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Research Article

Design of New Generation Low-Cost Dip Coating Device and Performance Tests in ZnO Thin Film Production

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ABSTRACT

In this study, a dip coating device was designed using low-cost materials and performance tests were performed. The dip coating method is an efficient coating technique used to dip samples into chemical solutions and produce thin films. The designed system provides precise movement in the vertical axis with a stepper motor, while a heating unit can be used to apply heat treatment during the coating process. The device controlled by Arduino allows the user to adjust the number of dips, waiting times and movement speed. In order to test the operation of the system, ZnO thin films were produced, and these films were evaluated with XRD, SEM and UV-spectrophotometer analyses. As a result of the analyses, it was determined that the structural and optical properties of the films produced by the device were in accordance with the data in the literature. These results prove that the designed dip coating system is successful and functional.

1. Introduction

The dip coater is basically a device that dips the substrate into a chemical solution using a holder and repeats this process cyclically. This device has become the most frequently used today by receiving various updates. Today, dip coater devices can not only perform the dipping process but also dry after dipping. In addition, it has become a device that can affect the sample produced by determining the cycles it will perform, the time it will spend at each stage and even the dipping speed. [1–5].

The dip coating method, which is cheap and efficient, is used in obtaining chips, sensors and other micro/nano-sized semiconductors or conductive materials, which are considered high-tech products. This method, which is one of the pioneering methods in the development of high-tech products, allows cheap and useful experiments to be carried out. [6].

There are several methods for coating; either by a dry process; CVD, PVD, PECVD, etc. or by a wet process; spray coating, brush casting, spin coating, dip coating, etc. Wet methods are particularly suitable for the preparation of multiphase materials. In these methods, any non-volatile compound dispersed or dissolved in solution can be distributed uniformly in layers on the surface of the material, and the coating thickness can be controlled quite well. [7, 8].

Offering a wide range of uses with many advantages, the dip coater device is a basic equipment for a coating technique widely used in many industrial and research areas. Dip coating, which is basically based on the process of dipping a substrate into a liquid solution and then slowly pulling it, can be used for the production of thin films, surface modification, material synthesis and various surface treatment processes. Dip coating is an important method especially for the production of nano-scale materials and the preparation of thin film

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coatings. The use of dip coaters ensures the homogeneous application of thin film coatings and prevents the formation of unwanted layers by increasing the quality of the coating. In addition, multi-layered materials can also be produced with the dip coating method, which brings together various layers with different functions, along with the application of layered coating.
In the fields of materials science and nanotechnology, dip coaters are frequently used in the production of thin film coatings and in the modification of the surface properties of materials, and they play an important role in many industrial and research areas such as the production of optoelectronic devices, biomedical applications, sensors, junctions and solar cells [9–13].

Within the scope of this study, a dip coater system was established using low-cost and accessible materials and application tests were carried out.

2. Materials and Methods

The dip coater system is basically based on a holder with a single-axis movement moving at adjustable speeds between certain points. In this study, the dip coater system was designed so that heat treatment could be applied during coating. For this purpose, a heat chamber was built where the holder could move inside. The dip coater system was created using various components such as sigma profiles, carriage plate, stepper motor, Arduino, joystick and power supply (Figure 1).

A stepper motor was preferred to ensure that the axial movement of the sample holder would be precise in the up or down direction. Arduino was used to create a menu for entering different parameters and to control the movement of the stepper motor. The general design of the microcontroller-based dip coating device is presented in Figure 2.

Figure 1. Purchased stuf

XRD analysis of the sample produced with the system was carried out with Rigaku SmartLab at room temperature and in the range of 2θ=20-80º. Surface analysis was carried out with JEOL 6610 SEM and for optical examinations, SHIMADZU was carried out with UV-2600.

