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Custom vacuum load-lock for the sputtering vacuum chamber, loading/unloading and locking automatisisation mechanisms

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Abstract. This paper presents the continuity of my work presented in previous articles regarding my activity as a PhD student at the University of Oradea, Doctoral School of Industrial Engineering. After installing, cleaning, vacuum testing and developing an experimental system for vacuum measurement, we decided that the next best step would be to develop the system with a load-lock further, as the time required for experiments would drastically improve and the need for refurbishing the old positioning mechanism would be eliminated. The paper describes the steps taken, starting with CAD representing the sputtering vacuum chamber for the manufacturer to start their production process, and finalising with automating the whole start/stop and reload sequence for the load-lock with an experimental setup made from readily available equipment in our laboratory, as the initial sequences were manually only and the risk of misusing for non-trained personnel would be high.

1. The work so far

University of Oradea has some experience with vacuum devices and magnetron construction and deposition, but it has been approximately 20 years since experiments were conducted on-site [1], [2]. New emerging technologies and rapid advancements in nanomaterials have sparked the interest of research in this area, and new investments in an advanced materials research infrastructure called SMARTMAT [3] paved the way for new opportunities. Previous achievements of the authors from recent years are presented in [4], [5] and [6].

2. Lock-Load System

After realizing some experiments to determine the quality of the vacuum and the time required to obtain it by automating the measurement process [6], we realized that we could only perform at best 3 depositions in a day, due to the long waiting time until the high-vacuum of at least 10^{-6} mBar was achieved – about 3 to 4 hours. The process of deposition itself would only take up to 10 minutes, then a shutdown of pumps needed to be queued, with a processing time of approximately 30 minutes and eventually returning the whole chamber to atmospheric pressure. We estimated that with a Lock-Load system [7] installed and the vacuum pumps of the Steel chamber permanently running we could realise a sputtering deposition in under an hour, providing that the target on the sputtering gun doesn't need to be changed.



2.1. Preparations for acquiring the system

Building the system ourself would have involved plenty of preparations and the prerequisite of owning the right equipment. As we, at the University of Oradea, are not as well equipped as professionals doing this for a living, and our technology wouldn't have permitted us to build all of the subcomponents necessary, we outsourced this part to an external company. Externalising saved us both time and money.

But all the actions that were done before the actual building of the Lock-Load system were performed at the University of Oradea. First, measurements of the vacuum chamber were made to ensure that the loading mechanism was long enough to push the substrate under the target, and a CAD drawing was made available to the supplier. We identified the coupling mechanism for the Lock-Load onto the chamber – measurements were made only for diameter as the flanges are standard. Next, we had to choose the material, and we finally settled on Aluminium as it is more machinable and easier to find on the market than special alloys of Stainless Steel, from which the chamber is made of [8], [9], [10], [11]. Also, having in mind that very few electrons would escape in the aluminium chamber, causing a possible reaction, this fact was considered negligible from the Load-Lock viewpoint.

We opted for a vacuum solution that is independent of the vacuum mechanism of the main chamber. This raised the price, as individual roughing pump and a vacuum pump, both of small dimensions, needed to be added to the system. We concluded that by doing this, we would add a great deal of versatility to the system. The small pumps could also be used on other experimental vacuum setups that have an educational role. As the option for automating the valves drove the system price higher, and we already had some electro-pneumatic valves in our laboratory, we decided that the automation will be done by ourselves. The full system can be viewed in figure 1

