Educational mechatronics and applied to the design of an automated prototype for obtaining thin films

Mecatrónica educativa y aplicada al diseño de un prototipo automatizado para la obtención de películas delgadas

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Abstract

This project presents the design and development of an automated prototype for the deposit of thin films on glass substrates, using the chemical immersion method (SILAR). The importance of the development of these films lies in their multiple applications such as electronic resistors, thin film transistors and capacitors. One of the objectives of the project is to promote scientific, technological and innovation interest so that higher education students understand real problems, in which solutions can be provided through the development and integration of mechatronic prototypes. The final device has a 500mm vertical axis, a 100mm stroke end piston, a clamp driven by a stepper motor, a temperature control bath, a resistive oven, LCD16X2 screen, its structure is made of aluminum profiles. 4040 extrusion with 10mm acrylic walls and its operation is carried out using software based on the Arduino platform.

Automated prototype, Arduino platform, Thin films, SILAR method

4 Introduction

At present, globalization implies that people acquire competitive skills, knowledge, and values to solve problems of high complexity. For such a motive, it is necessary to form students into integral citizens who could identify the challenges in their environment with a basis in its criteria and capture of decision (Anderson, Londoño, & Martínez, 2022). One of the objectives of the project in its first stage is to promote scientific, technological, and innovation interests so that students of higher education understand real problems for which they can provide solutions through the development and integration of mechatronic interactive prototypes, thus supporting the teaching and learning process.

This project presents the design and technological development of a prototype that allows the automation of a process that was previously done manually within the university. The process is known as chemical immersion (or SILAR method), which consists of immersing a glass substrate in different chemicals for some time for the formation of thin films.

4.1 Background

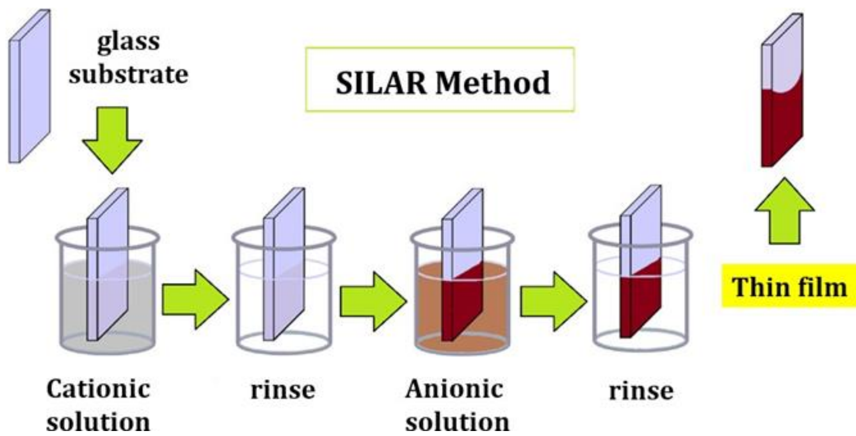
Thin films refer to a layer of material whose thickness ranges from fractions of a nanometer (1nm=10-9 m) to several micrometers thick. Controlled synthesis of materials such as thin films (process called deposition) is a fundamental step in many applications. A common example is the household mirror, which usually has a thin layer of metal on the back of a glass sheet to form a reflective interface.

Thin films have interesting properties that are quite different from those of bulk materials. As a film becomes thinner, the properties of the surface become more important than the thickness of the film. The other cause of interest is the miniaturization of elements such as electronic resistors, thin-film transistors, and capacitors. This is due to the fact that its properties depend on a number of interrelated parameters and also on the deposition technique. Despite the numerous strategies designed for the deposit of thin films, many of them require expensive specialized equipment, a fact that limits their use as an experimental tool in academic laboratories (Abengunde & et.al., 2019; Fayomi & et.al., 2019).