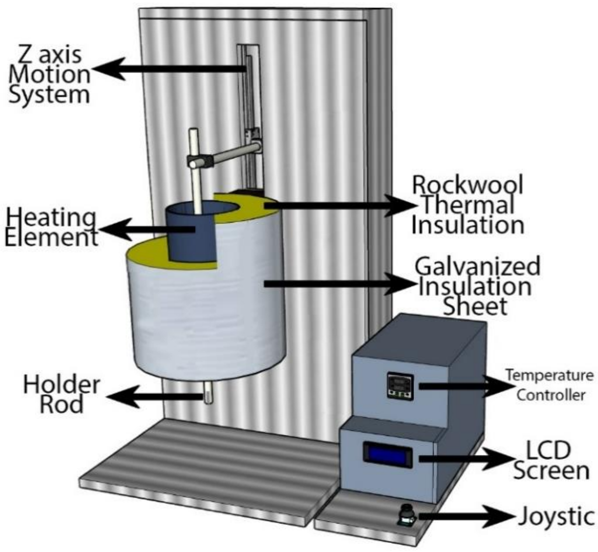


Figure 2. Dip coater design and components

3. Design and Development of the System

In the dip coater device, a stepper motor was preferred in order to make the movement on the vertical axis regularly and precisely. Since stepper motors can rotate precisely thanks to their low steps, they will ensure that the coating process does not miss the points where it will move. The holder rod constitutes the majority of the load that the motor will carry. Considering its resistance to heat and durability, 8 mm steel rods were preferred as holder rods. In addition, a Nema-14 stepper motor was preferred for axis movement where high weight carrying is not required. The hybrid bipolar stepper motor Nema-14 has a 1.8⁰ step angle, which corresponds to 200 steps per rotation. Approximately 1000g-cm holding torque can be provided in this motor, which can be applied with 500mA and 12V for each phase. The movement of the stepper motor is transferred to the carrier plate that can move on the sigma profile via a gear pulley and belt. The stepper motor, which is driven using the A4988 stepper motor driver, is adjusted to a 1.8⁰ degree rotation angle. Two microswitches were preferred to determine the axis limits for the stepper motor that will carry out the Z axis movement. Microswitches are basically switches that control the flow of electricity. The microswitch; which sends 0 information to the microcontroller in the closed position, will send an information to the system when the carrier car comes into contact with it and moves to the open position. These microswitches, which are usually placed in the mechanism where the carrier plate moves, ensure the safety of the moving mechanisms and the coated material against the possibility of entering unexpected situations. The connections of the circuit diagram are given in Figure 3.

As can be seen from the electronic design, Arduino was used in the system and software development was carried out with ArduinoIde accordingly. LiquidCrystal_I2C and Wire libraries were used in the software, and no ready-made libraries were used. Figure 3a shows the schematics of the movement and other software-dependent systems, while Figure 3b shows the connection diagram of the heating resistance and digital thermostat. In order to control the temperature of the heating unit, rockwool was coated on the resistance, and a galvanized metal shell was placed on it to try to minimize thermal leaks. In this way, it was aimed to balance the temperature and also to minimize the oscillation at the targeted temperature value.

When the device is turned on, the software must first reset the y-axis so that the system can record the nape length. The system determines the number of steps by going to the lowest and highest points and records this value. No intervention is allowed by the user during this process. After determining the number of steps, the user attaches a substrate to the slide mount and aligns it according to the highest point of the solution to be dipped. This process provides information input for the z-axis to the software. Now that the system knows all the number of steps and where the solution is; values such as total dip number, waiting durations at different points such as in solution, in oven and at drying can be defined. In addition, the movement speed between each point can be determined from the menu. After these operations, the dipping process can be started by exiting the settings menu. In case of a possible error during the adjustments, the microswitches at the top and bottom points of the y-axis protects the system during dipping.

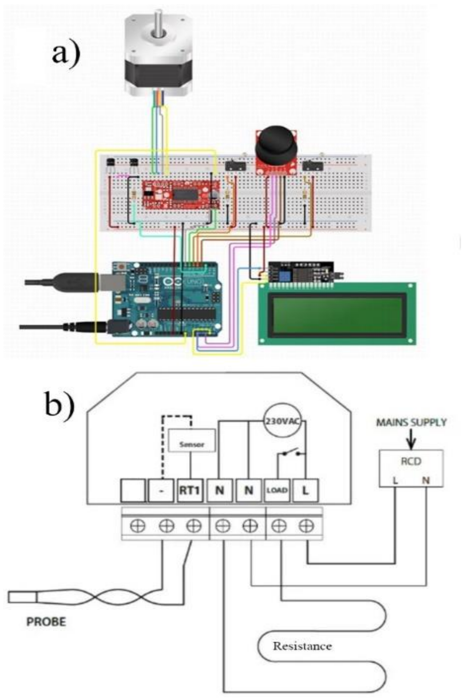


Figure 3. a) Dip coater electronic symatic, b) Heating system connection diagram

The final state of the system with its design and electronics is given in Figure 4. The software and other information about the system are given clearly [14].

