion into the sol and controlled withdrawal at specific rates to form liquid layers that subsequently undergo gelation and evaporation, producing xerogel films whose thickness and uniformity are precisely controlled by withdrawal speed, sol viscosity, and surface tension;
- **Bulk material synthesis:** where controlled solvent evaporation transforms the gel into xerogel through carefully monitored drying processes, which can then undergo thermal treatment for densification and crystallization, resulting in ceramic powders.

This comprehensive process, as illustrated in [Figure I.5](#), demonstrates the pathway from precursor solution to final ceramic materials through various processing routes.

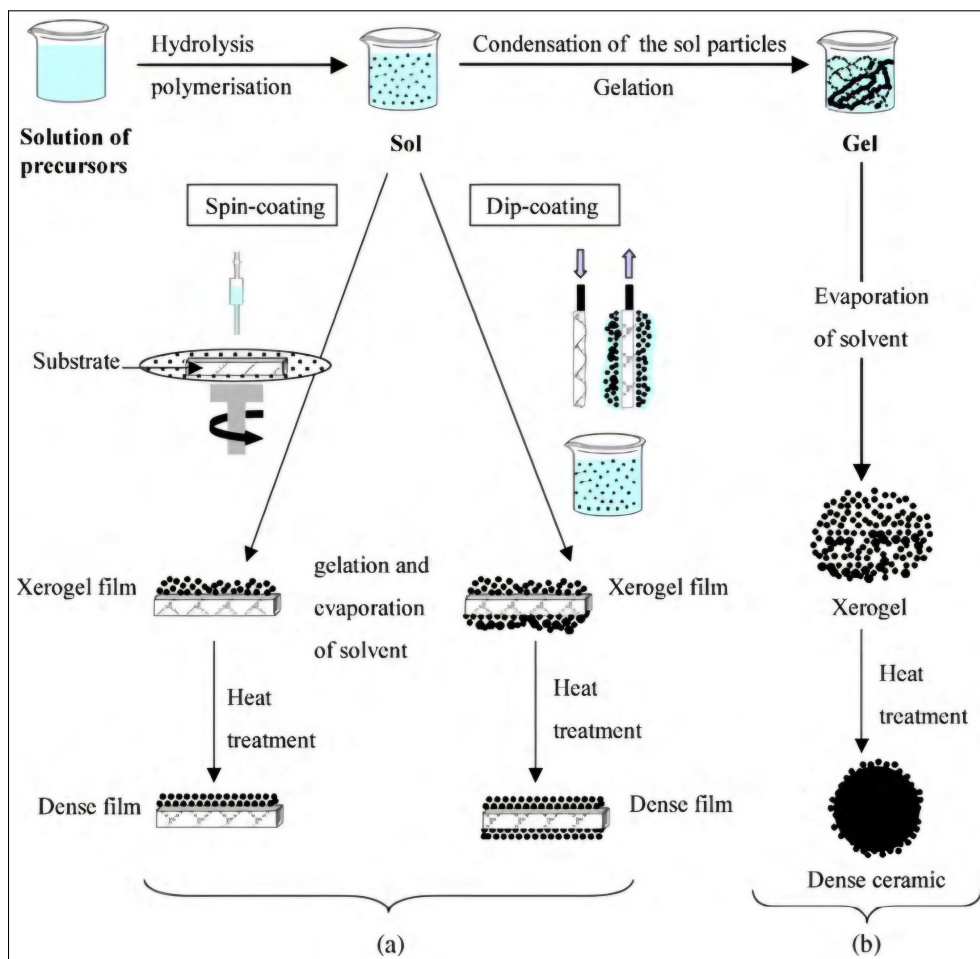


Figure I.5: Sol-Gel Processing Pathways: Film (a) and Powder Synthesis (b) Methods [11].

I.2.3 Applications of Thin Films

Thin films find extensive applications in numerous domains, including electronics, optics, photonics, and energy storage, among others. In electronics, thin films serve critical functions, such as acting as insulators, semiconductors, or conductive layers in devices like transistors and diodes [12, 13]. For instance, antimony-doped tin oxide (ATO) thin films have shown promise for transparent conducting applications, with their electrical and optical properties significantly enhanced through treatments such as argon-plasma treatment [14].

Thin films are also indispensable in photovoltaic devices, where semiconducting materials such as cadmium sulfide (CdS) and zinc oxide (ZnO) are frequently utilized. CdS thin films exhibit favorable optical and electrical characteristics, making them popular choices for solar cell applications. Similarly, ZnO thin films with their structure and optical properties show their effectiveness as transparent conductive oxide (TCO) layer in thin film solar cells [7, 15–17].

Optoelectronics is another domain where thin films excel, particularly in the manufacture of light-emitting diodes (LEDs) and laser diodes. For example, the alignment of liquid crystals on a silicon oxide thin film layer can produce substantially improved performance characteristics in devices [18]. The development of multilayer optical thin films has made significant strides in achieving higher optical contrast and confinement, thereby enhancing device performance [19]. This multilayer approach is pivotal in applications such as anti-reflection coatings and beam splitters.

Additionally, in optics, thin films play a prominent role in the enhancement of optical devices such as sensors, filters, and mirrors. Chalcogenide thin films are often used for their unique optical properties in applications ranging from optical computing to phase-change memories [6, 20]. The scalability of thin film technologies also allows for the development of large-scale optical arrays, substantially contributing to advancements in optical communication technologies.

I.3 Spin Coating Technique

I.3.1 Definition and Working Principle

Spin coating is a widely used technique for the deposition of thin films onto substrates, characterized by its simplicity and efficiency in producing uniform coatings. The process involves applying a small amount of liquid solution onto the center of a substrate, which is then rapidly spun at high speeds, typically ranging from 1000 to 5000 rpm. This spinning action generates centrifugal forces that spread the liquid across the substrate, resulting in a thin and uniform film as the solvent evaporates. [21].

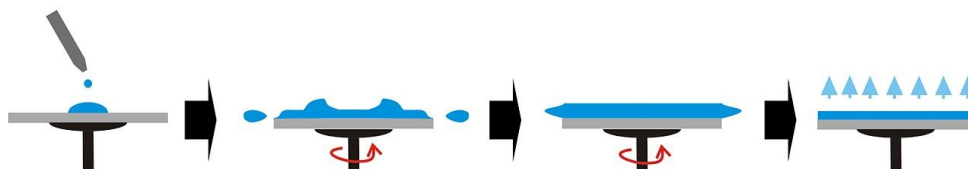


Figure I.6: Spin Coating Process: Stages and Film Formation [22].

The working principle of spin coating relies on several key factors, including the viscosity of the coating solution, the spin speed, and the duration of spinning. The viscosity affects the flow and spreading of the solution, while the spin speed determines the thickness of the resulting film; higher speeds generally lead to thinner films due to increased centrifugal force [23, 24]. Additionally, the evaporation rate of the solvent plays a crucial role in film formation, as it influences the final morphology and uniformity of the coating [25, 26].

Spin coating is particularly advantageous for applications in electronics, optics, and materials science, where precise control over film thickness and uniformity is essential [27, 28]. It is commonly employed in the fabrication of organic solar cells, sensors, and various optoelectronic devices, demonstrating its versatility and effectiveness in producing high-quality thin films [29, 30].

I.3.2 Process Parameters

• Spin Speed

The rotational speed of the substrate during the spin coating process significantly affects the film thickness. Higher spin speeds generally lead to thinner films due to increased centrifugal forces that spread the liquid more effectively and remove excess material [31][32]. The relationship between spin speed and film thickness can often be described by a power law, indicating that small changes in speed can lead to substantial variations in thickness [31][23].

• Spin Time

The duration of the spin cycle is another crucial parameter. Longer spin times can allow for more uniform film formation, but excessive time may lead to unwanted thinning or defects in the film [33]. The optimal spin time often depends on the viscosity of the solution and the desired film properties.

• Solution Viscosity

The viscosity of the coating solution plays a vital role in determining the final film characteristics. Solutions with higher viscosity tend to produce thicker films, while lower viscosity solutions can lead to thinner films [34]. Adjusting the viscosity through solvent choice or concentration can help achieve the desired film properties.

- **Dispensing Volume**

The amount of solution dispensed onto the substrate before spinning can also affect the film thickness and uniformity. A larger volume may lead to thicker films, while insufficient volume can result in incomplete coverage [35].

- **Substrate Characteristics**

The type and surface properties of the substrate, including its flatness and surface energy, can influence the wetting behavior and, consequently, the uniformity of the spin-coated film [35, 36]. Pre-treatment of the substrate can enhance adhesion and improve film quality.

- **Environmental Factors**

Such as temperature and humidity, can also impact the spin coating process. For instance, higher temperatures can increase the evaporation rate of the solvent, affecting the drying time and the final film thickness [37, 38]. Similarly, humidity can influence the solvent's evaporation rate and the overall coating quality [39, 40].

I.3.3 Challenges in Spin Coater Design

Despite the advantages of spin coating, several challenges exist in the design and implementation of spin coaters. Researchers illustrate challenges in the mechanical design and fabrication of the coater structure, emphasizing the need for robust, rigid platforms that can counteract motor-induced vibrations[41]. Additionally, integrating in situ functionalities, introduces further complexity in synchronizing heating, spinning, and real-time measurement systems[42, 43]. Moreover, the degradation of motor performance over prolonged use necessitates the implementation of closed-loop control approaches [44], while vibration analysis remains vital to minimize film thickness variability, underscoring the intricate interplay between mechanical design, control precision, and process scalability in commercial spin coater systems [45].

I.3.4 Review of Recent Advances in Homemade Spin Coaters Fabrication

Microcontroller Integration and Electronic Component Selection Programmable microcontrollers significantly enhanced early designs by enabling precise motor speed and deposition time control, while Arduino-based implementations simultaneously reduced costs and improved accessibility. These systems incorporate PWM and closed-loop feedback control mechanisms to optimize accuracy and operational stability, with standard platforms such as Arduino Uno offering particularly cost-effective and programmable solutions. Furthermore, the adoption of modular architectures facilitates straightforward component replacement or upgrades, thereby

accelerating development cycles and enabling efficient troubleshooting and customization capabilities [46–48].

Sensor-Enabled Closed-Loop Control Systems Advanced sensor technologies, including infrared sensors and optical encoders, have enabled increasingly sophisticated closed-loop control systems that actively regulate process variables through continuous feedback mechanisms. These integrated systems leverage digital sensor outputs for high-precision calibration while simultaneously addressing critical performance challenges such as overshoot and settling time issues. Recent advances in control algorithms further enhance system performance by optimizing the processing of sensor data, while ongoing sensor miniaturization and improved affordability have significantly elevated overall system reliability and accessibility [46–49].

Brushless DC Motor Technology

Brushless DC motors offer enhanced efficiency and reduced mechanical wear compared to standard DC motors. Their electronic modules allow nuanced speed control and dynamic adjustments, resulting in systems with lower maintenance and higher precision. Integration with microcontrollers improves durability and reliability [46, 50].

IoT and Wireless Capabilities

Internet of Things (IoT) capabilities enable remote monitoring and adjustable spin recipes. Wireless systems allow real-time monitoring, parameter adjustments, and automatic data archiving. Wi-Fi enabled devices reduce operator errors and exposure to hazardous chemicals [47, 49].

Mechanical Design Improvements

Chassis design improvements influence vibration damping and stability. Advanced designs with low-vibration rotary tables minimize disturbances affecting film uniformity. Optimized structural design reduces axial deflections during high-speed rotation [51].

Open-Source Development

Open-source platforms have facilitated design sharing and improvements. Available design files, codes, and instructions have lowered barriers for researchers and educators. This community approach fosters rapid improvements and innovation sharing, promoting cost savings while encouraging collaborative engineering [46].

Economic Considerations and Cost-Performance Balance The declining costs of essential components—microcontrollers, sensors, and motor drivers—have revolutionized access to sophisticated film deposition systems at a fraction of industrial equipment costs while providing greater process customization flexibility. This widespread accessibility particularly benefits small laboratories, educational institutions, and emerging industries where budget constraints would otherwise prevent adoption of precision deposition techniques. Importantly, this cost reduction does not compromise performance outcomes, as homemade systems produce films comparable to commercial equipment. Strategic innovations in sensor integration coupled with the combination of traditional mechanical approaches and modern electronics enable

precision and reliability levels that rival significantly more expensive commercial alternatives [46, 48, 50, 52].

I.3.5 Performance Evaluation Methods for Spin Coaters

Performance evaluation methods for spin coaters are critical to ensuring high-quality thin films. Techniques employed for this evaluation often include assessing the film thickness and uniformity using profilometry and optical interference methods [53, 54]. Additionally, the impact of spin coating parameters on film quality can be quantified through statistical modeling and empirical assessments, allowing for the determination of optimal operational parameters [55]. These evaluations foster continuous improvement in spin coating processes, ensuring high reproducibility and quality in end products. Specifically, studies focusing on empirical modeling have displayed the relationship between speed, material properties, and resulting film thickness, reinforcing the importance of systematic analysis [56, 57].

I.4 Tin Oxide (SnO_2) Thin Films

I.4.1 Properties of Tin Oxide (SnO_2) Thin Films

Tin oxide (SnO_2) thin films are widely recognized for their unique properties, which make them suitable for various applications in electronics, optics, and materials science. One of the most notable characteristics of SnO_2 is its wide band gap, typically around 3.6 eV, which classifies it as a semiconductor. This property allows SnO_2 to exhibit significant electrical conductivity, especially when doped with elements such as fluorine or indium. The n-type conductivity of SnO_2 is attributed to the presence of oxygen vacancies and tin interstitials, which serve as electron donors [58–60].

The **optical properties** of SnO_2 thin films are also of great interest. These films exhibit high transparency in the visible spectrum, making them ideal candidates for applications as transparent conductive oxides (TCOs) in devices such as solar cells and touch screens. The optical transmittance of SnO_2 thin films can exceed 80%, which is crucial for their effectiveness in optoelectronic applications. Additionally, the films can be engineered to have specific optical characteristics by adjusting deposition parameters and doping levels [59, 61–63].

The **structural properties** of SnO_2 thin films are influenced by the deposition technique used. For instance, films deposited via sol-gel spin coating often exhibit a tetragonal rutile structure, which is favorable for many applications due to its stability and high crystallinity. The morphology of the films can also be tailored through various synthesis methods, affecting their surface roughness and porosity, which in turn influences their electrical and optical performance [64–66].

