Building a low cost spin coater with Arduino

André Brito Linhares
Instituto de Física
Universidade Federal do Rio de Janeiro
Rio de Janeiro, Brasil
linhares.ab@gmail.com

Raphael Nunes da Silva Moreira Souza*
UFR de Physique
Sorbonne Université
Paris, France
Raphael.Nunes_Da_Silva_Moreira_Souza@etu.sorbonne-universite.fr

Germano Maioli Penello
Instituto de Física
Universidade Federal do Rio de Janeiro
Rio de Janeiro, Brasil
https://orcid.org/0000-0001-9067-6407

***Abstract*— In this study, a low-cost spin coater was developed for use in a teaching laboratory for semiconductor device fabrication. All stages of construction, from idealization to assembly of the final prototype, are presented. In the first version of the spin coater, the control logic was built using an Arduino Micro with PID control. An obsolete computer was disassembled to obtain the voltage source (which also served as the basis for the body of the spin coater) and the brushless motor from a broken hard disk. Three-dimensional parts were modeled and printed on a 3D printer, and vectorized drawings were made to use a laser cutter in the manufacture of the rotating base of the final prototype. The equipment is controlled by a cell phone application developed specifically for this project, in which communication is performed wirelessly via Bluetooth. The results of the first prototype showed an accuracy of approximately 0.5% at the desired speed of 4000 RPM. We are currently working on a second version of the equipment.**

Keywords—Photolithography, Spin coater, Arduino, Low-cost

I. Introduction

Spin-coating is used in the semiconductor industry during the photolithography stage, such as in the development of optoelectronic devices [1, 2]. The process consists of using an equipment called a spinner, which has a rotating base to which a deposition surface, usually a semiconductor wafer, is firmly coupled. After the wafer is attached to the rotating base, a fluid called photoresist is dropped over the wafer. By rotating the base, the photoresist spreads evenly over the surface [3]. The final thickness of the photoresist on the top of the wafer depends on the speed and time of rotation [4]. For this reason, an accurate speed control is necessary to guarantee the quick stabilization of the rotation speed of the spinner.

Professional quality equipment is usually manufactured to meet the diverse uses of different research groups. This is normally done so that the equipment can be sold to groups with different needs, making the equipment versatile and flexible for the different applications in which it can be used. The disadvantage of this approach is related to the cost of the components used to build the equipment. To be versatile and able to reach a wide range of uses, parts and components must be able to work under different conditions, increasing the cost of these key components. On the other hand, equipment that has only one specific use may have a reduced cost because it does not require as much versatility and because it has the possibility of being built with materials that do not require as much flexibility of use. This is an example of a spin coater, as demonstrated in this study.

In this project, a low-cost spin coater was developed to be used in a specific semiconductor photolithography application in which the rotation is controlled in a range around 4000 RPM. This spin coater is currently being built and improved for use in a semiconductor device fabrication teaching laboratory. In this type of teaching environment, it is important that the student can visualize the phenomenon, practice using the equipment, insert themselves in a research environment, be stimulated by working in a laboratory, and develop experimental skills. With the construction of low-cost equipment [4–6], all these learning steps can be performed without having to worry about damaging professional equipment, which has high acquisition and maintenance costs. Another advantage of building one's own equipment is that project developers perform equipment maintenance themselves. This makes damaged parts or components easily identifiable in the blueprint, shortening the problem identification and repair time.

A project of this type is vital for stimulating future researchers in the experimental area. The development of low-cost equipment encourages students to participate not only in the creation of the equipment but also in its use, and it creates a stimulating research environment for the students. It is important to note that this type of approach is greatly facilitated by modern digital fabrication equipment such as 3D printers and laser cutting machines and/or electronic prototyping boards such as Arduino and Raspberry Pi (or similar).

The initial objective of this project was to construct a spin coater to serve as a demonstration in a teaching laboratory. In this specific case, it is not necessary to use precision electric motors or control electronics designed specifically for this type of motor. The first alternative that we present demonstrates that a spin coater made of reused materials from an obsolete computer (voltage source and brushless motor obtained from a hard disk) is sufficient for this task in a demonstrative laboratory. In addition, the use of an Arduino [5] as a digital control electronics and the preliminary results obtained suggest the possibility of using this equipment in a very specific step of photolithography carried out in an international research environment.

II. Spin coater

The first version of the spin coater is primarily made up of two main blocks: the box to which the electronic part of the equipment is confined, and the rotation base, which is formed by the motor and the toothed wheel. The rotation control is based on a feedback system, as shown in Fig. 1.

Fig. 1. Feedback loop uses the PID library available in the Arduino IDE library manager. A reflective infrared sensor is used to measure rotation and an Electronic Speed Controller (ESC) is connected to the brushless motor.

Fig. 2. Image of the Android app created for the user interface. The speed (in RPM) and the rotation time are inserted by the user in the app. The wireless communication is performed via Bluetooth protocol.