There are several deposition techniques to obtain thin films, including low-cost techniques such as chemical bath deposition, electrodeposition, and the SILAR method. To facilitate the work of obtaining thin films in the laboratory, developments aimed at the automation of the SILAR process have been carried out. For example, researcher Calixto-Rodriguez and collaborators built a prototype controlled through a man-machine interface. They used an HMI and state machine-based programming to control the SILAR process variables and number of cycles for the formation of thin films. This system consists of three stages: structural design, electronics and control programming, and HMI (Calixto-Rodríguez, Valdez-Martínez, & et.al., 2021). Subsequently, a group of researchers from the Veracruzana University developed an instrument composed of three different systems: a mobile platform with two degrees of freedom, an 8-bit microcontroller to adjust speeds over the XY axes, and free code software to program and monitor the main deposition parameters of the SILAR device (Woo García, Rodríguez Ibarra, & et.al., 2022).

This work focused on the deposition of thin films by means of the chemical immersion method, also known as SILAR, which consists of the adsorption and reaction of successive ionic layers to deposit films of different chemical precursors (Nkamuo, Okoli, & Igweze, 2021) but in an automated way. Figure 4.1 shows an outline of the SILAR process for the formation of thin films.

Figure 4.1 SILAR Process Outline



Source: (Calixto-Rodríguez, Valdez-Martínez, & et.al., 2021)

Our prototype is capable of handling glass substrates in a particular position, and by means of software, it is possible to control the time, position, speed, movement of the piston, and temperature monitoring. Another advantage of this tool is that this prototype is able to protect itself since it is completely closed. Furthermore, its software is capable of adapting to various requirements, offering greater flexibility to the user. Also, it has a system of emptying and filling of water containers that contain chemical solutions, which allows it to handle temperatures higher than the ambient temperature. This project has the main objective of impacting the training of mechatronics students in the automation area, because to build it, you will need to apply the skills and knowledge you have acquired in your subjects. It also allows the development of other skills such as leadership, resource management, time management, teamwork, problem-solving communication skills, as well as their professional and comprehensive training as engineers. In addition, the nanotechnology program will benefit from having a specialized tool for the development of new materials due to the versatility of the prototype, allowing students in this area to expand their competencies and enrich their educational learning.

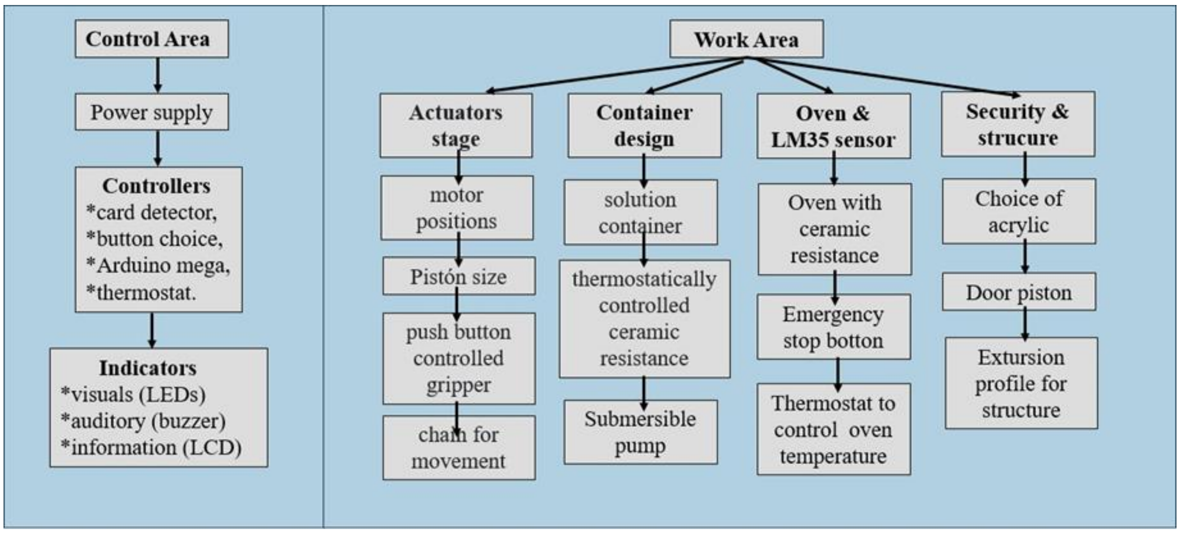
4.2 Methodology

This project consists of the design and construction of a prototype to develop thin films by chemical immersion deposition (SILAR method). The following specifications were proposed to design the equipment:

