Designing a vacuum chamber and substrate positioning system for magnetron sputtering deposition applications

D.I. Țarcă[1], R.V. Ghincu[1], D. Crăciun[2]

[1]Doctoral School of Industrial Engineering, University of Oradea
[2]Faculty of Managerial and Technological Engineering, University of Oradea

tarca.danioan@student.uoradea.ro

Abstract. A new custom vacuum chamber with a substrate positioning system in our SMARTMAT laboratory is needed, as the previous one that we installed did not suit our needs. Based on our experiences with the old sputtering system, we designed a smaller vacuum chamber that could be attached to our existing load-lock system, and that could have a substrate positioning system suited for our magnetrons which would work with the load-lock. The new system replicates our initial experiments and is compatible with our experimental data acquisition system. We mounted the sensors and vacuum equipment on the chamber, and initial vacuum tests were a success, which validated our design.

1. Introduction

After installing a high-capacity sputtering system in our SMARTMAT [1] laboratory, we had the necessary expertise to elaborate a design that would better suit our needs [2-5]. The new chamber has some old parts, such as the rough and turbopump, the vacuum sensors, and the gas inlet flange, but the rest are new and specific to our needs. While the existing vacuum chamber could have been modified to our needs, the process would have been too expensive and would require more moving parts inside the main compartment, which could have malfunctioned and required a lot of design work. So we opted instead for a simple solution with as few moving parts as possible while still getting the job done. We followed some basic guidelines set by previous researchers [6-11] while designing the chamber and positioning system, with the goal of making an experimental setup that is easier and faster to operate.

2. Vacuum chamber

We started designing the chamber represented in Figure 1. by having some minimal requirements and left some unused flanges for further expansion if needed.

We needed three DN40CF flanges on the cylindrical shape: two for measuring the pressure (one for rough vacuum, one for high vacuum) and one flange for the gas inlet. The gas inlet flange has no importance where it is situated. Still, the flanges where the measuring equipment will be mounted are best positioned in a spot with no direct line of sight with the magnetron as there will be less cleaning needed – so we put them underneath the magnetron gun. Although some scattered electrons may hit the measuring equipment, the chances are significantly reduced. Also, on the cylindrical shape, we have three DN 100CF flanges: one for the turbomolecular pump (which we already had) and two for seeing inside the chamber. Just one viewing flange would be insufficient as we discovered with the old equipment that we need a source of artificial light to see inside the section, and shining a light through the same viewing port has some drawbacks such as reflection. At this time, as we are experimenting with an uncalibrated and self-developed system, it is essential to visually confirm that the substrate is in the correct position and that we do not hit the positioning system with the load-lock rod. Therefore, one DN160CF flange is needed for the already built and tried load-lock system.

