Hands-on project aimed at technical education

Realizing a DC magnetron sputtering system

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Total number of authors:
15

Published in:
Proceedings of SPIE

Link to article, DOI:
10.1117/12.2594434

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

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Event: SPIE Optical Engineering + Applications, 2021, San Diego, California, United States

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Keywords: dc magnetron sputtering, X–ray optics, DTU Space, Teaching, Engineering work

ABSTRACT

We present a teaching concept which combines theory, experimental work, project management and organization. As part of the Earth and Space Physics and Engineering education at DTU Space, a group of first year undergraduate students were given the task to design, build and test a DC magnetron sputtering system within a very limited budget and time frame. The teaching concept is designed to promote the students' autonomous learning, and a major part of the project was to teach the students how to develop group dynamics successfully. The students successfully managed to build a direct current magnetron sputtering system wherein a plasma glow was produced. The system can be used for depositing thin film coatings, an enabling technology for numerous applications.

1. INTRODUCTION

In the first year of the Bachelor/undergraduate degree in the Earth and Space Physics and Engineering education at the Space department of the Technical University of Denmark (DTU Space), students are following a mandatory course named *Engineering work*. The aim of the course is to provide the students with a general introduction to studying at DTU and introduce them to the typical tasks a researcher in Geophysics and Space technology carry out on a daily basis. Students are given multiple project options, ranging from satellite ground observations to space observations. Each project includes a theoretical aspect and an experimental part, which have to be documented as a technical report and presented as a poster.

At DTU Space a group of scientists are developing state-of-the-art thin film coatings for X-ray optics. The thin film coatings are produced in a direct current (dc) magnetron sputtering system installed at DTU Space[1,2]. The coating chamber has been utilized to produce the multilayer coatings for the NuSTAR mission[3] and develop the thin film coatings for the Athena mission[4–6].

Teaching students how the dc magnetron magnetron sputtering system works, can be an overwhelming amount of information and difficult to understand in detail without any hands-on experience.

We developed the idea, that students could build their own low-budget coating system and offered a project in the *Engineering work* course, with the title - *building a direct current magnetron sputtering system*. A group of six students with different backgrounds (high-school degrees from different study lines) were selected to work on

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Novel Optical Systems, Methods, and Applications XXIV, edited by Cornelius F. Hahlweg, Joseph R. Mulley, Proc. of SPIE Vol. 11815, 118150Q · © 2021 SPIE · CCC code: 0277-786X/21/$21 · doi: 10.1117/12.2594434

this project with limited resources in terms of time and budget. For each project, the students were allowed to spend ∼500 USD on materials and all the work would have to be completed within 60 lectures, each lasting four hours.

2. FIRST LECTURES AND PRELIMINARY DESIGN

In the first lecture, the students were given a theoretical introduction to the direct current magnetron sputtering technique along with the thin film coating applications. This amount of information is normally distributed across a number of lectures, however, due to the time constraints on this project, it was necessary to bring the students up to speed quickly. In the end of the lecture, the students were given the task to brainstorm possible designs for building a custom made dc magnetron system. To lead them in a direction, they were introduced to an example of how to build your own custom made magnetron system[7].

The second lecture started with the students presenting their ideas on how to build a magnetron sputtering system. Most suggestions were too ambitious and the students were guided towards a more "simple" design. The preliminary design, is shown in Figure 1.

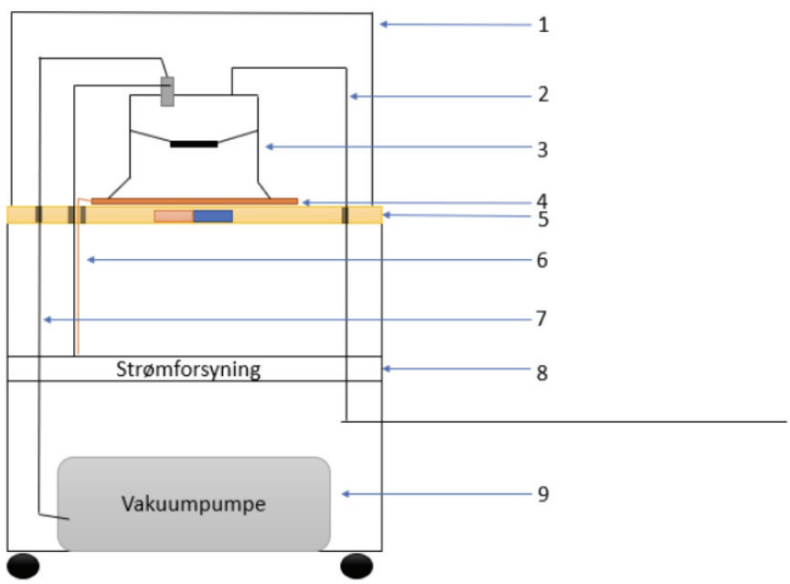


Figure 1: Illustration of the custom made magnetron sputtering system. 1) Protective Plexiglas. 2) Air intake. 3) Vacuum chamber. 4) Cathode. 5) Structural wooden plate. 6) Electrical connection to the anode. 7) Vacuum piping. 8) Power supply. 9) Vacuum pump.