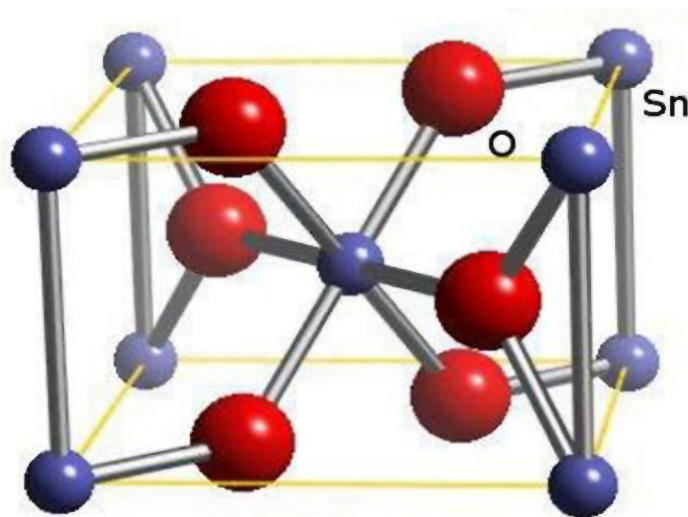


Figure I.7: The Rutile-type tetragonal crystal structure of SnO_2 [67].

I.4.2 Applications of SnO_2 Thin Films

The applications of SnO_2 thin films are diverse, owing to their advantageous properties. One of the primary uses of SnO_2 is in **gas sensing**. SnO_2 -based sensors are widely employed for detecting various gases, including carbon monoxide (CO), hydrogen (H_2), and nitrogen dioxide (NO_2). The high sensitivity of SnO_2 to reducing gases makes it an excellent choice for environmental monitoring and safety applications. The electrical resistance of SnO_2 changes significantly in the presence of target gases, allowing for effective detection [58, 60, 68].

In the field of **photovoltaics**, SnO_2 thin films are utilized as transparent conductive electrodes in solar cells. Their high optical transmittance and good electrical conductivity make them suitable for this role, enhancing the efficiency of solar energy conversion. SnO_2 can also serve as an antireflection coating, improving light absorption in solar cells. The ability to tailor the properties of SnO_2 through doping and structural modifications further enhances its applicability in this domain [59, 61, 62, 69, 70].

Another significant application of SnO_2 thin films is in **transparent electronics**. They are used in devices such as liquid crystal displays (LCDs), organic light-emitting diodes (OLEDs), and touch screens, where their transparency and conductivity are critical. The integration of SnO_2 in these devices allows for the development of flexible and lightweight electronic components, paving the way for advancements in consumer electronics [61, 62, 70].

Furthermore, SnO_2 thin films have been explored for use in **catalysis** and **photocatalysis**. Their ability to facilitate chemical reactions under light exposure makes them suitable for applications in environmental remediation and energy conversion processes, such as water splitting and pollutant degradation. The photocatalytic activity of SnO_2 can be enhanced through doping and the creation of heterojunctions with other semiconductor materials [58, 60, 68].

Chapter II

Design and Implementation of the Homemade Spin Coater

II.1 Introduction

This chapter presents the design and implementation of a homemade spin coater for thin film deposition applications. The discussion covers essential components, alongside detailed mechanical design with 3D-printed parts. The chapter explains the assembly process, system architecture, and operational workflow through the different process phases, demonstrating how this cost-effective device achieves laboratory-grade thin film production capabilities.

II.2 Device Components

Arduino Uno Board

At the core of the spin coater is The Arduino Uno, a microcontroller board that serves as the central control unit, selected for its ease of use and extensive development support [46]. The Arduino Uno features, a USB connection, a power jack, a reset button, 6 analog inputs, 14 digital input/output pins, of which 6 are capable of generating Pulse Width Modulation (PWM) signals, providing all necessary electronic components to support the microcontroller and manage peripheral

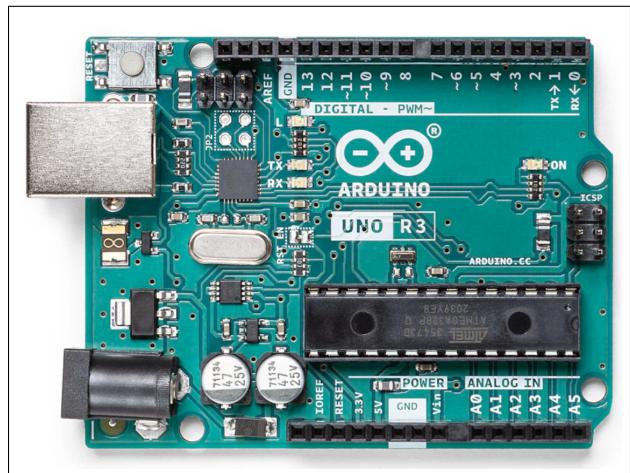


Figure II.1: Arduino Uno board [71]

devices[71].

Arduino IDE (Integrated Development Environment) facilitates the programming of the control system through a structured interface comprising a text editor, message area, text console, and function toolbar. Control algorithms, written as "sketches," are compiled and transferred to the Arduino board's memory via USB connection.



Figure II.2: Aruino IDE interface [71]

Once programmed, the Arduino continuously executes these instructions to coordinate all spin coating operations, from user interface to precise motor speed regulation, ensuring reproducible thin film deposition with minimal operator intervention.

Brushless DC Motor

The mechanical component of the spin coater is primarily the brushless DC (BLDC) motor. This type of motor is selected for its efficiency, reliability, and ability to deliver smooth rotational motion across a wide operating range. BLDC motors are known to maintain high performance while ensuring lower noise levels and reduced maintenance needs compared to traditional brushed motors [73]. Consequently, the motor's performance is critical to achieving desired film thickness and uniformity during spin coating.



Figure II.3: Brushless DC motor [72].

Electronic Speed Controller

To facilitate precise control of the BLDC motor, an Electronic Speed Controller (ESC) is incorporated into the system. The ESC interprets the PWM signals from the Arduino and adjusts the voltage sent to the motor accordingly. This allows for smooth acceleration and deceleration, crucial for minimizing defects in the thin films produced [41].

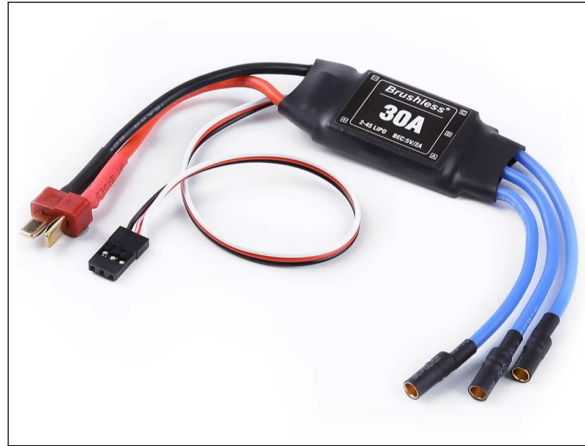


Figure II.4: 30A Electronic speed controller model [74]

Keypad

User interaction with the spin coater is managed through a 4x4 matrix keypad, which allows direct user interaction with the system for parameter input and process control. Its 16 buttons (digits 0-9 plus function keys A, B, C, D, and symbols * and #) provide a comprehensive interface for navigating menus, inputting process parameters such as spin speed and duration, and controlling system operation [75].



Figure II.5: Keypad [76]

LCD Screen

To provide real-time feedback to users, a 20x4 LCD display is incorporated. This display allows for clear visualization of system parameters, status messages, and any necessary operational data, making it crucial for effective monitoring [75].

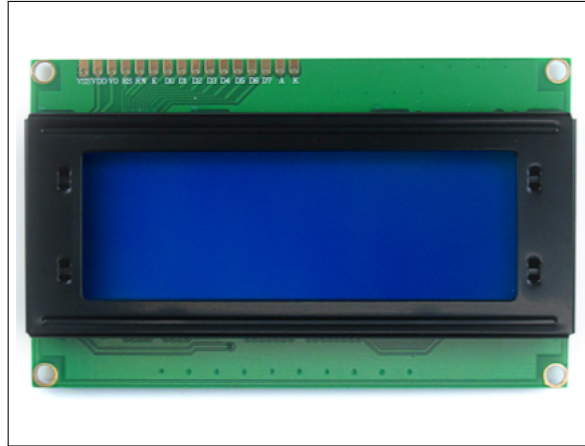


Figure II.6: 20x4 LCD screen [77]

Power Supply

This component provides the necessary electrical power for the entire system, converting standard 220V AC household electricity into the 12V DC required by the motor and control electronics.



Figure II.7: DC power adapter [78]

II.3 Mechanical Design

II.3.1 3D Printed Components

- LCD Display Cover

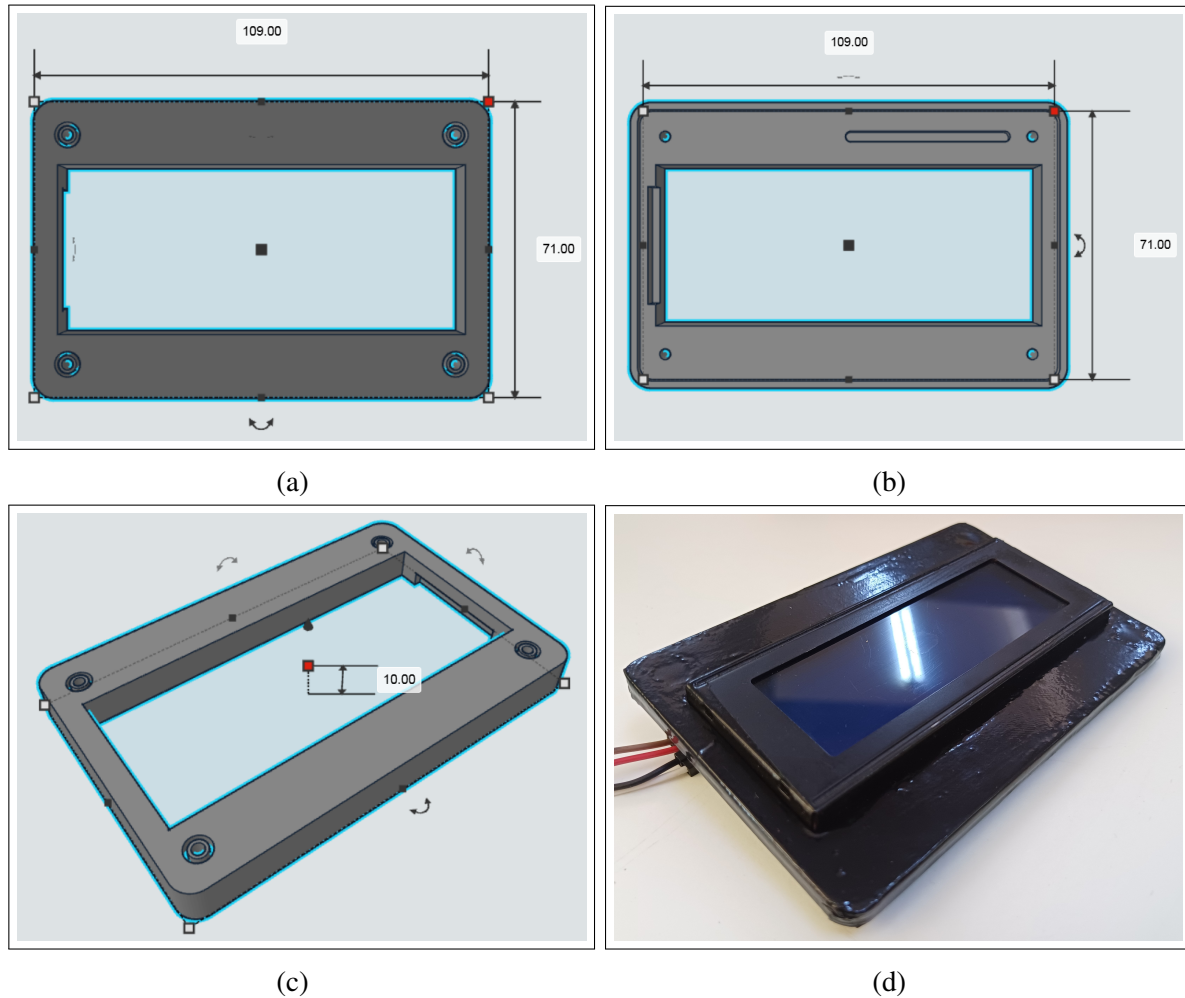


Figure II.8: LCD cover perspective projection; (a) top perspective; (b) bottom perspective; (c) isometric perspective; (d) assembled case cover after fabrication [79].

- Dimensions:**
- Length: 109.00 mm
 - Width: 71.00 mm
 - Height: 10.00 mm

The cover appears to be designed with practical features including rounded corners for safety and aesthetics, four mounting holes in the corners for secure installation, and rectangular cutout in the center that allows the LCD screen to be visible.

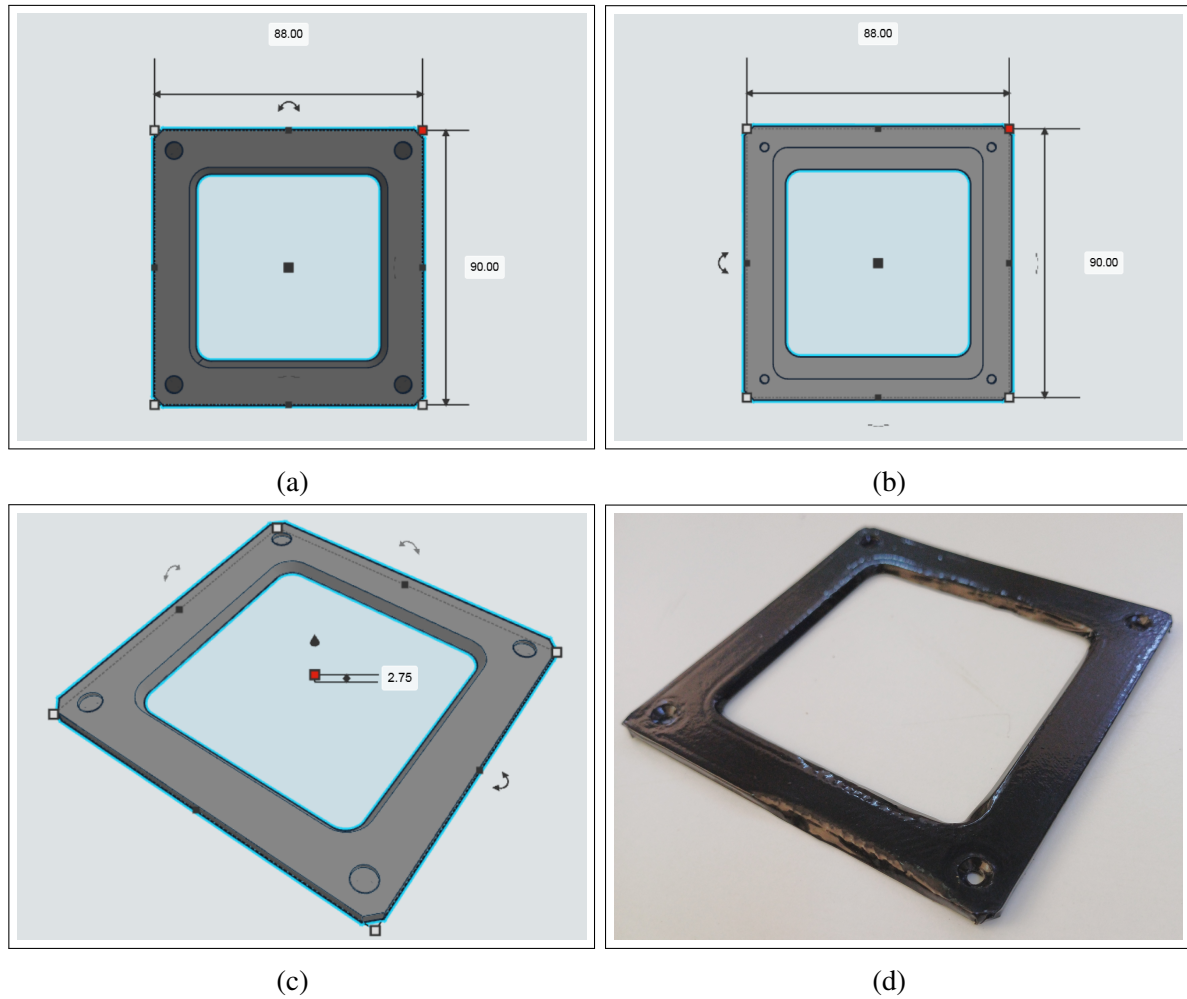
- Keypad Cover

Figure II.9: Keypad cover perspective projection; (a) top perspective; (b) bottom perspective; (c) isometric perspective; (d) actual printed piece [80].