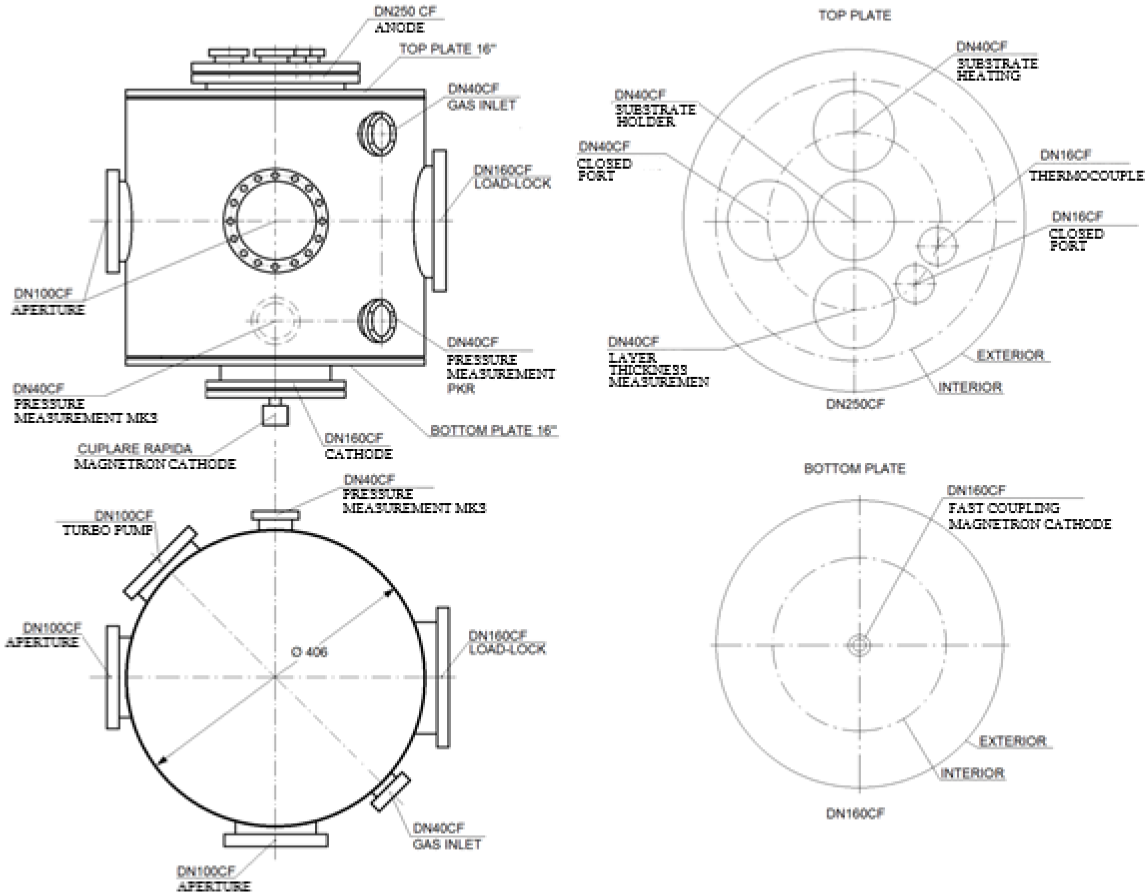

Figure 1. Vacuum chamber design.

On the top of the chamber, we have six flanges: two DN16CF and four DN40CF. One of the two DN16CF flanges will be used as a feedthrough for a thermocouple, and the other one is a spare. The four DN40CF will be used as follows: one for measuring the thickness of the deposited layer, one for heating the substrate, one for the substrate positioning system also designed by us and covered in this paper, and one is a spare. In order to measure the thickness of the deposited layer, we are also developing a piezoelectric sensor that will be mounted on this system.

There is only one DN160CF flange for the sputtering gun that can accommodate both old and new guns on the bottom of the chamber. It has a central position to be in line with the opposite counterpart, the substrate positioning system.

The top plate with the six flanges is an independent part of the vacuum chamber and can easily be removed. A Viton synthetic rubber makes the seal for easy access inside. The bottom plate is welded on the vacuum chamber.

The whole chamber is made of aluminum. However, it is not the best material as diffusion is faster because it is not as dense as steel, and some targets can react with the aluminum and contaminate the chamber. Still, on the other hand, it is cheaper, lighter, and easier to machine than steel. In addition, aluminum is non-magnetic, while for non-magnetic steel, the price is significantly higher than standard steel.

Price and execution time was an essential part of deciding if the vacuum chamber should be made of aluminum or steel. However, given that this is an experimental setup, and we already have a steel chamber if needed for specialized applications, choosing aluminum was a natural choice. Also, we now can experiment with different types of materials used in building vacuum chambers and how it affects the vacuum, deposition quality etc.

3. Substrate positioning system

The design of the vacuum chamber revolves around the substrate positioning system and the gun. Therefore, it is essential to have a positioning system that can hold the substrate and position it closer to the magnetron gun (target). Also, it has to have a substrate heating system that can reach about 300° Celsius. The heater is essential because the electric charge can heat the target. Electrons emitted by it do not adhere well to the substrate if there is a significant temperature difference. Therefore, by reducing the difference in temperatures, the deposited layer adheres better to the substrate.