- That the prototype is closed to give greater security to the user.
- Have a water filling system with heating resistance to control the temperature of the solutions.
- Add a resistive oven to dry thin films after each immersion cycle is finished.
- Incorporate screens to monitor temperatures and process.
- Program a presence card that works as a key to operate the computer.

The design and construction of the equipment are divided into two areas: the control area and the work area. The control area consists of the power source, microcontrollers, user interface buttons, indicators, and card detector. The work area includes the stepped motor, 100-mm piston, vertical shaft, a heating resistance container to control the temperature of chemical solutions, and a resistive furnace for drying thin films between each cycle. In Figure 4.2, a block diagram is observed where each of these areas is briefly described.

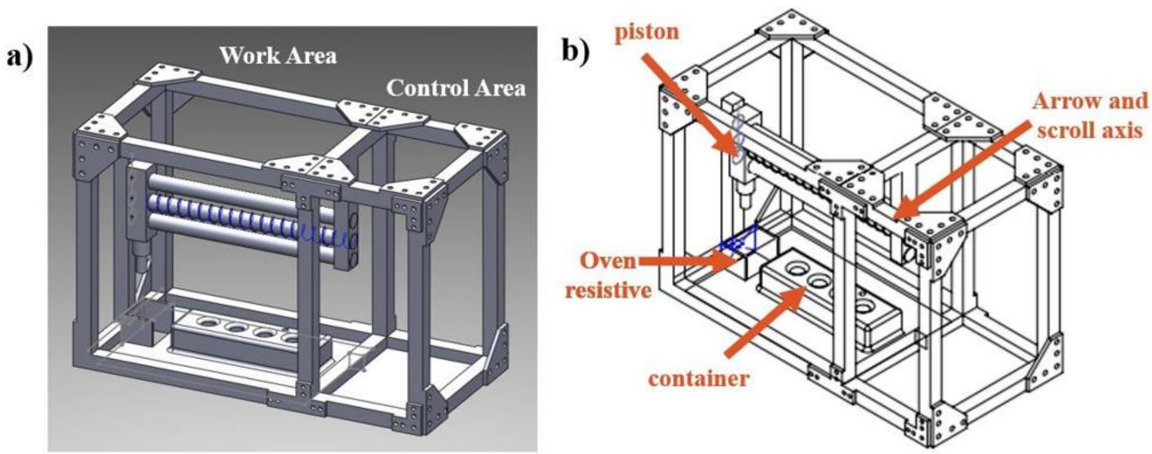
Figure 4.2 Block diagram with description of the work áreas.



Source: Own elaboration

The prototype was designed using SolidWorks software. Figure 4.3 shows the final design indicating the aforementioned work areas.