- Dimensions:**
- Length: 90.00 mm
 - Width: 88.00 mm
 - Thickness: 2.75 mm

The cover appears to be designed with practical features including rounded inner corners for safety and aesthetics, four mounting holes in the corners for secure installation, and square cutout in the center that allows access to keypad buttons .

- Bowl Design

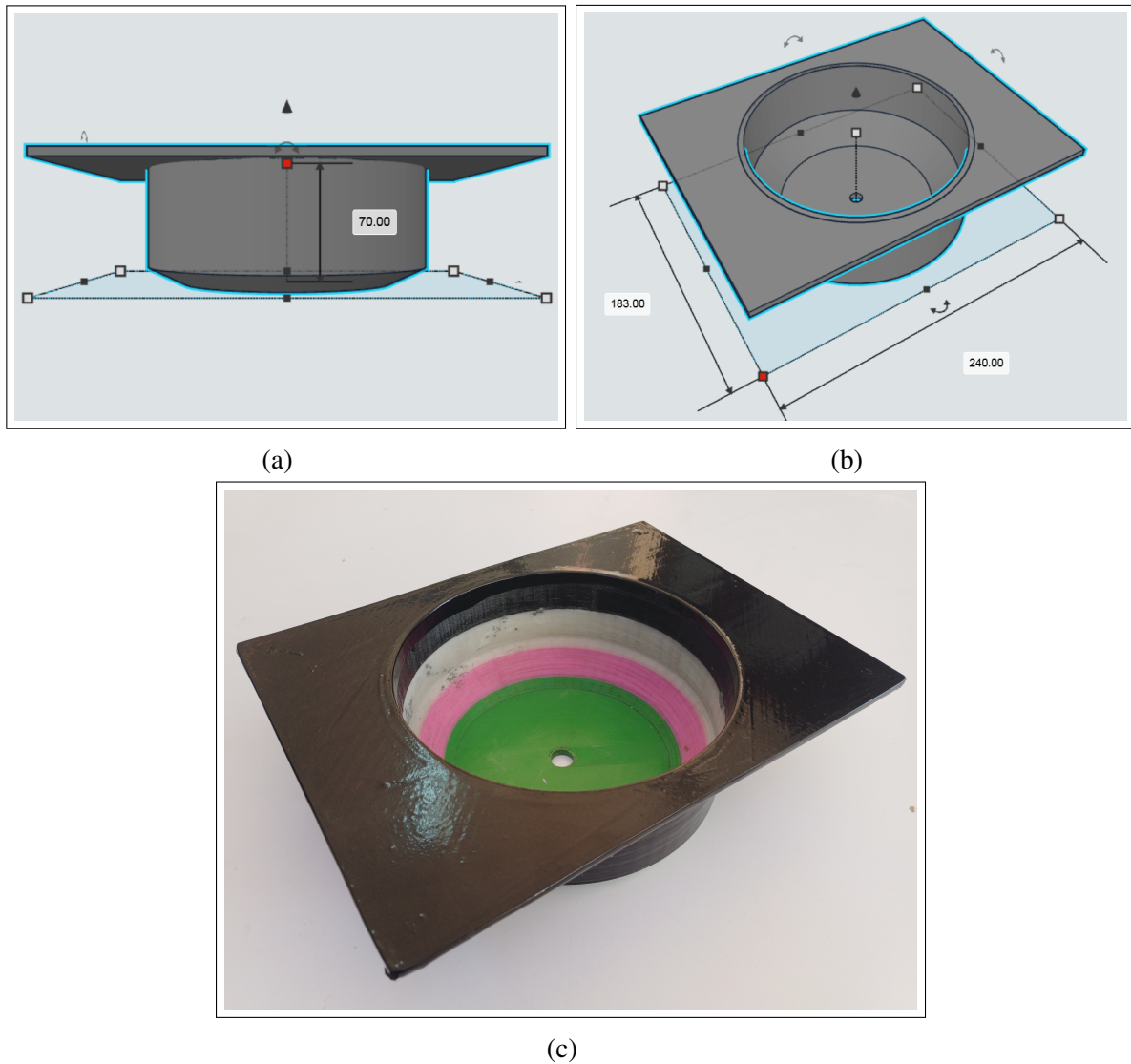


Figure II.10: Spin coater bowl perspective projection; **(a)** Cross-sectional side perspective; **(b)** isometric top-down perspective; **(c)** actual printed piece.

<u>Dimensions:</u>	• Length: 240.00 mm	• Inner bowl diameter: 152.00 mm
	• Width: 183.00 mm	• External bowl diameter: 160.00 mm
	• Height: 70.00 mm	• Inner bowl height: 66.00 mm

The bowl appears to be designed with practical features including four mounting holes in the corners for secure installation, and significant bowl diameter that allows access to substrate preparation and thin film deposition .

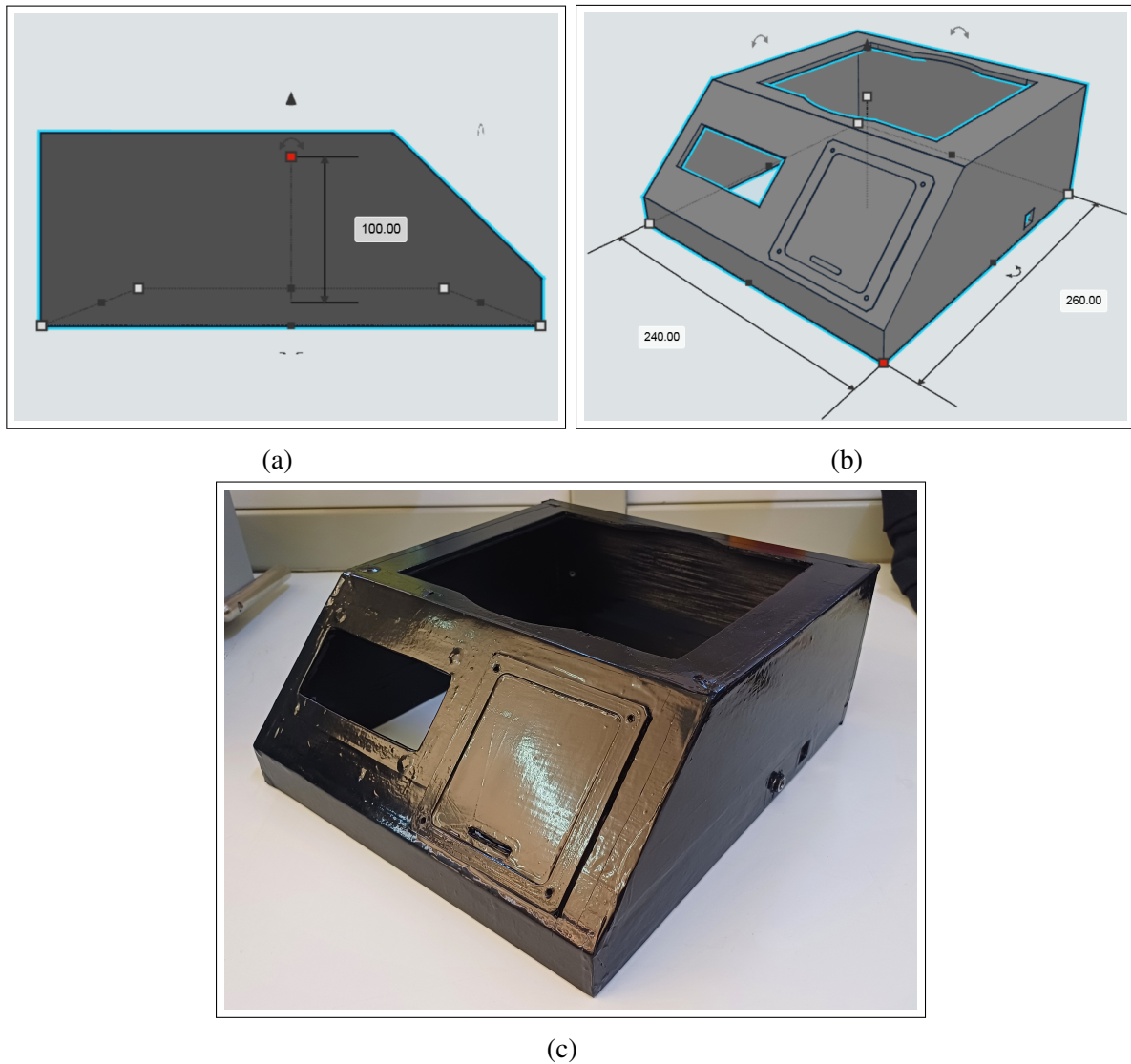
- External Enclosure Design

Figure II.11: Homemade spin coater enclosure perspective projection; (a) Cross-sectional side perspective; (b) isometric top-down perspective; (c) actual printed piece.

- Dimensions:**
- Bottom Length: 260.00 mm
 - Top Length: 183.00 mm
 - Width: 240.00 mm
 - Height: 100.00 mm

The enclosure appears to be designed with practical features including rectangular window on the angled front face, four mounting holes in the corners for secure installation, and designed cutout in the top center that allows bowl attachment.

II.4 Device Construction

II.4.1 Wiring Diagram

Wiring the components correctly is essential for the spin coater's functionality. The components are connected as follows:

Arduino to ESC

- Connect the ESC signal wire to pin 10 on the Arduino.
- Connect the ground wire of the ESC to the ground (GND) of the Arduino.
- Connect the power wire of the ESC to the 12V power supply.

Arduino to LCD

- Connect the VCC (5V) and GND of the LCD to the 5V and GND of the Arduino.
- Connect the SDA and SCL pins of the LCD to the corresponding SDA (A4) and SCL (A5) pins on the Arduino.

Arduino to Keypad

- Connect the rows and columns of the keypad to the designated digital pins on the Arduino (pins 3, 4, 5, 6 for rows and 7, 8, 9, A0 for columns).

Power Supply

- Connect the 12V power adapter to the ESC and ensure all grounds are connected (Arduino GND, ESC GND).

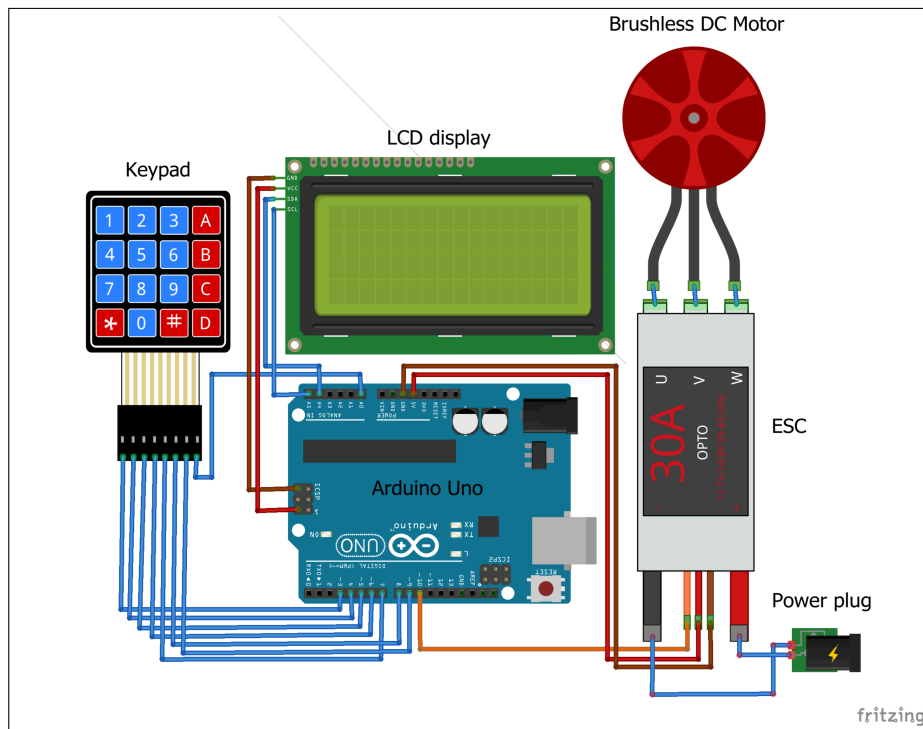


Figure II.12: Homemade spin coater system wiring diagram using Fritzing software [81].

II.4.2 Mechanical Assembly

1- Base Preparation:

- Secure the brushless DC motor to the solid base plate using four mounting screws, ensuring vertical alignment for balanced speed rotation.
- Attach the Arduino Uno board to one side of the base, leaving enough room for wiring ([Figure II.13a](#)).
- Add rubber feet under the base plate to reduce operational vibration and ensure the spin coater remains stable during high-speed runs ([Figure II.13b](#)).

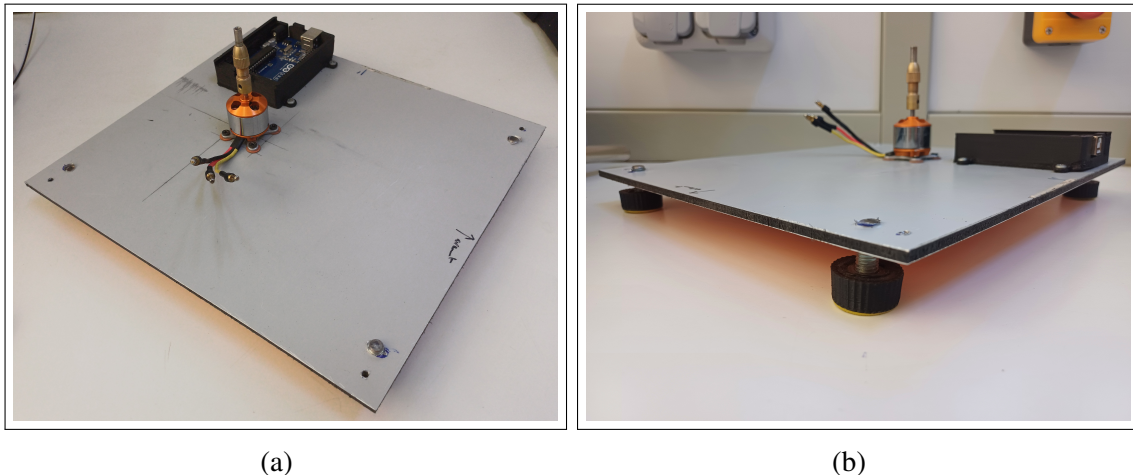


Figure II.13: Spin coater base preparation.