ZnO has been selected as an ideal sample material for thin film production by dip coating method. Because ZnO is a very suitable material for obtaining homogeneous coating and low cost production. In addition, production parameters can be easily obtained thanks to the deep source pool formed in this area [15–20]. In terms of repeatability of the device, the samples obtained in the study were produced more than once.

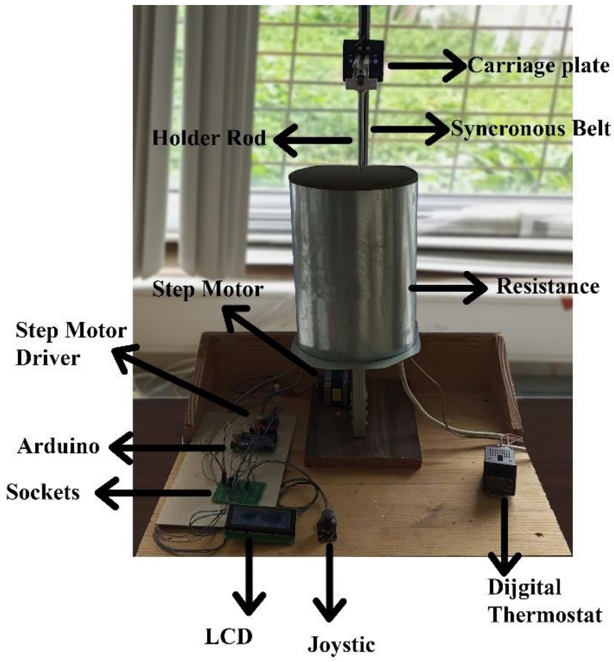


Figure 4. Fabricated dip coating system

Thin film production was carried out with the system whose software and electronics were completed. In this experiment, zinc oxide thin film production was aimed, and preparations were made accordingly. For this purpose, zinc oxide solution was prepared by dissolving zinc acetate dehydrate salt with methanol and adjusting its fluidity with monoethanolamine [21, 22].

The solution prepared based on previous studies was coated on microscope coverslips that were carefully cleaned beforehand and then ultrasonically cleaned in ethanol and distilled water. The parameter information entered the dip coating system produced during this coating process is given in Table 1.

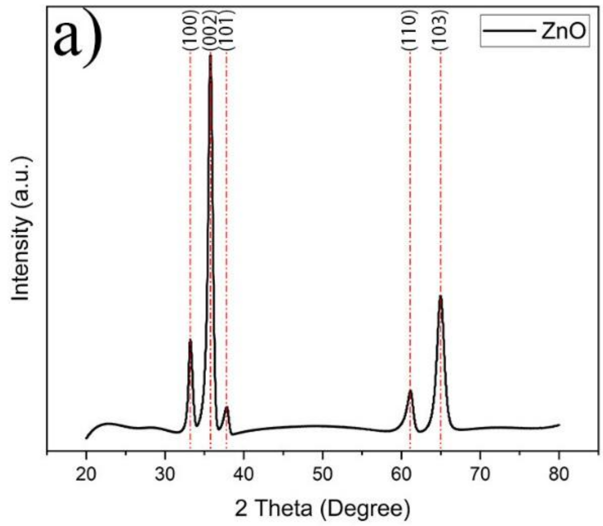
Table 1. Parameters entered on the fabricated dip coating system

	Name	Value
1	Total dipping number	5
2	Waiting time in furnace	180 sec
3	Waiting time in air/cooling	120 sec
4	Waiting time in sollution	2 sec
5	Diping speed	100 step/ms
6	Resistance temp	300 ⁰C

4. Results and Discussion

After the dipping process was completed with a total of 5 cycles, the samples were subjected to heat treatment in a muffle furnace and in an atmospheric environment at 450 ⁰C for 30 minutes. In this way, the formation of the crystal structure was ensured [23, 24]. After obtaining the crystal structure, the produced samples were analyzed by X-ray diffractometer (XRD) for structural analysis, scanning electron microscope (SEM) for morphological analysis, and UV-Spectrophotometer for optical properties.

The X-ray pattern obtained by structural examination is given in Figure 5a. When the peaks obtained in the figure are compared with the literature, it is seen that they are classical ZnO peaks [24–27]. In this case, it was concluded that the production phase was successful, and the dip coating device obtained gave sufficient performance.