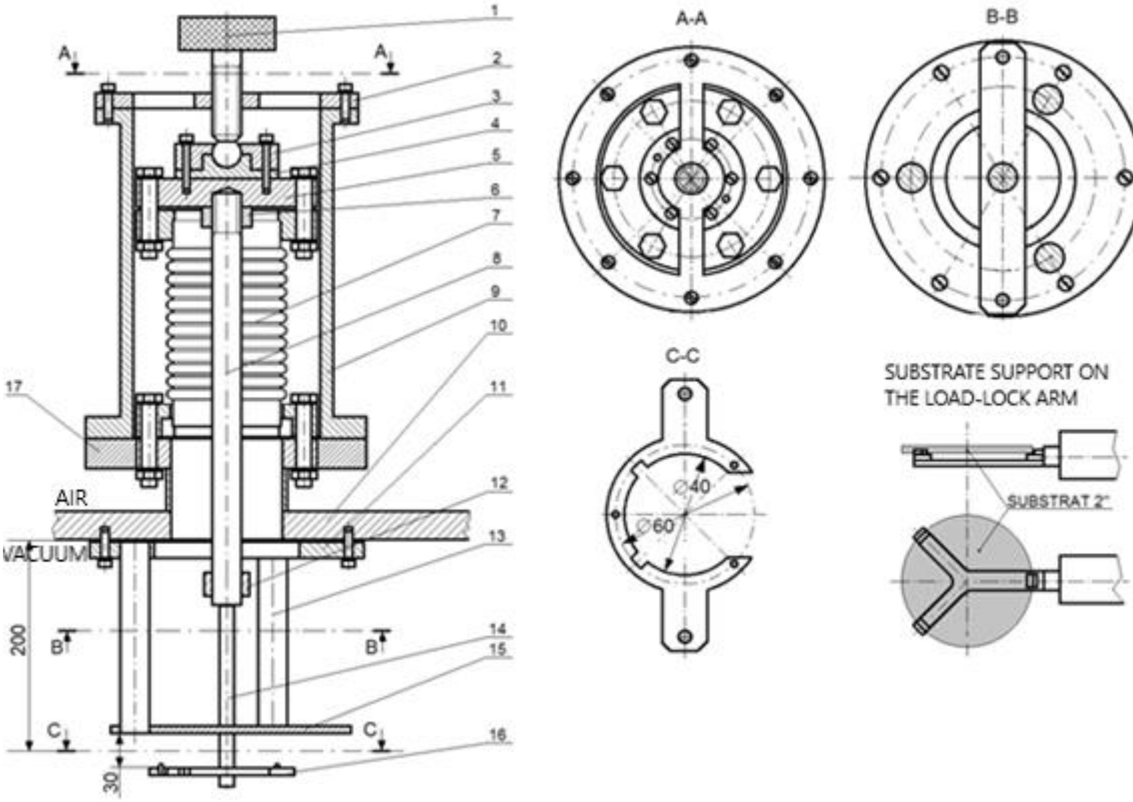

Figure 2. Substrate positioning system: 1 - Drive screw; 2 – Lid; 3 – Spherical join connection element; 4 - Spherical joint base plate; 5 – Blank flange DN40CF; 6 – Lock-nut; 7 – Bellows DN40CF; 8 – Central rod; 9 – Cylindrical shield; 10 – DN250CF flange; 11 - Fixed rod support ring; 12 – Yoke for moving rods; 13 – Fixed rods; 14 – Moving rods; 15 – Substrate base plate; 16 – Substrate support. 17 – Flange. C-C represents a top view for the substrate support (16), matching with the substrate support on the Load-Lock arm.

The substrate positioning system design presented in Figure 2 is based on similar designs, with some components already available on the market – such as the bellows or the spherical joint connection. The whole operation is airtight, with no direct contact with the exterior, as it is magnetically driven. By rotating the drive screw (1), the moving rods (14) are pushing or pulling the substrate support (16). The Y-shaped substrate support on the load-lock arm is accommodated by the substrate support (16) from the substrate positioning system thanks to the two notches. As the load-lock arm positions the substrate on the substrate support (16), the rods (14) are pulling up the substrate and fixing it against the substrate base plate (15). Thanks to the notches, the Y-shaped substrate support on the load-lock arm stays at the same vertical level and can be retracted. After a successful deposition, the moving rods (14) lower the substrate support (16) by turning the drive screw (1). The load-lock arm waits in position, right below the substrate support (16). As the substrate support (16) lowers, the substrate will be placed on the load-lock arm, which can be retracted to evacuate the substrate from the vacuum chamber.