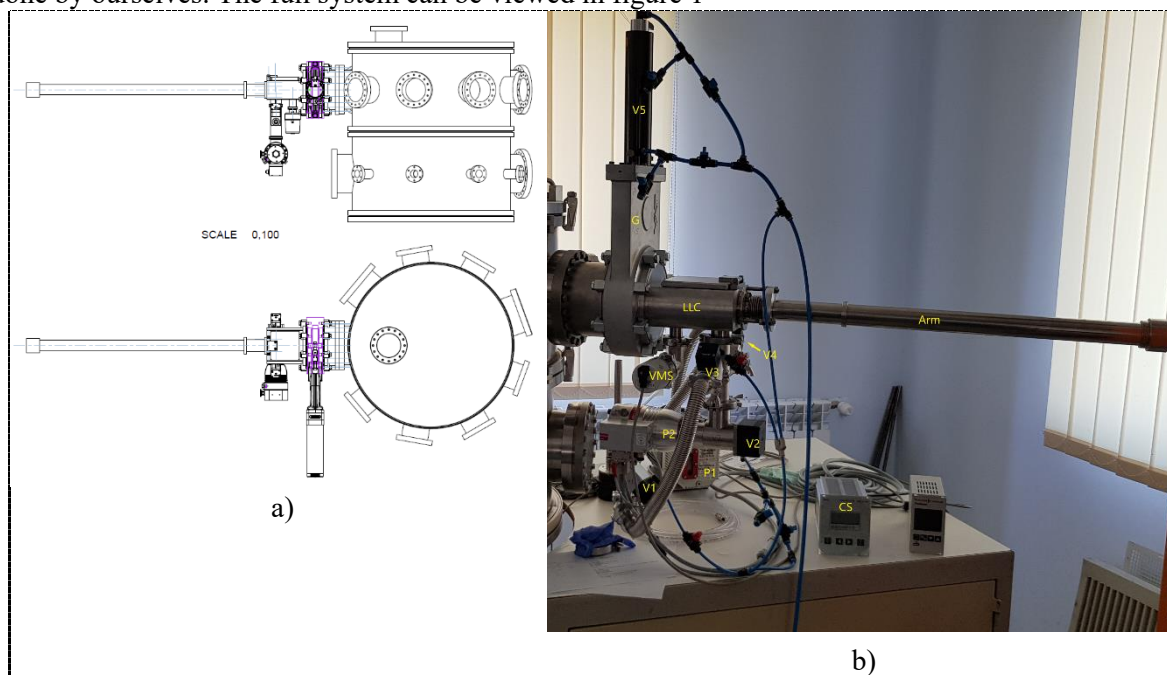


Figure 1. A figure depicting the Load-Lock system. a) CAD representation (left) vs b) actual system (right); V1 – Valve 1; V2 – valve 2; V3 – Valve 3; V4 – Valve 4; V5 – Valve 5; P1 – roughing pump; V2 – turbomolecular pump; CS – control system for turbomolecular pump; VMS – Vacuum measurement system; LLC – Load-Lock Chamber; G – Vacuum Gate; Arm – loading/ unloading mechanism

2.2. Receiving, mounting and testing the system

After receiving the system, we assembled it and ran a short test with the team that delivered it to us. A schematic for the operating procedures is presented in figure 2.

As it can be seen from figure 2, some steps must be followed in the exact order as in the operating procedures, or else the entire system can be compromised. The High-vacuum pump cannot be started until the whole system has achieved a rough vacuum, as the blades within it will capture big molecules of air that will damage them. Also, the vacuum system of the Load-Lock is more complicated than the one on the Stainless Steel vacuum chamber, on which all the components are mounted in line and are started sequentially, beginning with the rough pump and ending with the turbomolecular pump. The operating principles of both the roughing pump and the vacuum pump are explained in [9] [12] and [13].

The roughing pump has just a mechanical switch, but the turbomolecular pump has a processor and different settings can be changed and viewed, such as power draw, blades speed, current vacuum level etc. This is perfect, as we can connect it to our PXI [6] and get actual readings without the need of an extra Pfeiffer gauge [6].

After mounting the Load-Lock mechanisms with its valves, chambers, pumps and tubes, we needed the control the pneumatic valves. Our first and cheapest solution on the spot at the time we received the system was to manually control them, as we didn't know exactly how the final product will look until they shipped it to us. Further developments are presented below, but unfortunately due to the COVID pandemic, the research has stopped before getting to an actual result in this matter. However, the automation process is 95% ready - we only need a controller for the valves and program the sequence presented in figure 2. The pressurised air is and still will be provided by an external pressurised tank of 50L that has an air pump attached and can go up to 8 atm.