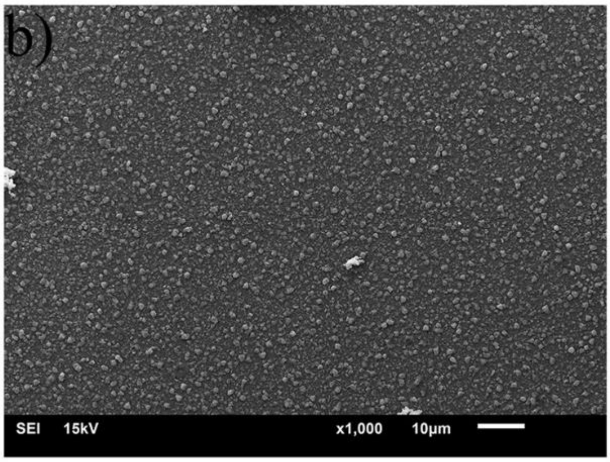


Figure 5. a)XRD pattern, b) SEM image of fabricated thin film

The surface and the particles formed are seen in the scanning electron microscope images given in Figure 5b. The particle size value related to the heat treatment temperature and time was calculated as 550 nm on average [28–31].

The transmittance and energy band gap (Eg) values are given in Figure 6. It was observed that the obtained band gap values are compatible with the literature [22,32–34]. In the litrature the optical band gap of ZnO films are about 3.69 – 3.82 eV [35]. And also many experimentally produced ZnO thinf ilms have different band gap energy values like 3.15-3.65 eV [22,32,36–38].

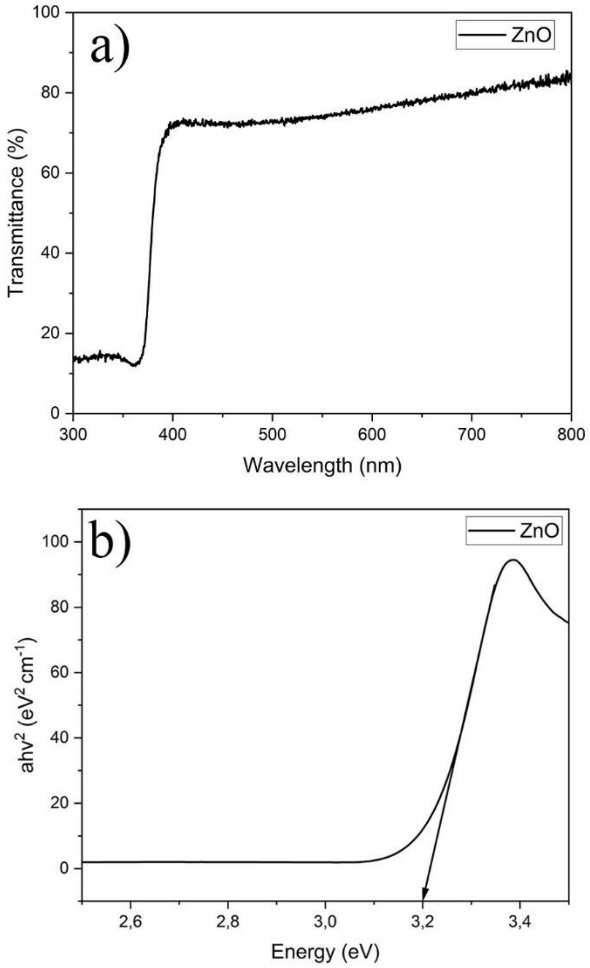


Figure 6. a)Transmittance, b)Band Gap results of fabricated thin film

5. Conclusion

The mechanical and software parts of the dip-coating device designed within the scope of the study have been completed. The device has a much smaller heater chamber compared to previously designed models. Since the microcontroller on the system only deals with the number of steps and distances, the number of dips entered by the user, time, etc., it does not have any involvement in the control of the heater section. Thanks to the controller of the heater section, temperature stability is easily provided in the system. Trial productions were made with the system and the structural, morphological and optical properties of the obtained ZnO thin film were examined. It was seen from the comparative studies made with the literature that the XRD pattern obtained from the ZnO thin film produced with the system was compatible with the literature. Similarly, the fact that the band gap value calculated from the UV results was compatible with the literature revealing the success of the system in the production phase.

Article Information Form

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Authors' Contribution

The authors contributed equally to the study.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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