2- Drill Chuck Installation: Attach the mini universal drill chuck directly to the brushless DC motor's output shaft, then insert the screw-type mandrel into the mini universal drill chuck ([Figure II.14](#)), ensuring tight and secure connection for precision rotation without wobble.

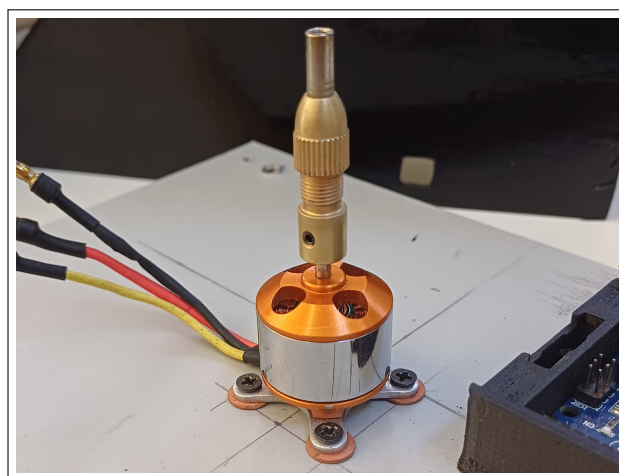


Figure II.14: Motor system preparation

3- Enclosure Installation: Position the enclosure upon the base plate and fasten it with four screws at the corners, providing a stable foundation.

4- Control Interface Installation: Mount the keypad and digital display screen on the angled front panel of the enclosure, ensuring proper ergonomics and visibility during operation.

5- Electrical Connection Completion: Finalize all wiring between the Arduino controller and control system components, implementing proper wire management inside the enclosure.

6- Bowl Installation: Mount the containment bowl onto the top surface of the enclosure, carefully aligning its center opening with the mandrel attached to the motor shaft underneath.

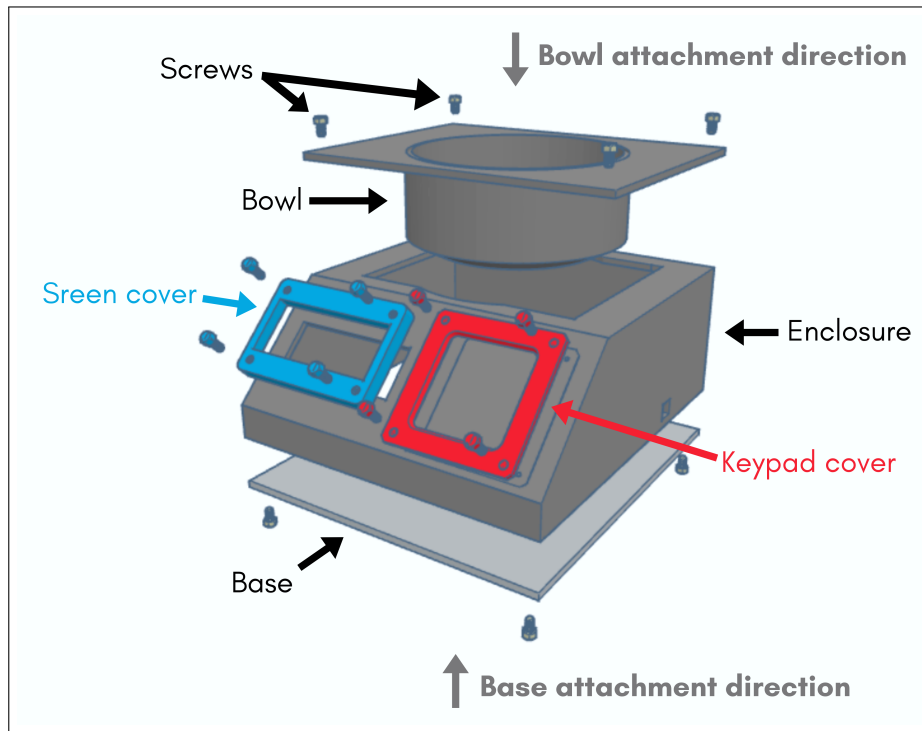


Figure II.15: Mechanical drawing of spin coater mechanical assembly process.

7- Spinning Plate Attachment: As the final assembly step, attach the spinning plate to the top of the screw-type mandrel, securing it firmly in place with the central screw, as shown in [Figure II.16](#).

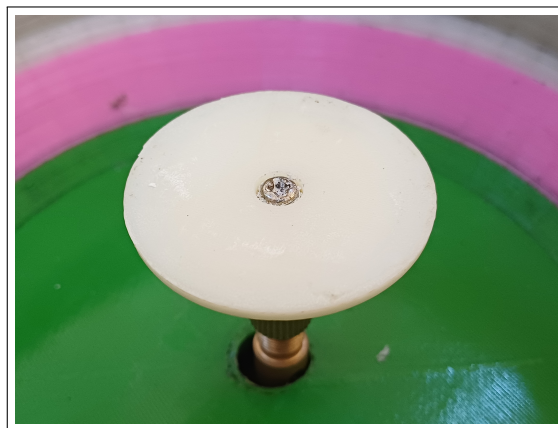


Figure II.16: Spinning plate attachment

8- Sample Adhesion Preparation: Apply double-sided tape segments to the spinning plate surface, strategically positioned for optimal substrate adhesion during spinning operations, as shown in [Figure II.17](#).



Figure II.17: Spinning substrate preparation.

9- Lid Installation: The lid, featuring a central handle, consists of circular transparent polycarbonate that fits securely to provide splash protection while maintaining visibility of the spinning process.



Figure II.18: The spin coater built

II.5 System Architecture

1. Initialization System (Setup): The initialization sequence performs three critical functions:

- **User Interface Initialization:** Establishes communication with the LCD display and presents a welcome message that identifies the system and its creator.
- **Hardware Calibration:** Performs essential ESC calibration by sending appropriate pulse-width modulation (PWM) signals to establish the operational speeds (2800-5000 RPM) range.
- **Configuration Management:** Checks for existing configuration profiles in microcontroller memory and either loads them or initializes default values if no valid profiles are detected.

2. Main Control Loop: The control loop implements a state machine approach where:

- A main menu is continuously displayed when not in other operational states
- User input is captured through the 4×4 matrix keypad
- Specific functional modules are activated based on user selection

3. Parameter Configuration Module: This module:

- Solicits and validates user input for critical process parameters
- Implements boundary checking to ensure parameters remain within operational limits
- Provides immediate feedback through the LCD interface
- Maintains temporal context through timeout mechanisms

4. Process Execution Module: The process execution module implements the core spin coating sequence:

- **Coating Phase:** Applies the initial rotational speed for distributing the coating material
- **Transition Phase:** Controls acceleration between phases for smooth speed changes
- **Deposition Phase:** Maintains the specified deposition speed for controlled film formation Each phase incorporates real-time feedback mechanisms and allows for user intervention through skip or stop commands.

5. Diagnostic Subsystem: The diagnostic module implements testing sequences for verifying proper operation of the ESC at different speeds, providing immediate feedback on system functionality.

6. Profile Management System: This sophisticated module allows for:

- Storage of up to five complete parameter profiles in non-volatile memory
- Loading of previously saved profiles
- Visual inspection of saved parameters
- Navigation between profiles with intuitive keypad controls

II.6 Working Principle of Homemade Spin Coater and User Interaction

This homemade spin coater system offers a comprehensive user interface through its LCD screen and keypad, enabling precise control over the thin film deposition process. Upon powering the system by connecting the power supply to a standard socket, users are greeted with an initialization sequence displaying welcome messages while the system performs ESC calibration in the background.

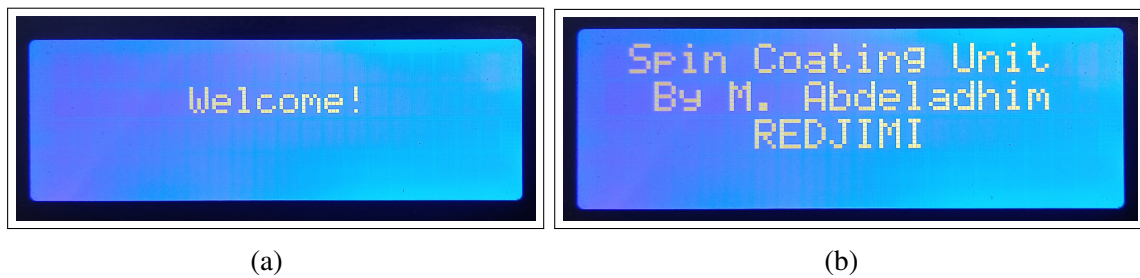


Figure II.19: Welcome Messages

The main menu then presents four primary options:

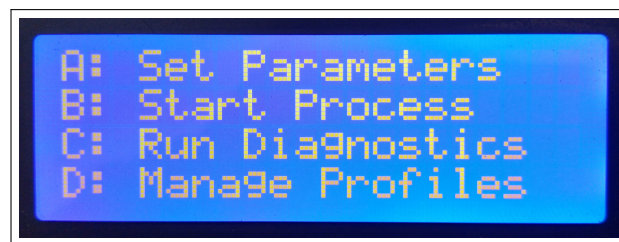


Figure II.20: Options list

When setting parameters, the system guides users through a sequential input process for each critical variable (coating speed, coating time, deposition speed, deposition time, and acceleration rate) validating each entry against predetermined operational limits to ensure both safety and process effectiveness. Numerical inputs are entered via the keypad, with the # key confirming entries and the C key allowing correction of mistaken inputs. The system provides continuous feedback through the LCD display, showing current input values and providing context-appropriate guidance.



Figure II.21: Windows of coating phase setting parameters



Figure II.22: Windows of deposition phase setting parameters

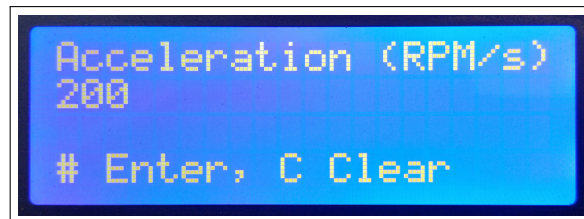


Figure II.23: Window of acceleration setting parameter

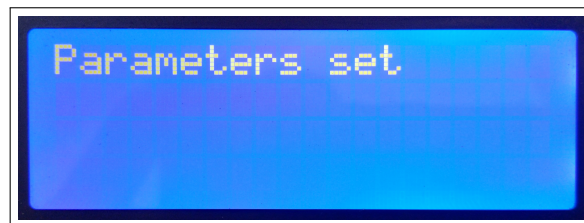


Figure II.24: Configuration Complete

Upon selecting "**Start Process**" (**option B**), the system executes the process in three distinct phases.

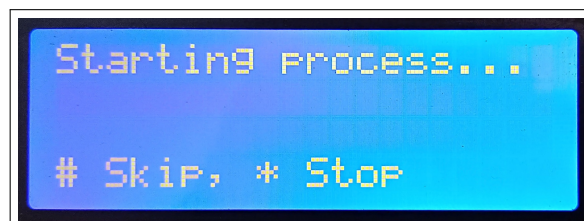


Figure II.25: Beginning of process execution

During the coating phase, the motor accelerates to the user-specified coating speed (typically lower than the deposition speed) while the substrate rotates and the coating solution is spread across its flat surface. The LCD continuously displays the current phase name, set speed, and remaining time, with interactive options for the user to skip this phase (#) or terminate the process (*).



Figure II.26: Coating phase execution.

Following successful coating, the system enters the Transition Phase where it smoothly ramps from coating speed to deposition speed based on the user-defined acceleration parameter. This carefully controlled transition prevents sudden speed changes that would adversely affect film uniformity, with the LCD providing real-time updates on current speed and transition progress.

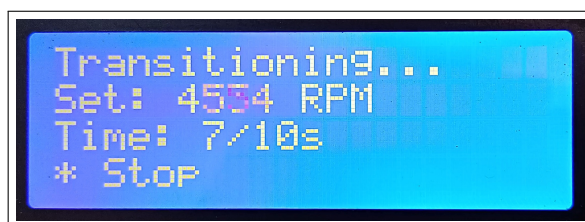


Figure II.27: Transitioning phase execution.

In the final Deposition Phase, the motor maintains the higher deposition speed for the specified duration, allowing centrifugal force to spread the deposited material evenly across the substrate surface to create a uniform thin film.



Figure II.28: Deposition phase execution.

Throughout all phases, the display constantly updates with real-time information including the current phase, actual motor speed, elapsed time, and remaining duration, while simultaneously offering interactive control options. Upon process completion, the motor decelerates to

a stop and the LCD displays a "**Process complete!**" message, indicating successful thin film deposition and that the coated substrate can be removed.



Figure II.29: Process complete window.

Beyond the basic coating process, the system offers additional functionality including Diagnostics (**option C**), which tests motor performance at various speeds to verify system integrity. Profile Management (**option D**), allows users to save, load, and browse up to five distinct parameter sets for different coating applications.

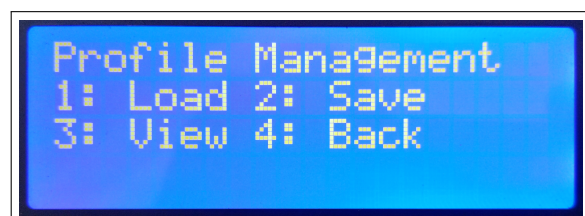
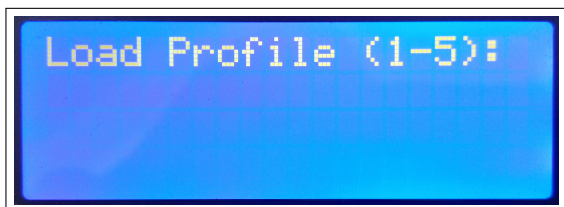


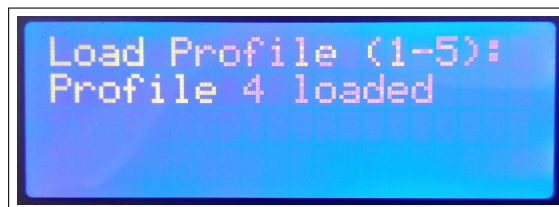
Figure II.30: Profile management.