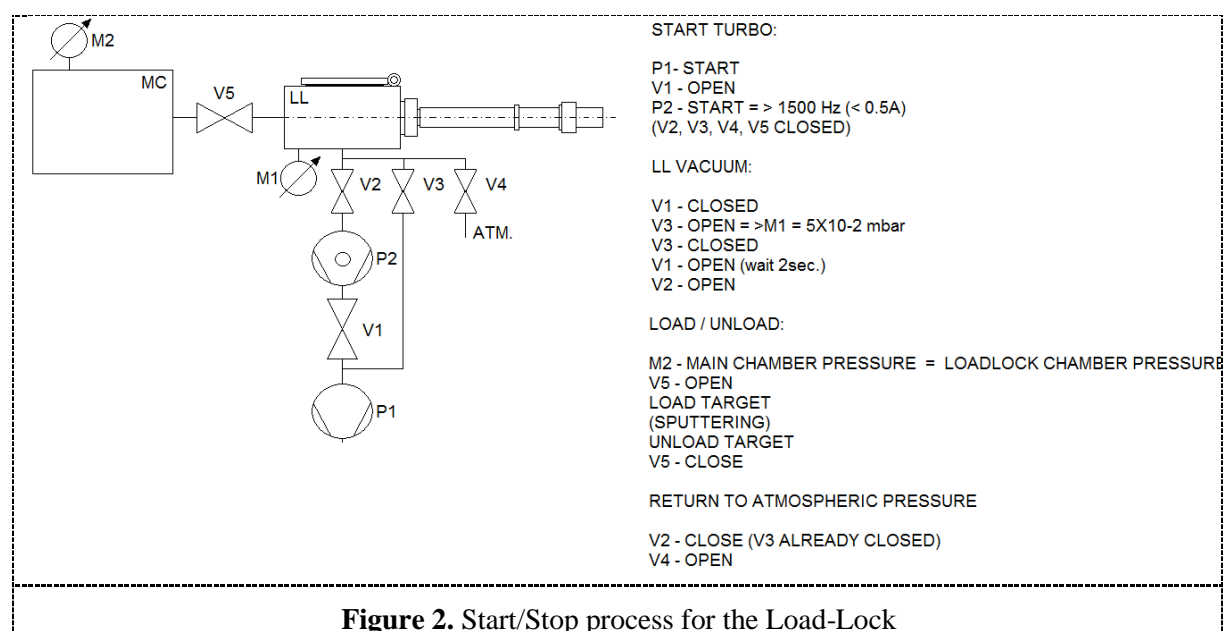


Figure 2. Start/Stop process for the Load-Lock

2.3. Working procedures with the Load-Lock

The start of working procedures without the pumps already running have a prerequisite of going through a checklist. If all the answers are yes, then the procedure can begin:

1. Are the pumps connected to the mainline?
2. Is the arm fully retracted from the main chamber?
3. Is the gate valve of the Load-Lock mechanism closed?
4. Are all the pneumatic valves closed?
5. Is the load-lock chamber empty and clean?

Next procedural steps are the following:

1. *Start the rough pump by flipping the switch.
2. *Open the valve that connects to the vacuum pump to achieve primary vacuum in the tubes and the turbomolecular pump.

3. *Start the turbomolecular pump and wait for it to get to operating speed at about 1500 Hz.
4. Put the substrate in the Load-Lock chamber and close the lid.
5. Close the valve that connects the roughing pump to the turbomolecular pump, as we need to evacuate air from the Load-Lock chamber; not closing the valve could result in breaking the turbomolecular pump due to a rapid change in pressure.
6. Open V3 and wait until the pressure inside the Load-Lock chamber is at least 5×10^{-2} bar.
7. Close V3 and open V1.
8. Wait 2-3 seconds to get to the first stage of vacuum in case of leaks.
9. Open V2 that connects the turbomolecular pump to the Load-Lock chamber.
10. Wait for the pressure inside the Load-Lock chamber to drop to at least 10^{-5} mBar.
11. Open V5 that actions the gate valve.
12. Load the target by pushing the arm inside.
13. Wait for deposition.
14. Unload substrate from Stainless Steel chamber by retracting the arm.
15. Close V5 – the gate valve.
16. Close V2 as we need to preserve the vacuum inside the pumping and tubes system.
17. Open V4 to get to atmospheric pressure inside the Load-Lock chamber.
18. Open the lid and take out the finished sample.
19. *Stop the turbomolecular pump – and wait for it to slow down to under 500 Hz. If the speed is higher, the blades could break at the change in pressure.
20. *Vent the system by opening V3. If this step is skipped, oil from the roughing pump can penetrate the system. Wait at least 10 seconds for the ventilation process.
21. *Shutdown the roughing pump.
22. *Unplug the system from the power line

To put another sample inside the whole deposition process, we just need to follow the steps from 4-18. The rest of the steps that begin with * are necessary only in the situation that we need to startup or shutdown the pumps.

3. Automation mechanism and process

The automation mechanism presented in Figure 3 consists of 4 electro-pneumatic valves that connect to the pressurised tank and to the valves depicted in Figure 2 – V1, V2, V3, V4 and V5. These are all powered by a 5-20V AC to DC source and controlled by a small programmable board, similar to an Arduino. A step-down is required for the board to function at 5V. Once the automation process is complete, all the processes depicted in figure 2 that do not have an * will be done by the push of two buttons (on/off) and two switches: one for achieving vacuum, and one for returning to atmospheric pressure in the Load-Lock chamber. Powering up and down the two pumps will not be necessary, as they are better left in a permanent running state, due to less friction.