The spin coater is based on a 6-tooth sprocket. When one of the teeth passes over an infrared reflective sensor, the infrared light is reflected, generating a pulse at the output. A vectorized design was created for the laser cutter to cut a 6 mm acrylic that was used to build the sprocket.

The detection of six pulses by the Arduino translates into a complete rotation of the sprocket. Speed corrections will be performed through the feedback provided by the microcontroller to the motor and will be adjusted using the PID Library available in the Arduino IDE Library Manager.

The spinner is powered by a 450 W ATX power supply, and the communication between the spinner and the user is performed wirelessly via a Bluetooth communication protocol with a smartphone application (Fig. 2), produced in the MIT App Inventor platform. The desired speed and rotation time were inserted into the app by the user. The application also shows the actual speed of the equipment in real-time. A HC-05 Bluetooth module was connected to the Arduino, and the smartphone used the device's native Bluetooth function to connect to the spinner.

With the connection between the phone and the microcontroller, tests were performed to verify the connection of the motor to our PID control system. The motor was connected to an Arduino using an Electronic Speed Controller (ESC) module. Brushless motors require a current that feeds the motor to be pulsed, and the ESC module is responsible for synchronizing the pulses at each of the three motor terminals. The sensor used to measure the rotation of the sprocket wheel must consider the costs as well as whether it works at high rotations (approximately 4000 RPM). In this study, we used a reflective infrared sensor for this task.

The sprocket wheel was the main part of our rotation measurement system. The first prototype of the wheel was made using a 3D printer, but a better approach was obtained through the laser cutting of an acrylic plate. Bearing in mind that the acrylic used was transparent to infrared radiation, a second cut was made of reflective material with the same dimensions as the geared wheel that could be glued to the acrylic.

Fig. 3. Final assembly of the first version of the spin coater. The yellow arrow highlights the position where the reflective infrared sensor was attached.

To avoid increasing the thickness of the acrylic and disturbing the measurement, a sheet of white paper was cut on a laser cutter for this purpose (Fig. 3). The reflective infrared sensor has been attached to the base of the bracket so that it is aligned with the teeth of the sprocket wheel as shown in Fig. 3.

The rotation measurement and system calibration stage sought to vary the desired rotation speed as well as the PID algorithm variables that control the application of feedback to the system input. Thus, the proportional, integral, and derivative gains were adjusted carefully.

Fig. 4 shows an overshoot when the designated speed was set to 4000 RPM and the PID gains were not within their correct values. It can be seen that the measured speed reached a value of approximately 5200 RPM before stabilizing. This overshoot can be eliminated by correctly using control parameters. Therefore, careful calibration of the PID gains is essential to guarantee the accuracy of the spinner.

III. Results

As a preliminary result, we obtained the rotation speed graph through the Serial Monitor, a native function of the Arduino IDE. The results (Fig. 5) were obtained at the desired speed of 4000 RPM for 120 s. The following plot was achieved for the PID factors with Kp = 0.3, Ki = 0.2 and Kd = 0.02.

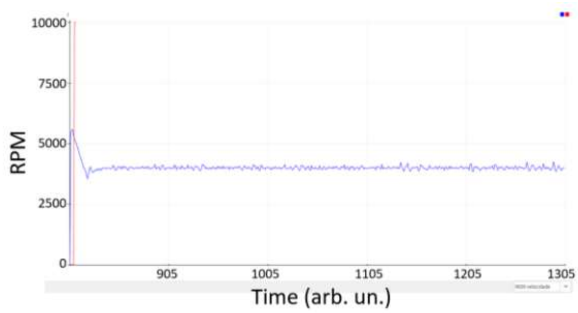

Fig. 4. Overshooting example. Note that the rotation control is still not very well tuned. Even after the rotation reaches the desired speed, there are still visible variations on this scale.

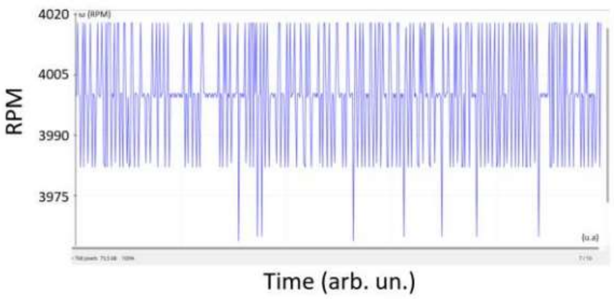

Fig. 5. Rotation speed result after calibration of the PID control system.

After its stabilization, the spinner presents an accuracy of approximately 0.5% in relation to the desired speed of 4000 RPM. The peaks and valleys were attributed to a reading error from the infrared sensor. If a sprocket tooth is not accounted for in one revolution, the error in the revolution count is on the order of the observed value. This result shows that this spinner is useful in a demonstrative laboratory for teaching semiconductor device manufacturing, and that the rotation measurement system still has room for improvement.