This thoughtful interface design allows researchers to maintain complete oversight throughout the coating procedure, making real-time decisions based on visual feedback from both the system display and the substrate being coated. For recurring applications, the profile management system enables rapid recall of optimized settings for specific coating materials or substrate types without the need to manually re-enter values for each session.

1- Load Profile: Selecting option '1' allows the user to load an existing profile (numbered 1-5) from memory. This transfers the stored parameters of the selected profile to the current working parameters.



(a)



(b)

Figure II.31: User chooses "profile 4" parameters to be loaded

2- Save Profile: Selecting option '2' enables the user to save the current parameters to one of

five profile slots. This operation permanently stores the current process parameters in micro-controller memory for future use.

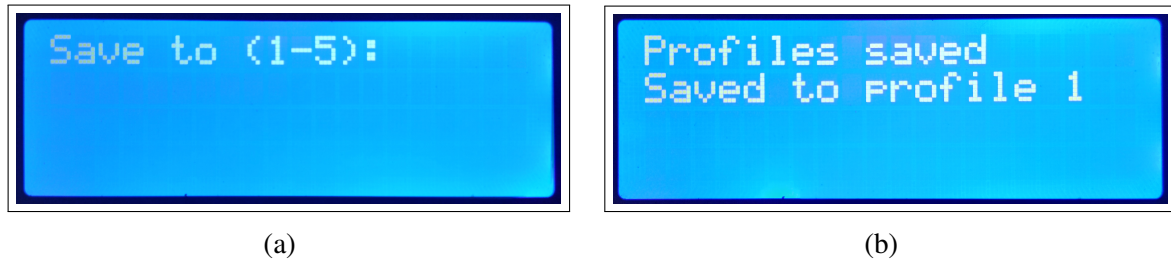


Figure II.32: User chooses "profile 1" parameters to be saved.

3- View Profiles: Selecting **option " 3 "** enters a viewing mode where the user can examine the details of each stored profile. The display shows:

- The profile number
- Acceleration rate (in RPM/s)
- Coating parameters (speed in RPM and duration in seconds)
- Deposition parameters (speed in RPM and duration in seconds)

While in viewing mode, the user can:

- Press " # " to advance to the next profile
- Press " B " to go back to the previous profile
- Press " * " to exit the viewing mode

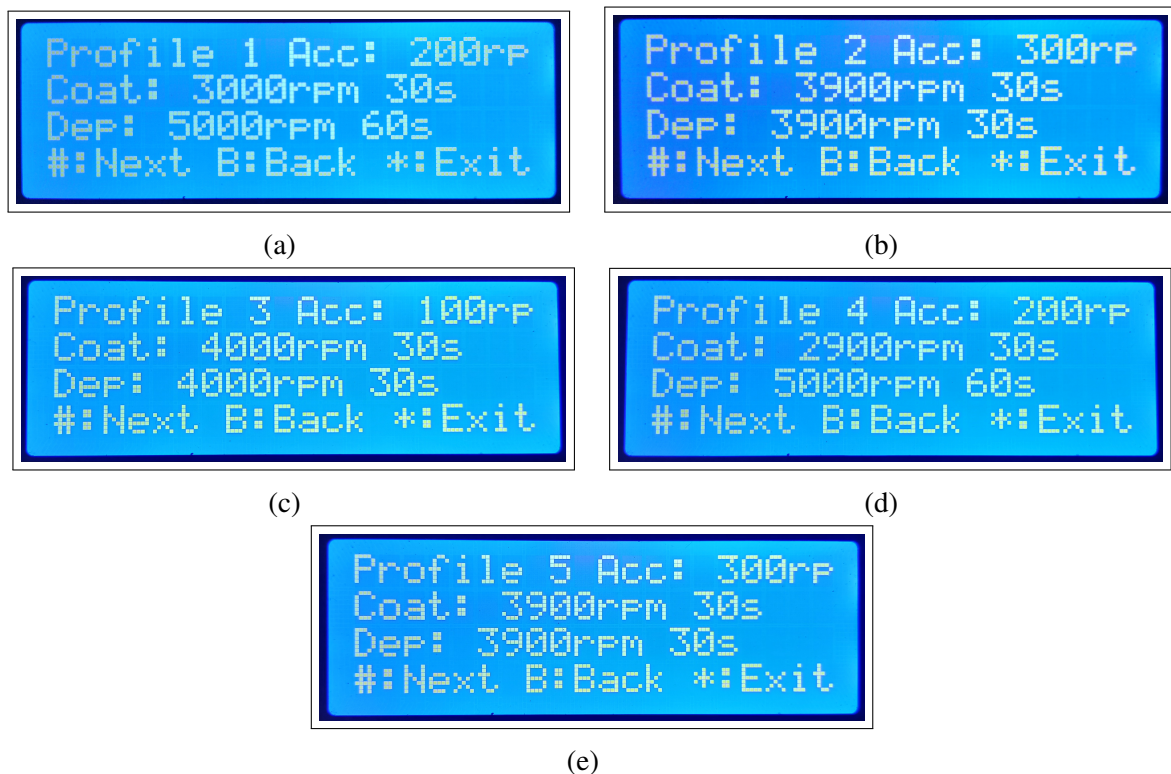


Figure II.33: Available profiles and their saved parameters.

4- Back: Selecting option '4' returns the user to the main menu (Options list in [Figure II.20](#)).

II.7 Cost Analysis

A significant advantage of our homemade spin coater is its cost-effectiveness compared to commercial alternatives. This section provides a detailed breakdown of the expenses involved in constructing this laboratory-grade equipment.

II.7.1 Component Cost Breakdown

[Table II.1](#) presents an itemized list of all components required for constructing the spin coater, along with their individual costs.

Table II.1: Cost breakdown of homemade spin coater components

Component	Quantity	Unit Cost (DZD)	Total Cost (DZD)
Arduino Uno Board	1	6000	6000
Brushless DC Motor	1	2900	2900
Electronic Speed Controller (30A)	1	2800	2800
4x4 Matrix Keypad	1	300	300
20x4 LCD Display	1	1600	1600
12V DC Power Adapter	1	1500	1500
Mini Universal Drill Chuck	1	1500	1500
3D Printing Filament (PLA+)	-	-	50000
Mounting Hardware (screws, nuts)	24	25	600
Wiring and Connectors	15	40	600
Polycarbonate Sheet (for lid)	1	1000	1000
Double-sided Tape	1 roll	500	500
Total			~ 70000DZD $\simeq$ 400\$

II.7.2 Comparison with Commercial Systems

Commercial spin coaters designed for research laboratories typically range from \$3,000 to \$10,000, depending on the specifications and additional features. [Figure II.34](#) illustrates the significant cost difference between our homemade system and commercial alternatives.



(a) Our homemade spin coater (\$400).



(b) HOLMARC Spin Coating Unit HO-TH-05 model (\$2,534) [82].



(c) Ossila spin coater standard model (\$2,633) [83].



(d) KW-4C spin coater model (\$5,000) [84].

Figure II.34: Cost comparison between our homemade spin coater (\$400) and commercial systems ranging from \$2,534 to \$7,468. The homemade system provides comparable performance for thin film deposition at approximately 5-16% of the commercial cost.

The total cost of our homemade spin coater is approximately \$400, which represents only 15,8% of the cost of HOLMARC commercial unit (\$2,534) [82]. This cost-effectiveness makes thin film research more accessible to institutions with limited resources, educational settings, and small-scale research laboratories.

II.7.3 Cost-Performance Analysis

While cost reduction is substantial, it is essential to evaluate this saving against performance metrics. Table II.2 presents a comparison of key performance indicators between our homemade system and a typical commercial spin coater (HOLMARC Spin Coating Unit HO-TH-05 model as example).

Table II.2: Cost-performance comparison with HOLMARC Spin Coating Unit HO-TH-05 model [82]

Performance Metric	Homemade System	Commercial System
Speed Range	2800 - 5000 RPM	60 - 10000 RPM
Maximum Substrate Size	100 mm	203 mm
Programmable Profiles	5	9
Initial Cost	\$400	\$2,534

This analysis demonstrates that our homemade spin coater trades some performance capabilities for substantial cost savings. While the HOLMARC commercial system offers greater speed range, and more programmable options, our system provides adequate performance for many research and educational applications at approximately 15,8% of the commercial cost. For labs with budget constraints or applications that don't require the full range of commercial capabilities, our design offers an economically attractive alternative with a cost-to-performance ratio that makes it particularly suitable for several research projects.

II.7.4 Long-term Cost Considerations

Beyond initial construction costs, our homemade spin coater offers additional economic advantages:

- **Maintenance Costs:** All components are readily available commercial parts, making replacements affordable and accessible.
- **Upgradability:** The modular design allows for incremental improvements without requiring complete system replacement.
- **Training:** The intuitive interface reduces training time for new users compared to more complex commercial systems.

This cost analysis confirms that the homemade spin coater represents an economically viable alternative to commercial systems for many thin film deposition applications, particularly in settings where budget constraints would otherwise limit access to this critical technology.

II.8 System Limitations

- The current design's speed range is constrained compared to commercial systems, potentially limiting its applicability for materials requiring higher or lower spin speeds for optimal deposition.
- The maximum substrate size is also restricted by the dimensions of the spinning plate and substrate attachment process.
- Fewer programmable profiles.
- Potential for more vibration due to consumer-grade components.
- Non-existence of temperature control and sensors.

II.9 Future Improvements

- Expanded speed range through motor and controller upgrades.
- Improved motor mounting to reduce vibration.
- Addition of vacuum chuck for better sample adhesion instead of double-sided tape.
- Integration of temperature control for heated deposition.
- Enhanced user interface with touchscreen display.
- Data logging and computer connectivity for process monitoring.
- Addition of humidity and temperature sensors for ambient condition monitoring.
- Software improvements for more complex multi-stage deposition profiles.
- Improved enclosure for better splash containment and safety

Chapter III

Experimental Study of SnO₂ Thin Films

III.1 Introduction

This chapter investigates SnO₂ thin films produced with our homemade spin coating system. We describe the experimental methods used, analyze the films' structural properties through X-Rays Diffraction (XRD), and examine their optical characteristics including transmittance and band gap measurements through Ultraviolet–Visible spectroscopy (UV-Vis). Our results demonstrate that cost-effective equipment can yield high-quality SnO₂ films suitable for several applications.

III.2 Experimental Procedure

• Substrate Preparation

The experimental procedure utilized commercial laboratory glass slides measuring 25.4×76.2 mm² with a thickness of 1.0-1.2 mm as the base substrates. These rectangular slides were precisely sectioned into three equal square pieces using a diamond scribe pen to ensure consistent edges. Before deposition, substrates were thoroughly cleaned using distilled water, dried using absorbent paper through gentle blotting, and then exposed to thermal drying to ensure complete moisture elimination.

• Solution Preparation

The preparation began with the synthesis of a precursor solution utilizing tin (II) chloride dihydrate (SnCl₂·2H₂O) as the primary reactive compound, which was dissolved in 20 ml of ethanol (CH₃CH₂OH) with 5 drops of hydrochloric acid (HCl) added as a catalytic agent to enhance solubility. This solution underwent thermal agitation at 80°C for 3 hours to ensure complete dissolution and initiate the necessary chemical reactions, followed by a 24-hour aging period at room temperature to achieve solution stability.

• Deposition Parameters

For the deposition phase, glass substrates were selected, upon which the aged precursor solution was applied dropwise and immediately subjected to spin coating at 3500 rpm for 60 seconds to achieve uniform thickness distribution across the substrate surface. To achieve the desired film thickness, 10 sequential deposition cycles were performed, with each newly deposited layer undergoing intermediate thermal treatment at 230°C for 5 minutes to eliminate residual solvents and initiate preliminary crystallization processes. Upon completion of the tenth cycle, the composite film structure was subjected to final thermal annealing at 500°C for 2 hours.

III.3 Results and discussions

III.3.1 Structural properties

X-ray diffraction is a non-destructive analytical technique used to identify the nature and structure of crystalline materials. This method applies exclusively to materials that exhibit characteristics of the crystalline state, specifically an ordered and periodic arrangement of their constituent atoms. X-rays, with wavelengths shorter than 1 nanometer, allow scientists to observe diffraction phenomena in crystals.

The technique involves bombarding a sample with X-rays and measuring the intensity of X-rays scattered in different spatial directions. The scattered X-rays interfere with each other, creating intensity maxima along certain directions, a phenomenon known as "diffraction". Researchers record the detected intensity as a function of the deviation angle (2θ) of the beam [85].

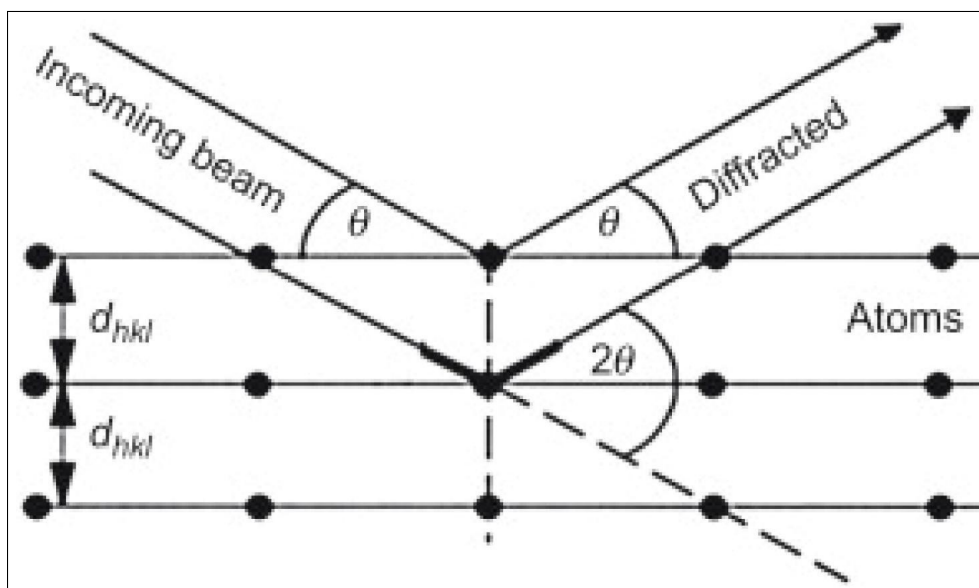


Figure III.1: Bragg diffraction diagram [86]

The X-ray diffraction (XRD) analysis was conducted on the SnO₂ thin film deposited using a custom-built spin coating apparatus, employing a rotation speed of 3500 revolutions per

minute (rpm) for a duration of 60 seconds. The resulting diffractogram was obtained using "Rigaku MiniFlex 600" (Thin Films and their Applications Laboratory - Biskra), as presented, clearly demonstrates the presence of crystalline phases within the deposited material. Several discernible diffraction peaks are observed across the 2θ range of 20° to 80° , indicating the ordered arrangement of atoms characteristic of a crystalline structure.