Figure 4.3 a) Areas of final prototype, b) description of elements of work area



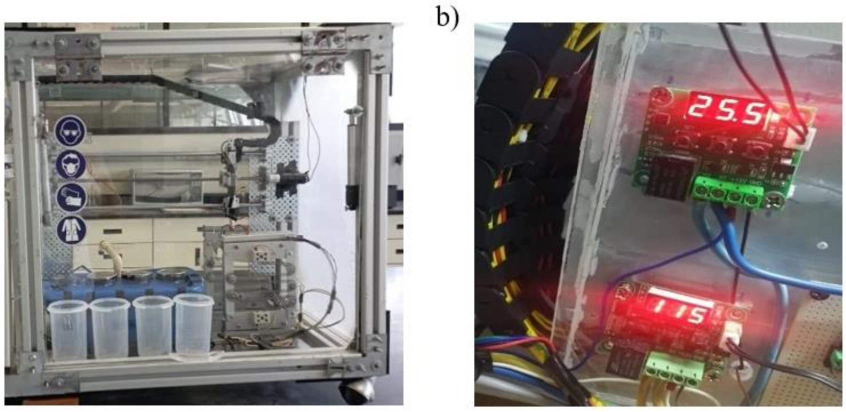
Source: Own elaboration

4.2.1 Works area

Within the working area is the mechanical module, which consists of a stepped motor, a piston, and a claw, which are limited to 480 mm of linear displacement, a maximum voltage of 12V for the piston with a height of 23 cm, and a clamp to control the pressure on the substrate. Also used were two thermostats with tolerances of ± 2 ° C and ± 5 °C, one intended to control the resistance of the container of water and the other to check the temperature of the resistive furnace, respectively. Figure 4.4 shows a) the working area of the finished prototype, and b) the thermostats used are also observed.

Figure 4.4 Work area of the final prototype and its thermostats

a) b)



Source: Own photographs of the prototype

4.2.2 Control area

The RFID module (which allows reading the key code), visual and auditory indicators were incorporated. Libraries that are included within the software of the Arduino platform were used to be able to manipulate and give programming instructions independently; therefore, the engine was first programmed in steps for the shaft, the piston, the claw, and the RFID module. Also activating each independent function, we proceeded to migrate each part of the programs to join them in itself and to be able to combine all the actions by means of the conditions (if, else, for) that helped us to make use of the libraries together using a C++ programming language. Figure 4.5 shows the control area with its respective buttons and indicators, some of the libraries used for programming are also observed.

Figure 4.5 Control area of the final prototype and programming libraries

```
        //MODULO DE RECEPCION DE TARJETAS
#include <LiquidCrystal_I2C.h>
#include <Wire.h>
LiquidCrystal_I2C lcd(0x27, 16, 2);
#include <SPI.h>
#include <MFRC522.h>
#define SS_PIN 53
#define RST_PIN 2
MFRC522 mfrc522(SS_PIN, RST_PIN);   // Create MFRC522 instance.


        //INDICADORES VISUALES Y AUDITIVOS


#define LED_G 8 //define green LED PIN 7
#define LED_R 9 //define red LED PIN 8
#define BUZZER 10 //buzzer PIN 9

       // PINZA

#include <Servo.h>
Servo servo1;

//---------------PISTON-----------//
//ACTUADOR

        int INMERSION = 2500; // mover al tiempo de inmersion deseados
```