IV. Spin coater - V2

The second version of this equipment is currently under construction, and uses a different approach. Instead of reusing parts of an old computer, the new version aims to allow construction using off-the-shelf components and simplifying the mechanical assembly (Fig. 6). The acrylic sprocket wheel was replaced by a 3D printed disc, with a single piece of electricians tape on the side to function as the IR reference for the sensor; the ATX power supply is replaced by a simple 9V socket supply; and the bluetooth interface is replaced by built-in controls with an LCD screen, in order to simplify the design and reduce failure points. An ESC is still in use, controlled by an Arduino via PID.

A standard PID library is still in use. The tuning of the controller algorithm follows the order proposed by the Ziegler-Nichols [7] method: Kp adjusted first until oscillation around the setpoint, then smaller amounts of Ki and Kd applied accordingly.

This version is almost in its final format, lacking only the interface, which will be completed shortly and will be tested under standard use conditions. The interface will allow the user to select a desired RPM (from 3000 to 5000 rpm) and the amount of time the spin coater will rotate, both factors that determine the outcome of the coating process.

Capturing RPM information with an IR sensor is a well known method, therefore other ways are still being considered, including acquiring this information directly from the ESC, which would eliminate the need for any kind of sensor. This may be possible here because BLDC motors are synchronous.

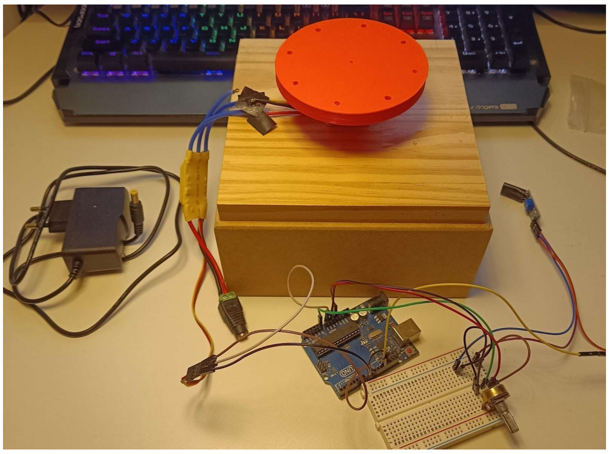

Fig. 6. Spin Coater V2 components: power supply, ESC, 3D printed disc with motor, Arduino board and IR sensor.

V. Conclusion

In this project, we present a low-cost prototype of a spin coater that can be used in a teaching laboratory for semiconductor device fabrication. The spin coater was built with parts from an obsolete computer, an Arduino Micro, Arduino modules (Bluetooth, ESC controller, reflective infrared sensor), and parts manufactured in a digital fabrication laboratory (using laser cutters and 3D printers). The Arduino and mobile app codes were specifically designed for this project. Speed control tests were performed on the prototype, and an accuracy of 0.5% was obtained for speeds of 4000 RPM (speed typically used in the deposition of photoresist in microfabrication laboratories).

A new version of the spin coater is being developed to improve the mechanical assembly and to avoid dependence on cell phone applications. The new version also seeks to use only off-the-shelf components, avoiding the necessity of scavenging parts from other devices, thus facilitating the acquisition of the necessary parts. Tests of spin coater operation after applying a photoresist on a surface will be conducted in the future.

Acknowledgment

This study was financed in part by the Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ projects E-26/210.321/2022, E-26/210.019/2021, and E-26/010.001805/ 2019).

References

[1] Penello, G. M., et al., "Voltage-tunable dual-colour quantum Bragg mirror detector (QBMD)", Opto-Electronics Review, 2023, 31, e144559.

[2] DOBRZÁNSKI.L.A.; SZINDLER.M. Sol gel TiO2 antireflection coatings for silicon solar cells, J. Achieve. Mater. Manuf. Eng. vol.52, p.714. 2012.

[3] TYONA.M.D. A theoretical study on spin coating technique. Advances in Materials Research vol.2, p.195-208. 2013.

[4] THIRUNAVUKKARASU,C; SARANYA,K.K; JANARTHANAN.B; CHANDRASEKARAN.J. Design, Fabrication and Working of In-House Spin Coating Unit for Thin Film Deposition. International Journal of Innovative Research in Science, Engineering and Technology v.5, p.10017-10023. 2016.

[5] FARDOUSI.M; HOSSAIN.M.F; ISLAM.M.SAND e RUSLAN.S.R. Cost-Effective Home-Made spin coater for Depositing Thin Films. Journal of Modern Science and Technology vol.1, p.126-134. 2013.

[6] SADEGH-CHERI.M. Design, Fabrication, and Optical Characterization of a Low-Cost and Open-Source Spin Coater. Journal of Chemistry Education vol.96, p.1268-1272. 2019

[7] ZIEGLER, J.G.; NICHOLS, N.B. Optimum settings for Automatic Controllers, ASME Transactions vol.64, p.759-765. 1942.