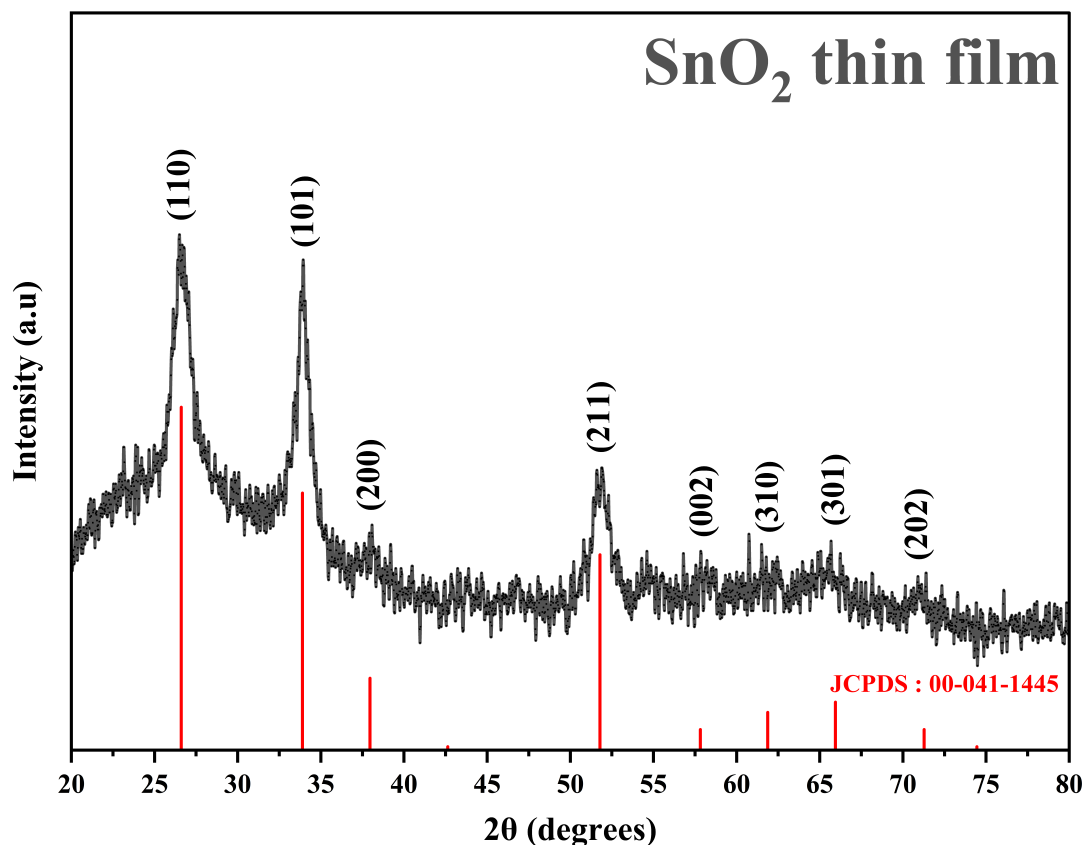


Figure III.2: XRD diffractogram of SnO₂ thin films deposited using homemade spin coater.

Specifically, prominent diffraction peaks are indexed corresponding to the crystallographic planes of tin dioxide (SnO₂). These include peaks at 2θ values of 26.50° , 33.86° , 37.86° , and 51.9° , corresponding to the (110), (101), (200), and (211) crystal planes. The angular positions (2θ values) of these experimentally obtained peaks are in good agreement with the standard reference pattern for SnO₂, as documented in the Joint Committee on Powder Diffraction Standards (JCPDS) database under the card number **00-041-1445**. The consistency between the observed peak positions and the reference data confirms the successful formation of the tetragonal rutile structure of cassiterite phase within the deposited thin film. The dominant (110) peak at 26.5° suggests preferential orientation along this crystallographic direction, which is commonly observed in SnO₂ thin films prepared by solution-based deposition methods [87].

• Crystallite Size and Strain Analysis

The crystallite size and lattice strain parameters were determined through analysis of the XRD diffraction peaks. These microstructural properties provide crucial information about the film quality produced by our homemade spin coater.

The average crystallite size (D) was calculated using the Scherrer equation [88]:

$$D = \frac{K\lambda}{\beta \cos \theta} \quad (\text{III.1})$$

Where:

- D : the average cristallite size (nm)
- K : the shape factor (0.9 for spherical crystallites)
- λ : the X-ray wavelength (1.541874 Å for Cu K $_{\alpha}$ radiation)
- β : the FWHM of the diffraction peak in (rad)
- θ : the Bragg angle in (rad)

Lattice strain (ϵ) represents the relative deformation or distortion of the crystal lattice from its ideal arrangement. This strain arises from various structural imperfections including dislocations, vacancies, interstitials, and substitutional defects.

The strains were determined using the following formula [85]:

$$\epsilon = \frac{\beta \cos \theta}{4} \quad (\text{III.2})$$

The XRD peak analysis presented in [Table III.1](#) characterizes the structural properties of SnO₂ thin films. The diffraction data reveals three principal crystallographic planes: (110), (101), and (211), with corresponding diffraction angles (2θ) of 26.50°, 33.86°, and 51.90°, respectively

Table III.1: XRD Peak Analysis for SnO₂ Thin Films

hkl	2θ (°)	FWHM (°)	D (nm)	D _{moy} (nm)	ϵ (10 ⁻³)	ϵ_{moy} (10 ⁻³)
110	26.50	1.236	6.68		5.25	
101	33.86	0.925	8.95	7.82	3.87	4.50
211	51.90	1.116	7.82		4.39	

The average crystallite size (D_{moy}) across all three planes is 7.82 nm, indicating nanocrystalline SnO₂ particles, aligns with previous reports for SnO₂ thin films prepared via spin coating deposition technique [89].

III.3.2 Optical properties

The optical properties of SnO₂ thin films were investigated using UV-visible spectroscopy in the wavelength range of 300-1000 nm. Figure III.3 displays the optical transmittance spectrum of the SnO₂ thin films deposited using the homemade spin coater.

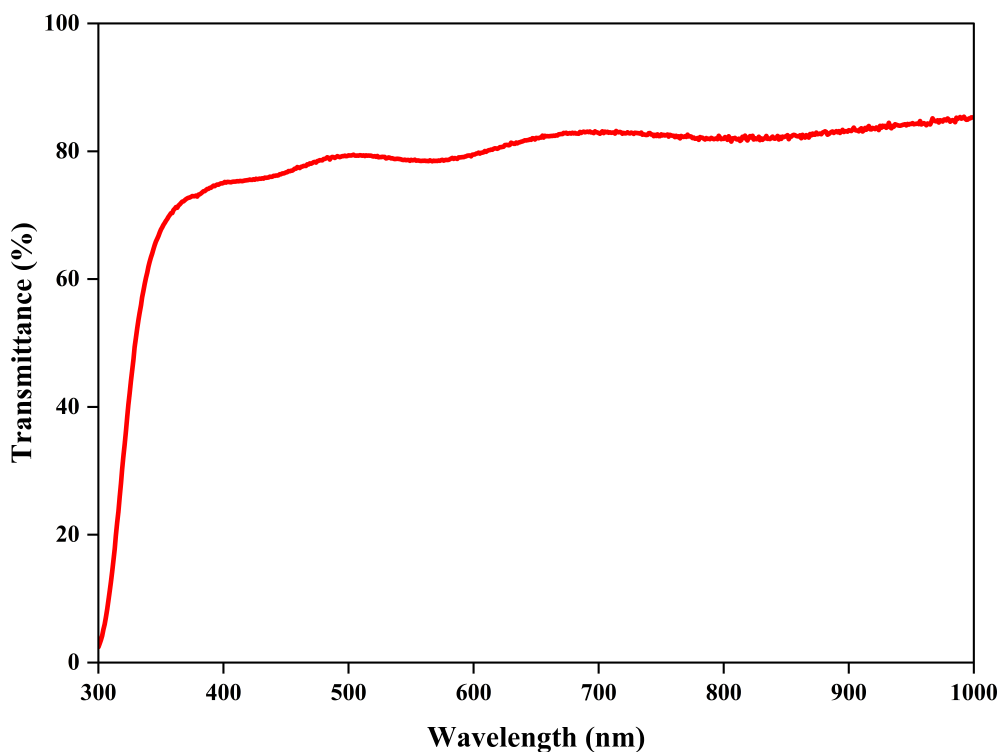


Figure III.3: Optical transmission of SnO₂ thin films deposited using homemade spin coater.

• Optical Transmittance

As observed in Figure III.3, the SnO₂ thin films exhibit excellent optical transmittance characteristics. The transmittance increases sharply from near 0% at 300 nm to approximately 70% at 350 nm, indicating the fundamental absorption edge of the material. In the visible region (400-700 nm), the films maintain a high average transmittance of approximately 75-80%, which is consistent with high-quality transparent conducting oxide (TCO) materials [87, 90]. The transmittance remains relatively stable throughout the near-infrared region and shows a slight increase toward 1000 nm, reaching values around 85%. The high transmittance in the visible region confirms the high optical quality and uniformity of the deposited films. This characteristic is particularly valuable for optoelectronic applications such as transparent electrodes in solar cells where high optical transparency is required [91].

• Optical Band Gap

The optical band gap of SnO₂ thin films was determined using the derivative spectroscopy method applied to transmittance data. This technique analyzes the first derivative of transmittance with respect to wavelength ($dT/d\lambda$), plotted against photon energy (eV) [92]. The derivative was calculated directly from experimental transmittance measurements according to:

$$\frac{dT}{d\lambda} = \frac{\Delta T}{\Delta \lambda} \quad (\text{III.3})$$

Wavelength values were converted to corresponding photon energies using:

$$E(\text{eV}) = \frac{1240}{\lambda(\text{nm})} \quad (\text{III.4})$$

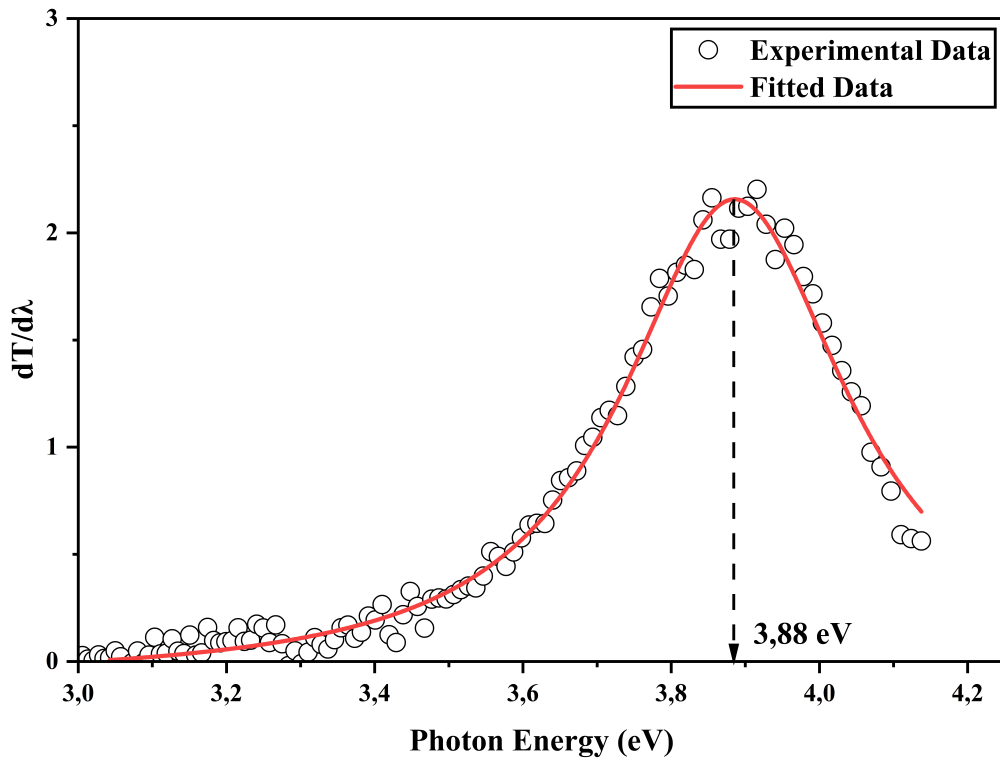


Figure III.4: Derivative spectroscopy plot ($dT/d\lambda$ vs. photon energy) for SnO₂ thin films.

Figure III.4 presents the derivative spectrum ($dT/d\lambda$ versus photon energy). A prominent peak is observed, centered at approximately 3.9 eV. The optical band gap was determined to be 3.88 eV, indicated by the vertical dashed line in the figure. This position corresponds to the maximum rate of change in the optical transmittance, signifying the fundamental absorption edge.

The derivative spectroscopy method provides direct identification of electronic transitions without requiring film thickness data or absorption coefficient calculations. This approach elim-

inates potential errors associated with extrapolation procedures common in traditional Tauc analysis. The measured band gap value of 3.88 eV aligns with previous reports for SnO₂ thin films prepared via solution deposition techniques [93].

Conclusion

This dissertation has demonstrated the successful design, construction, and validation of a low-cost, Arduino-based spin coater capable of producing high-quality SnO_2 thin films suitable for advanced materials research. The system was developed in response to the high cost and limited accessibility of commercial spin coating equipment, particularly for small-scale laboratories and educational institutions. By integrating open-source hardware, additive manufacturing, and modular design principles, the project achieved laboratory-grade performance at a fraction of the price of commercial alternatives, with a total cost of approximately \$400, just 15.8% of the cost of entry-level commercial systems.

The spin coater was designed around an Arduino Uno microcontroller, a brushless DC motor, an electronic speed controller, and 3D-printed structural components, all assembled to provide precise control over deposition parameters such as rotational speed (2,800–5,000 RPM) and process timing. The user interface, featuring a keypad and LCD screen, enables intuitive operation and real-time monitoring, while the modular architecture allows for easy upgrades and maintenance. The system's cost-effectiveness and adaptability address a critical gap in access to thin film deposition technology, empowering a broader range of researchers to engage in experimental investigations.

Validation of the homemade spin coater was achieved through the deposition and characterization of SnO_2 thin films. X-ray diffraction analysis confirmed the formation of crystalline SnO_2 with a tetragonal rutile structure, exhibiting average crystallite sizes of 7.82 nm and diffraction peaks consistent with JCPDS data reference patterns. Optical characterization revealed excellent transmittance (75–80% in the visible spectrum) and an optical band gap of 3.88 eV, properties that align with high-quality transparent conducting oxide materials. These results demonstrate that the cost-effective, open-source approach does not compromise the fundamental quality or reproducibility of thin films produced.

While the system's performance is robust for many research and educational applications, certain limitations are acknowledged. The operational speed range is narrower than that of commercial systems, and the maximum substrate size is constrained by the mechanical design. The use of consumer-grade components may also result in greater vibration compared to precision-engineered commercial equipment. However, these limitations are outweighed by the system's affordability, modularity, and accessibility, and are presented as conscious trade-offs that enable

significant cost savings without sacrificing core functionality.