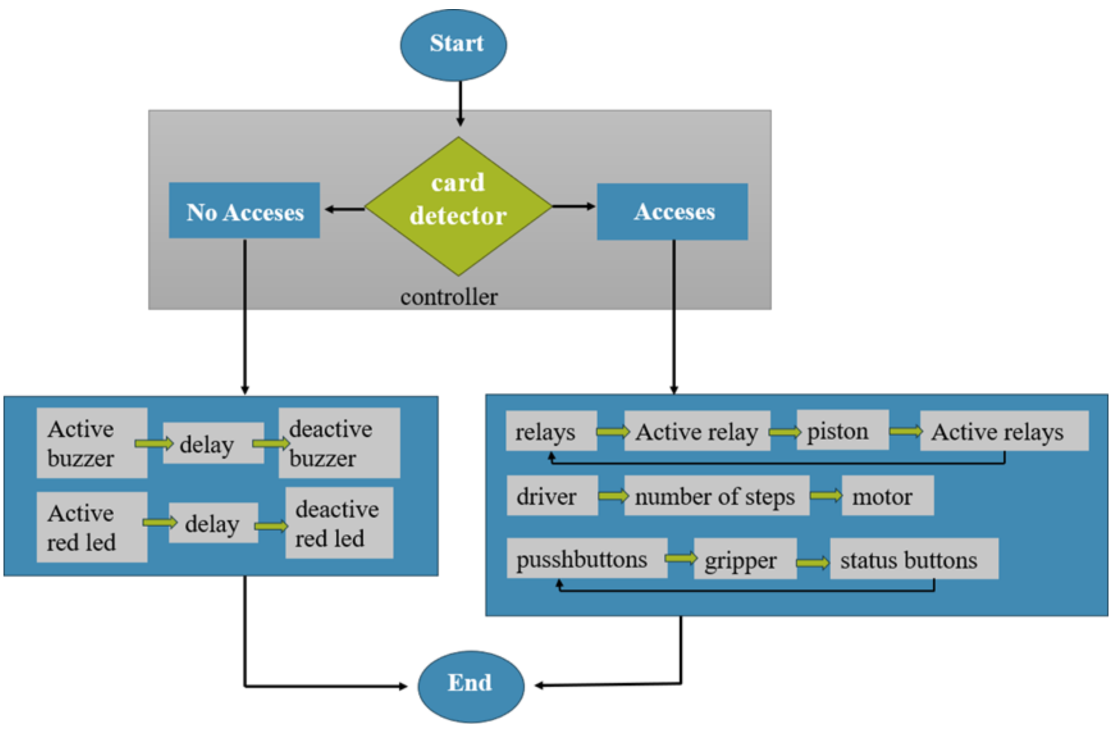
Source: Own photographs of the prototype

Figure 4.6 shows the final finished prototype, and Figure 4.7 shows the schedule flowchart, which serves to simplify the operator's execution actions when using the device.

Figure 4.6 Final prototype

Source: Own elaboration

Figure 4.7 Programming flowchart



Source: Own elaboration

4.3 Results

A prototype that meets the initial proposed requirements was obtained. Laboratory tests monitor the behaviour of this to check that everything works properly. Figure 4.8 shows a diagram that simply indicates the mode of operation of the prototype, and in the images, you can visually observe the stage of the process that is being executed.

Mode of operation:

1. The substrate is placed in the prototype clamp.

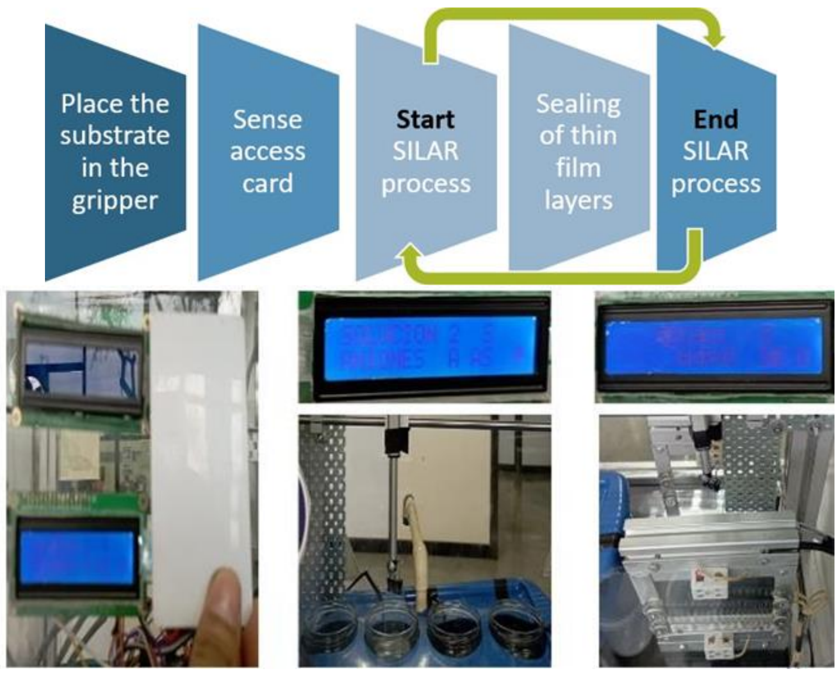
2. The card (key) is placed on the sensor to give access to the process and begin its execution.