Also, we are considering to implement a failsafe, in which the gate mechanism of the Load-Lock will not be able to close as long as the arm holding the substrate is present in the main chamber. This will prevent severing the arm by mistake. We need to add a Hall sensor, as the arm is magnetically driven in order to obtain a full sealing, and the sensor would detect the magnet.

By now, all that remains to do is to program the board and mount the whole system onto the table that holds the Stainless Steel chamber with the Load-Lock attached. All the other components besides the board are already installed, tested and fully working individually.

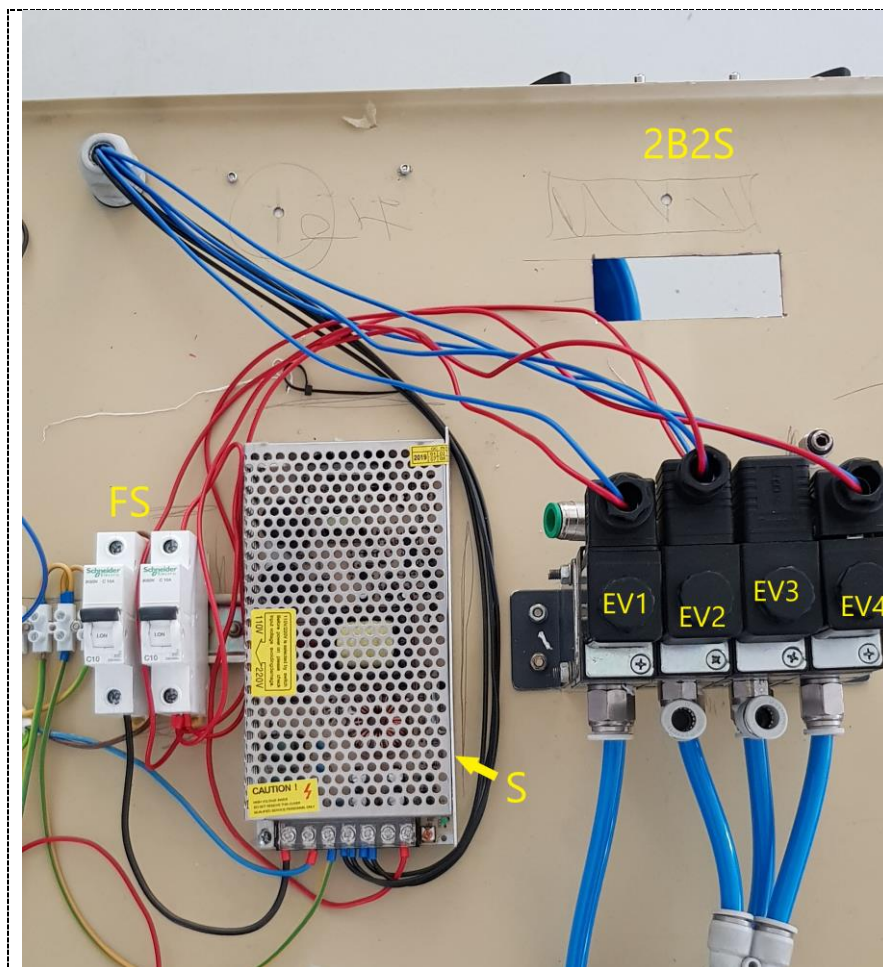


Figure 3. Automatisation system; EV1 – Electro Valve 1; EV2 – Electro Valve 2; EV3 – Electro Valve 3; EV4 – Electro Valve 4; S – AC to DC source; FS – Safety Flip-Switch; 2B2S – 2 buttons and two switches for on/off and start/stop sequences

4. Results and conclusion

Although we did not measure the time necessary for a full substrate change on the PXI [6], we did however make 2-3 measurement by timing the process with a stopwatch, and every time we came under an hour. That means that instead of a maximum of 3 depositions, we can make at least eight depositions per day, effectively tripling our output. This is a great achievement, and the whole experiment helped us understand the industrial approach towards the process, where every minute or second counts. Of course, fine-tuning of the system and further advancements in automation will be considered.

One of our goals is to get the magnetron sputtering deposition system in a state that can be used by other personnel or students from University of Oradea, with minimal training, or a one-sheet instruction page and a check-list ideally. The automation of the Load-Lock mechanism is a step further into reaching this goal, although it can be improved to visually show errors and the state of the valves and sensors.

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