The broader implications of this work extend beyond the immediate technical achievements. By providing detailed documentation of design, assembly, and control system architecture, the project offers a replicable blueprint for researchers seeking affordable alternatives to commercial spin coaters. The integration of open-source hardware and additive manufacturing exemplifies the potential of interdisciplinary approaches to advance scientific instrumentation. The systematic investigation of SnO_2 film properties as a function of deposition parameters provides foundational guidelines for optimizing sol-gel spin coating processes and offers valuable insights for researchers working with other metal oxide and functional materials.

Future improvements to the system could include expanding the speed range through motor and controller upgrades, implementing a vacuum chuck for improved substrate adhesion, integrating temperature and environmental sensors, and enhancing the user interface with touchscreen displays and computer connectivity. These advancements would further extend the system's capabilities and applicability, while maintaining its cost-effective and modular design philosophy.

In summary, this research underscores the transformative potential of open-source and additive manufacturing approaches in scientific instrumentation. By challenging the traditional reliance on high-cost commercial equipment, the project has established a foundation for continued development of accessible, customizable research tools. The documented success of the home-made spin coater provides a model for democratizing access to advanced materials research, fostering innovation, and supporting the global scientific community in both academic and industrial settings.

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Appendix A

Appendix

XRD Data Reference

Name and formula

Reference code:	00-041-1445
Mineral name:	Cassiterite, syn
Compound name:	Tin Oxide
Common name:	wood tin
PDF index name:	Tin Oxide
Empirical formula:	O ₂ Sn
Chemical formula:	SnO ₂

Crystallographic parameters

Crystal system:	Tetragonal
Space group:	P42/mnm
Space group number:	136
a (Å):	4,7382
b (Å):	4,7382
c (Å):	3,1871
Alpha (°):	90,0000
Beta (°):	90,0000
Gamma (°):	90,0000
Calculated density (g/cm ³):	6,99
Measured density (g/cm ³):	7,02
Volume of cell (10 ⁶ pm ³):	71,55
Z:	2,00
RIR:	1,90

Subfiles and quality

Subfiles:	Alloy, metal or intermetallic Common Phase Corrosion Educational pattern Forensic Inorganic Mineral
Quality:	Star (S)

Comments

Color:	White
Creation Date:	01/01/1970
Modification Date:	01/01/1970
Color:	White
Additional Patterns:	To replace 00-001-0657, 00-014-0567 and 00-021-1250
Optical Data:	B=2.006, Q=2.0972, Sign=+
Additional Patterns:	See ICSD 39173 (PDF 01-077-0447).

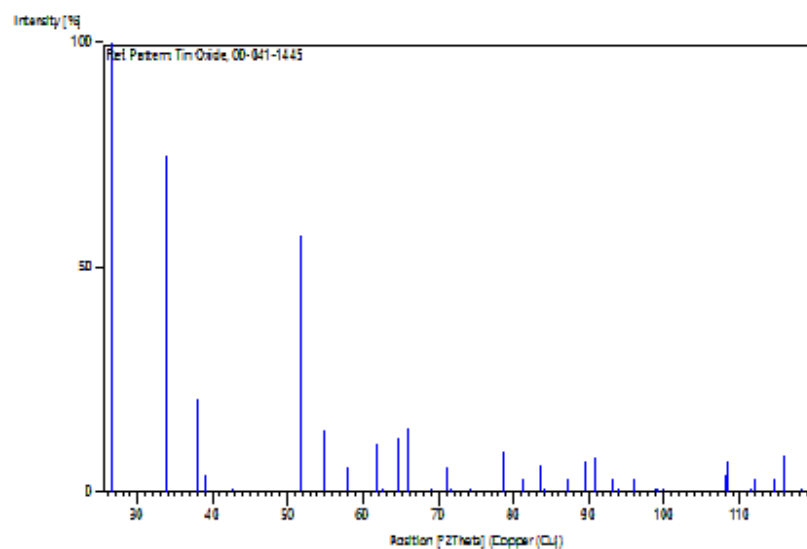
References

Primary reference: McCarthy, G., Welton, J., *Powder Diffraction*, **4**, 156, (1989)
 Structure: Baur, W., *Acta Crystallogr., Sec. A*, **9**, 515, (1956)
 Optical data: Winchell, A., Winchell, H., *Microscopic Character of Artificial Inorg. Solid Sub.*, 69, (1964)
 Other: Welton, J., McCarthy, G., North Dakota State University, Fargo, North Dakota, USA., *ICDD Grant-in-Aid*, (1988)

Peak list

No.	h	k	l	d [Å]	2Theta[deg]	I [%]
1	1	1	0	3,34700	26,611	100,0
2	1	0	1	2,64270	33,893	75,0
3	2	0	0	2,36900	37,950	21,0
4	1	1	1	2,30940	38,969	4,0
5	2	1	0	2,11890	42,635	1,0
6	2	1	1	1,76410	51,781	57,0
7	2	2	0	1,67500	54,759	14,0
8	0	0	2	1,59340	57,820	6,0
9	3	1	0	1,49840	61,872	11,0
10	2	2	1	1,48290	62,591	1,0
11	1	1	2	1,43920	64,719	12,0
12	3	0	1	1,41550	65,939	14,0
13	3	1	1	1,35600	69,231	1,0
14	2	0	2	1,32200	71,278	6,0
15	3	2	0	1,31410	71,773	1,0
16	2	1	2	1,27330	74,452	1,0
17	3	2	1	1,21470	78,714	9,0
18	4	0	0	1,18440	81,139	3,0
19	2	2	2	1,15440	83,714	6,0
20	4	1	0	1,14920	84,179	1,0
21	3	3	0	1,11670	87,229	3,0
22	3	1	2	1,09160	89,766	7,0
23	4	1	1	1,08100	90,891	8,0
24	4	2	0	1,05960	93,266	3,0
25	3	3	1	1,05390	93,925	1,0
26	1	0	3	1,03670	95,980	3,0
27	3	2	2	1,01380	98,896	1,0
28	1	1	3	1,01270	99,041	1,0
29	4	2	1	1,00550	100,008	1,0
30	4	0	2	0,95060	108,256	4,0
31	2	1	3	0,94970	108,407	7,0
32	4	1	2	0,93210	111,464	1,0
33	5	1	0	0,92930	111,973	3,0
34	3	3	2	0,91460	114,752	3,0
35	5	0	1	0,90840	115,984	8,0
36	2	2	3	0,89720	118,311	1,0

Stick Pattern



Appendix B

Appendix

Spin Coater User Manual



Homemade Spin Coater

User Manual

2025

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Chapter 1

Introduction

This manual provides comprehensive instructions for operating the homemade spin coater, a cost-effective laboratory device designed for thin film deposition applications in research and educational settings. The spin coater features programmable speed parameters, customizable operation sequences, and profile management capabilities for reproducible results across various thin film applications.

The homemade spin coater represents a significant cost advantage over commercial systems while maintaining laboratory-grade performance for most applications. This manual will guide you through proper setup, operation, and maintenance of your spin coater to ensure optimal results and extended equipment lifespan.



Figure 1.1: The homemade spin coater unit

Chapter 2

Technical Specifications

Table 2.1: Technical specifications of the homemade spin coater

Parameter	Specification
Speed Range	2800 - 5000 RPM
Maximum Substrate Size	100 mm diameter
Programmable Profiles	5
Power Requirements	240V AC, 50/60Hz (12V DC adapter)
Dimensions	260mm × 240mm × 132mm
Weight	Approximately 1.8 kg
Control System	Arduino Uno
User Interface	20×4 LCD display with 4×4 keypad

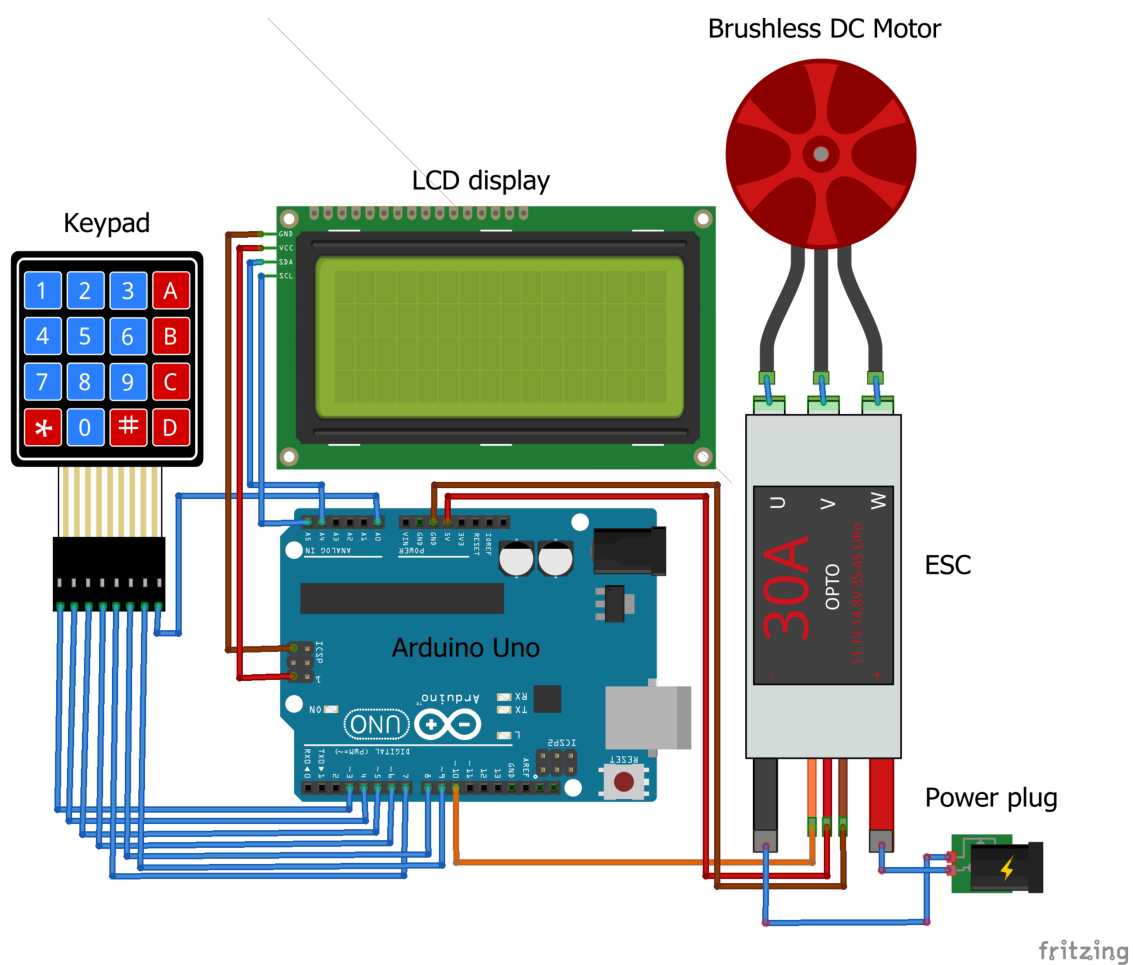


Figure 2.1: System wiring diagram of the homemade spin coater

Chapter 3

Safety Guidelines

Please observe the following safety guidelines when operating the spin coater:

- **Always secure the lid** before starting the spin coating process to contain any potential material splatter.
- **Ensure proper ventilation** when working with volatile solvents or hazardous materials.
- **Wear appropriate personal protective equipment (PPE)** such as gloves, lab coat, and safety glasses.
- **Balance your substrates properly** on the spinning plate to prevent vibration and potential damage.
- **Keep hands and loose items away** from the rotating parts during operation.
- **Disconnect power** when performing maintenance or when not in use for extended periods.
- **Do not operate with wet hands** or in wet environments.
- **Place the unit on a stable, level surface** to minimize vibration during operation.
- **Allow sufficient cool-down time** between consecutive high-speed operations.

Warning: Never operate the spin coater without the protective lid in place. Flying debris could cause injury or damage to surrounding equipment.

Chapter 4

Setup and Installation

4.1 Initial Setup

1. Place the spin coater on a stable, level surface away from sensitive equipment.
2. Ensure all components are securely attached and free from shipping damage.
3. Connect the power adapter to the unit and then to a suitable power outlet.

4.2 Substrate Preparation

1. Cut double-sided tape into small segments (approximately $1\text{cm} \times 1\text{cm}$).
2. Apply 2 tape segments symmetrically around the center of the spinning plate.
3. Clean your substrate thoroughly to ensure proper adhesion and film uniformity.
4. Carefully place the substrate at the center of the spinning plate, pressing gently to secure it to the tape segments.



Figure 4.1: Substrate attached to spinning plate with double-sided tape

4.3 System Check

Before first use, perform a system diagnostic check:

1. Power on the unit by connecting the power supply.
2. Wait for the welcome message and initialization to complete.
3. Select "Diagnostic" from the main menu (Option C).
4. Follow the on-screen prompts to verify proper motor function.

Chapter 5

Operating Instructions

5.1 System Initialization

1. Connect the power supply to an appropriate power outlet.
2. The system will display welcome messages.

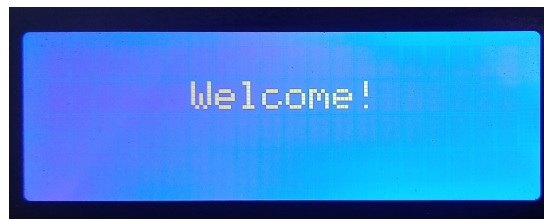


Figure 5.1: Welcome screen upon system initialization

3. After initialization, the main menu will appear with four options:
 - A: Set Parameters
 - B: Start Process
 - C: Run Diagnostic
 - D: Manage Profiles

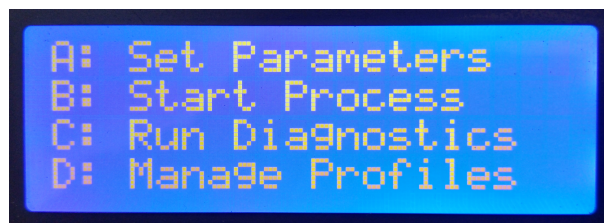


Figure 5.2: Main menu options display

5.2 Setting Parameters

Select Option **A** from the main menu to set process parameters:

1. **Coating Speed:** Enter the desired speed (in RPM) for the initial coating phase. Press **#** to confirm.

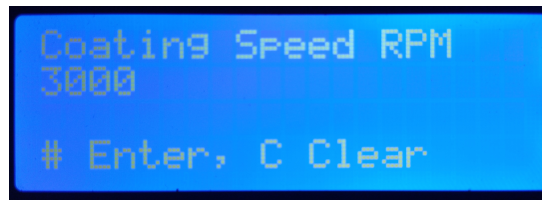


Figure 5.3: Coating speed parameter input screen

2. **Coating Time:** Enter the duration (in seconds) for the coating phase (5-15 seconds recommended). Press **#** to confirm.