3. Start the SILAR process. In this, you can vary initial parameters such as time, speed, and number of cycles depending on the specifications given by the user.

4. Once the substrate is immersed in the solutions with chemical precursors, the SILAR process ends until it passes to the stage of sealing or drying layers through the resistive furnace, then it starts again with the immersion in the solutions. Each time the substrate reaches the resistive furnace, it is counted as a complete cycle.

5. The process is complete until the device has completed all scheduled cycles.

Figure 4.8 Diagram of operation of the SILAR process



Source: Elaboration of diagram and own photographs

Tests were done to determine the time it takes for the water container to reach its maximum temperature (80 ° C). Table 4.1 shows information from independent tests performed, as well as the temperatures reached.

Table 4.1 Temperature monitoring in the container

Test	Temperature(°C)	Time (min)
1	35	11.9
2	35	11.6
3	40	13
4	40	12.7
5	50	16
6	50	16.3
7	60	20
8	60	19.8
9	80	26
10	80	26.2

Source: Own elaboration

From Table 4.1 it can be observed that the recorded temperatures are constant with respect to time. It was also concluded that above 40 ° C it will no longer be advisable to develop thin films in this device, since chemical solutions could begin to deliver toxic gases that could damage the prototype or even be harmful to the health of the user; however, this depends on the type of chemical precursor used to perform the film deposition process.

Table 4.2 shows the information collected from independent tests that monitor the time it takes for the resistive furnace to reach its maximum temperature.

Table 4.2 Temperature monitoring in the resistive furnace

Test	Temperature(°C)	Time(min)
1	80	34.3
2	80	35
3	90	38.8
4	90	39
5	105	39.7
6	105	39.4
7	120	45.1
8	120	45

Source: Own elaboration

From Table 4.2 it is again observed that the temperatures recorded in the tests are constant with respect to time. It was also concluded that the resistive furnace must reach its maximum temperature in order to dry thin films optimally and quickly.

In general, this prototype consumes 15A (amperes) when in maximum load (temperatures at their maximum range.) This data was obtained from the electrical tests carried out with the multimeter. Since the device is turned on, the ambient temperature is sensed, and the resistors start to heat, it can be used for 90 minutes and should be allowed to rest for 15 minutes before being used again.

Annexes Does not apply.

4.4 Acknowledgment

We thank the rector of our university, C.P. and Lic. Fernando Garza Rodríguez, for the support provided to this work, for the direction and rigor provided in its development.

We also thank the director of the Mechatronics -Automation Area, Engineer Juan José Gloria Puente, for the trust he gave us to develop this project.

We also thank the teacher Hilariona Martínez and all the teachers of the Mechatronics, Nanotechnology and Environmental Chemistry careers for all the ideas and suggestions provided during the design of the project.

4.5 Financing

This work has been financed by own resources of the Universidad Tecnológica General Mariano Escobedo.

4.6 Conclusions

An automated device was built to develop thin films by the chemical immersion deposition process (SILAR). This device allows you to control initial process parameters such as immersion time, speed, and number of cycles. The working temperature can be adjusted in solutions with chemical precursors, but it is necessary to consider that at temperatures above 40 ° C if these precursors are toxic or corrosive, they could damage the components of the prototype, so it is recommended to work at room temperature or check the technical sheets of the chemicals in order to keep the prototype in good condition.

This prototype is safe for the user as its work area is completely closed, plus with the access card, you can have greater control over people who want to manipulate it. It is important to take into account your working time so that they can function properly and films are developed optimally.

As a future work, it is intended to make an airtight system in order to control the characteristics and properties of thin films. It is also planned to add a grid with an extraction filter in the event of increasing the temperatures of the chemical solutions to avoid damaging the prototype. Another area for improvement is to separate the furnace section from the solutions to avoid any type of incident with the equipment.

4.7 References

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