4. Results

An image with the whole system is presented in Figure 3.

Preliminary results in vacuum measurements show that the new system is 3-4 times faster than the old one in terms of hitting 10^{-5}mbar, in large part because it is a smaller chamber, and the vacuum pump is oversized. More measurements will be made when the positioning system will be installed, and the whole deposition system will be mechanically complete.

As shown in Figure 3, the whole vacuum deposition system is placed on a steel frame because we want it to be a mobile system. The primary pumps are mounted inside the frame while the turbomolecular and the load-lock rod are exceeding the frame. As it is an experimental setup, by the time it will be complete, we will need to find a solution to protect both the pumps and the rod. However, the rest of the equipment can easily fit inside the frame.

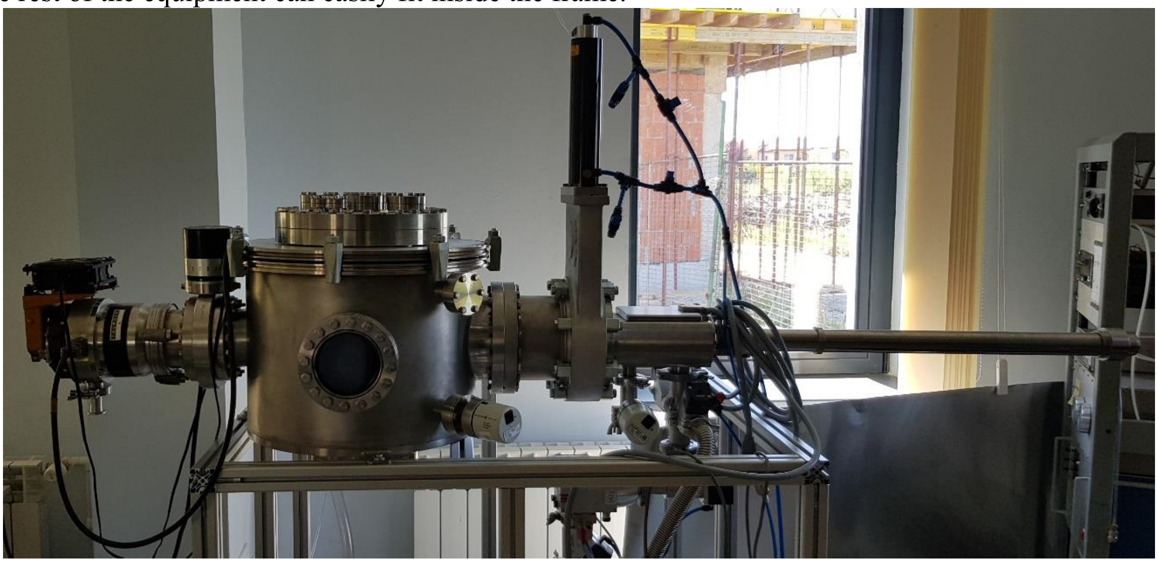

Figure 3. Vacuum chamber with sensors, load-lock, and vacuum pump

5. Conclusion and further work

The design activities are concluded, and tests are yet to come once the system is mechanically complete, the only piece missing being the positioning system.

Regarding the positioning system, moving from the design phase to the execution phase should not be difficult as the main components are readily available to be purchased from well-established retailers. The main challenge will be installing and adjusting the system so that it can correctly pick up the substrate and that it will also be at a minimal distance from the sputtering gun.

The next phase is to connect the magnetron to the power transformer and calibrate the gas intake. Once this step is finished, more calibrations will be needed on the whole deposition system before depositing some metal targets.

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