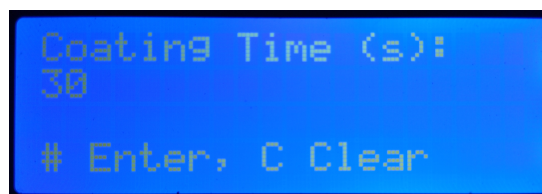


Figure 5.4: Coating time parameter input screen

3. **Deposition Speed:** Enter the speed (in RPM) for the main deposition phase. Press **#** to confirm.

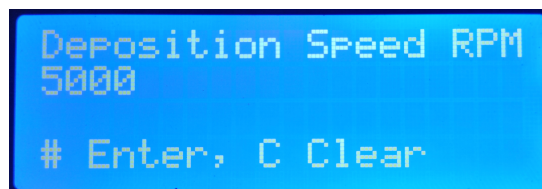


Figure 5.5: Deposition speed parameter input screen

4. **Deposition Time:** Enter the duration (in seconds) for the deposition phase. Press **#** to confirm.

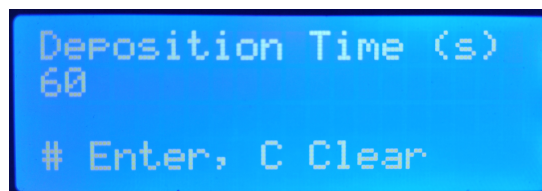


Figure 5.6: Deposition time parameter input screen

5. **Acceleration Rate:** Enter the rate of transition (in RPM/second) between coating and deposition speeds. Press **#** to confirm.

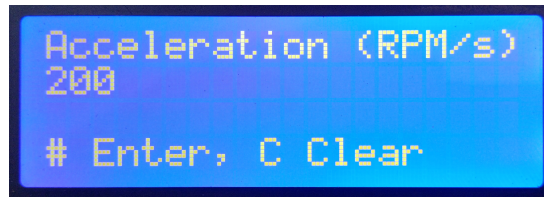


Figure 5.7: Acceleration rate parameter input screen

Note: Press **C** at any time during parameter entry to correct your input. The system will validate your input against operational limits to prevent incorrect operation.

After setting all parameters, the system will display a confirmation screen:

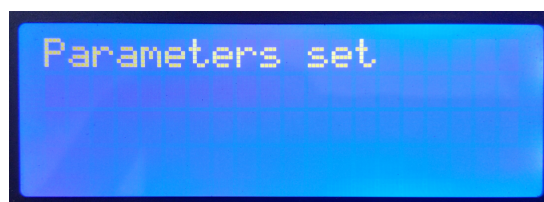


Figure 5.8: Parameters confirmation screen

5.3 Running the Spin Coating Process

Before starting the process:

1. Place your substrate on the spinning plate using double-sided tape.
2. Apply the coating solution to the substrate center (typically 2-5 drops depending on viscosity and substrate size).
3. Secure the transparent lid on top of the containment bowl.

To run the process:

1. Select Option **B** (Start Process) from the main menu.

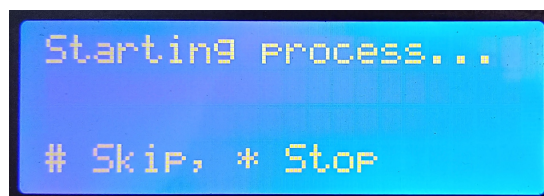


Figure 5.9: Process initiation screen

2. The system will execute the spin coating process in three phases:
 - **Coating Phase:** Initial desired speed rotation to spread the material.
 - **Transition Phase:** Gradual acceleration to deposition speed.



Figure 5.10: Coating phase execution screen



Figure 5.11: Transition phase execution screen



Figure 5.12: Deposition phase execution screen

- **Deposition Phase:** Last desired speed rotation for uniform film formation.
3. During any phase, you can:
 - Press **#** to skip to the next phase
 - Press ***** to stop the process entirely
 4. When the process completes, the motor will decelerate to a stop and the display will show "Process complete!"

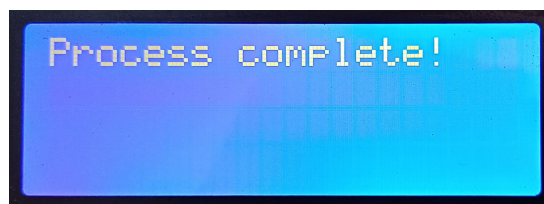


Figure 5.13: Process completion screen

5. Remove the lid and carefully retrieve your coated substrate.

5.4 Using Profile Management

Select Option **D** from the main menu to access profile management:

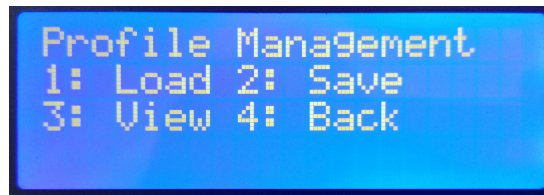


Figure 5.14: Profile management menu

• Load Profile (Option 1)

1. Select a profile number (1-5) to load

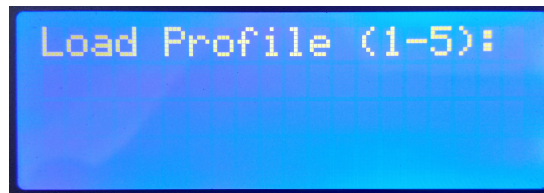


Figure 5.15: Load profile selection screen

2. The system will load all parameters from the selected profile

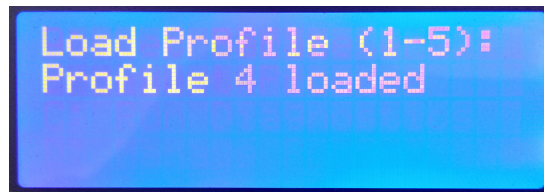


Figure 5.16: Profile loaded confirmation screen

• Save Profile (Option 2)

1. Select a profile number (1-5) where you want to save current parameters

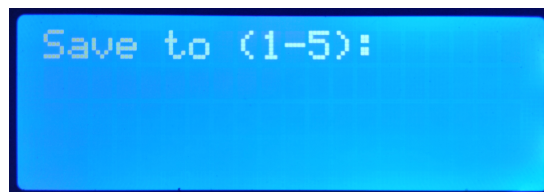


Figure 5.17: Save profile selection screen

2. The system will save all current parameters to the selected profile

• View Profiles (Option 3)

1. Browse through saved profiles
2. Press # to view the next profile

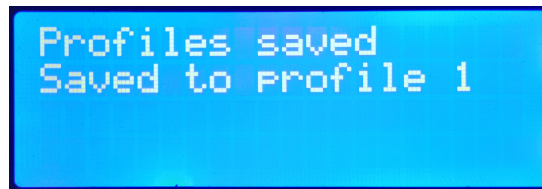
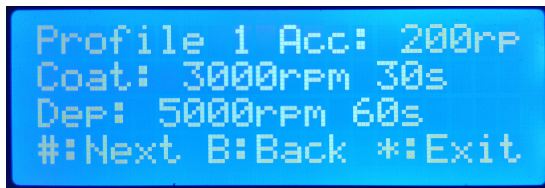
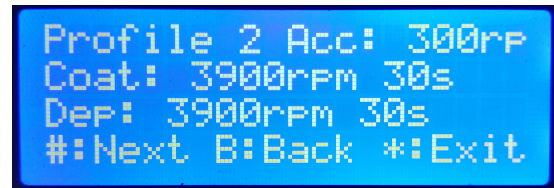


Figure 5.18: Profile saving confirmation screen

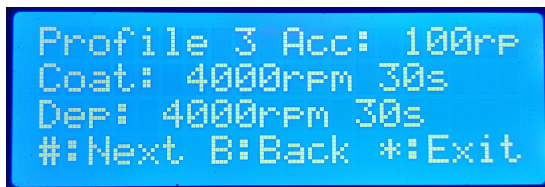
3. Press **B** to view the previous profile
4. Press ***** to exit viewing mode



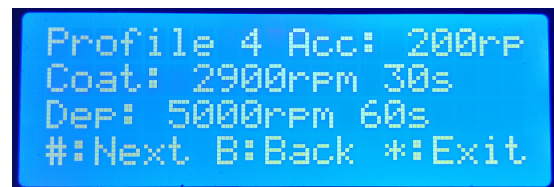
(a) Profile 1



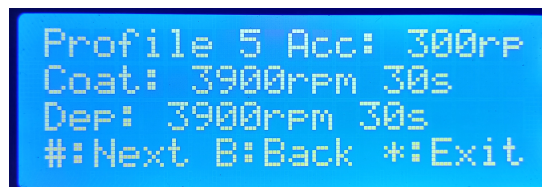
(b) Profile 2



(c) Profile 3



(d) Profile 4



(e) Profile 5

Figure 5.19: Profile viewing screens for all five profiles

• Back (Option 4)

- Return to the main menu

5.5 Using the Diagnostic Tool

Select Option **C** from the main menu to access the diagnostic tool:

1. Follow the on-screen prompts to test the motor at various speeds.
2. The system will run the motor at different RPM levels to verify proper function.
3. Observe for unusual noise, vibration, or speed inconsistency.

Chapter 6

Maintenance and Troubleshooting

6.1 Routine Maintenance

After Each Use

- Clean any material splatter from the containment bowl
- Remove tape residue from the spinning plate
- Wipe down external surfaces with a clean, damp cloth

Monthly Maintenance

- Check all screws and mechanical connections for tightness
- Inspect the power cable for damage
- Clean the interior of the containment bowl thoroughly
- Verify keypad function and responsiveness

6.2 Troubleshooting Common Issues

Warning: Do not attempt to disassemble the electronic components unless you have expertise in electronics. Contact technical support if you encounter persistent issues that cannot be resolved with the troubleshooting steps provided.

Table 6.1: Troubleshooting guide for common issues

Problem	Possible Cause	Solution
Unit does not power on	Power connection issue	Check power adapter connection both at wall outlet and unit
LCD displays garbled text	Communication error	Disconnect power, wait 30 seconds, then reconnect
Motor does not spin	ESC Connection issue	Run diagnostic test; if problem persists, check internal ESC wiring connection to Arduino
Unstable rotation speed	Imbalanced substrate	Ensure substrate is centered and securely attached
Keypad unresponsive	Connection issue	Check internal keypad wiring connection to Arduino
Parameters not saving	Memory issue	Reset the system by disconnecting power for 1 minute
Excessive vibration	Loose mechanical components	Check and tighten all screws, particularly motor mounting screws

Chapter 7

Mechanical Assembly Diagram

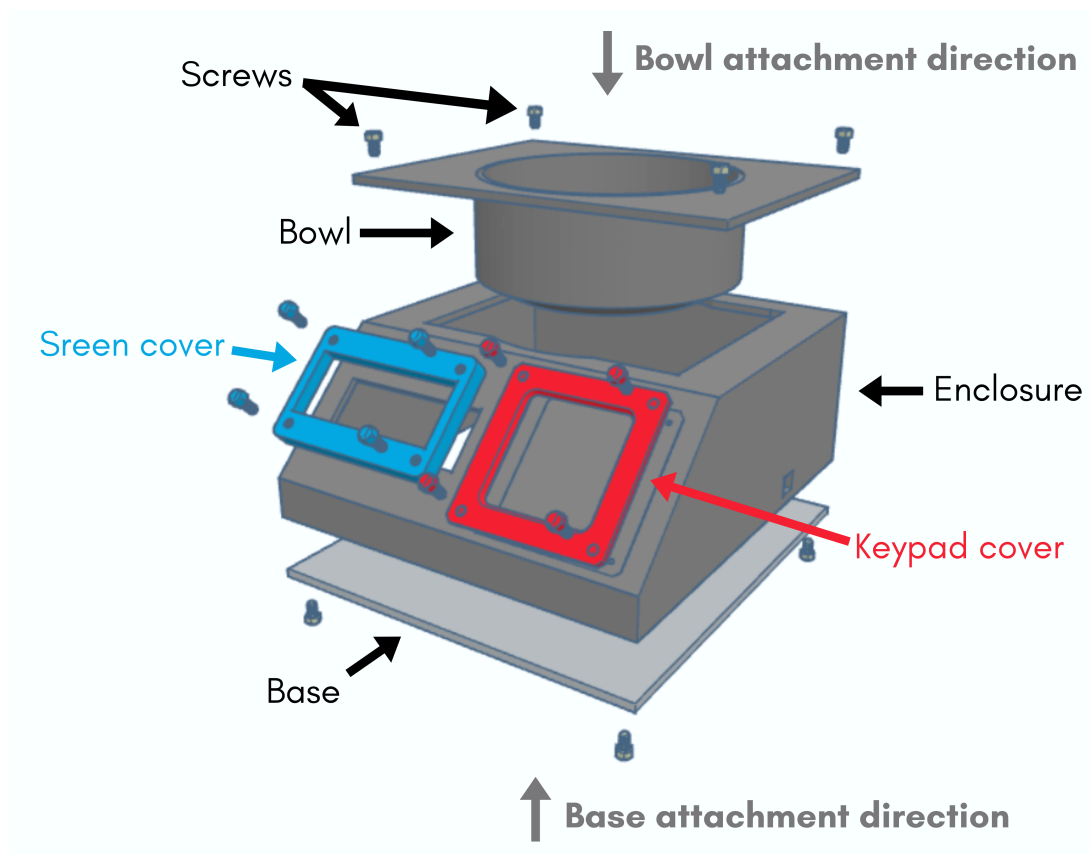


Figure 7.1: Mechanical assembly diagram of the spin coater

Chapter 8

Technical Support

If you encounter issues not addressed in the troubleshooting section, please contact technical support with the following information:

- Detailed description of the problem
- Photos or videos demonstrating the issue (if applicable)
- Current parameter settings
- Any error messages displayed

Technical support can be reached at:

mohamed_redjimi@univ-biskra.dz
Tel: +213-65-678-6134

Document End

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تصريح شرفي

تخص بالالتزام بقواعد النزاهة العلمية لإنجاز بحث

(ملحق القرار 1082 المؤرخ في 2021/12/27)



أنا الممضي أسفله،

السيد(ة): محمد عبد العظيم خيضر

تخصص: فيزياء ... ميكانيكا ... الطاقة ... المسحرة ... الصفة: طالب سنة ثانية ماستر

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المسجل بكلية: العلوم الدقيقة ... قسم: علوم المادة

والمكلف بانجاز أعمال بحث : مذكرة

عنوانها: Design of Spin Coater for Thin Film

Growth

أصرح بشرفي أنني ألتزم بمراعاة المعايير العلمية والمنهجية ومعايير الأخلاقيات المهنية والنزاهة الأكاديمية المطلوبة في إنجاز البحث المذكور أعلاه وفق ما ينص عليه القرار رقم 1082 المؤرخ في 2021/12/27 المحدد للقواعد المتعلقة بالوقاية من السرقة العلمية ومكافحتها.

التاريخ: 2025-05-25

إمضاء المعني بالأمر