As part of the second lecture, we introduced the students to project management. This included - how the projects are managed at DTU Space, with a focus on group structure, deadlines, meetings, risks and deliverables. The students were quick to divide the tasks in the project, such as, literature study, technical drawings and material list, and documentation.

As part of the project, a detailed design review (DDR) was scheduled after the first three lectures and the

students had to prepare a presentation of the materials required for the magnetron system, the expected budget and the proposed time line.

During the third lecture the students had prepared a list of materials and the estimated prices, which is shown in Table 1. We provided the vacuum pump, a combined roughing and turbo pump, along with the vacuum piping and the power supply, which were old reserved components. These two components did not count in the limited budget of the students project. The total price, excluding the free second hand materials and the used in stock materials, was 467 USD.

Table 1: Materials used to build the custom made magnetron system.

Materials	Purpose	Est. price (USD)
Glass jar	Vacuum chamber	5
Aluminium plate	Cathode	80
Plexi glass	Safety	80
Wooden plate	Structure	0 (Second hand)
Rack	Structure	130
Vacuum pump	Vacuum	∼2000 (Used, in stock)
Power supply	Power	∼3000 (Used, in stock)
Magnets	Plasma confinement	12
Pipes	Vacuum	80 (Used, in stock)
Electrical cords	Power	20 (Used, in stock)
O-rings	Vacuum	20 (Used, in stock)
Duct tape	Vacuum and structure	10
Epoxy	Structure	14
Silicone	Vacuum	16

3. EXPERIMENTAL WORK

With the design in place, it was time for the students to perform hands-on work. They designed and produced a 3D printed holder for the two ring magnets (Figure 2). The purpose of the magnets is to confine the plasma and thereby improve the plasma stability and was therefore a key accomplishment in the project.

A rack was purchased to accommodate the vacuum pump and the power supply. The vacuum pump is a Turbo-DRY 70 model from Varian which consists of a oil-free diaphragm pump and a compound turbo molecular pump. The power supply is a DC power supply from Powerbox which can generate up to 600 V and 2 A.
On top of the rack, the students created a technical drawing of a wooden table top for electrical and vacuum feed through. They milled room for the magnets on the backside of the plate and drilled holes to fixate the aluminum cathode plate. The technical drawing is shown in Figure 3. The black outer square indicates the wooden plate where the vacuum chamber was mounted on. The students, intentionally chose wood as a material due to its low heat and non-electrical conductive properties. The dotted blue square indicates the track where the Plexi

glass is placed. The three circles are feed throughs for air in, electrical wires and air out, when seen from left to right. The middle black square indicates the aluminium plate (cathode). The green square indicates the copper plate mounted to the aluminium plate and the inner black square indicates the magnets.

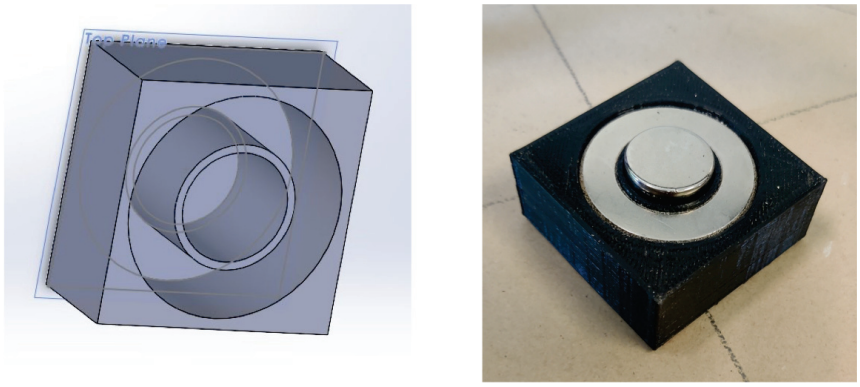


Figure 2: CAD design of the 3D printed magnet holder and the realized holder design including the two magnets.

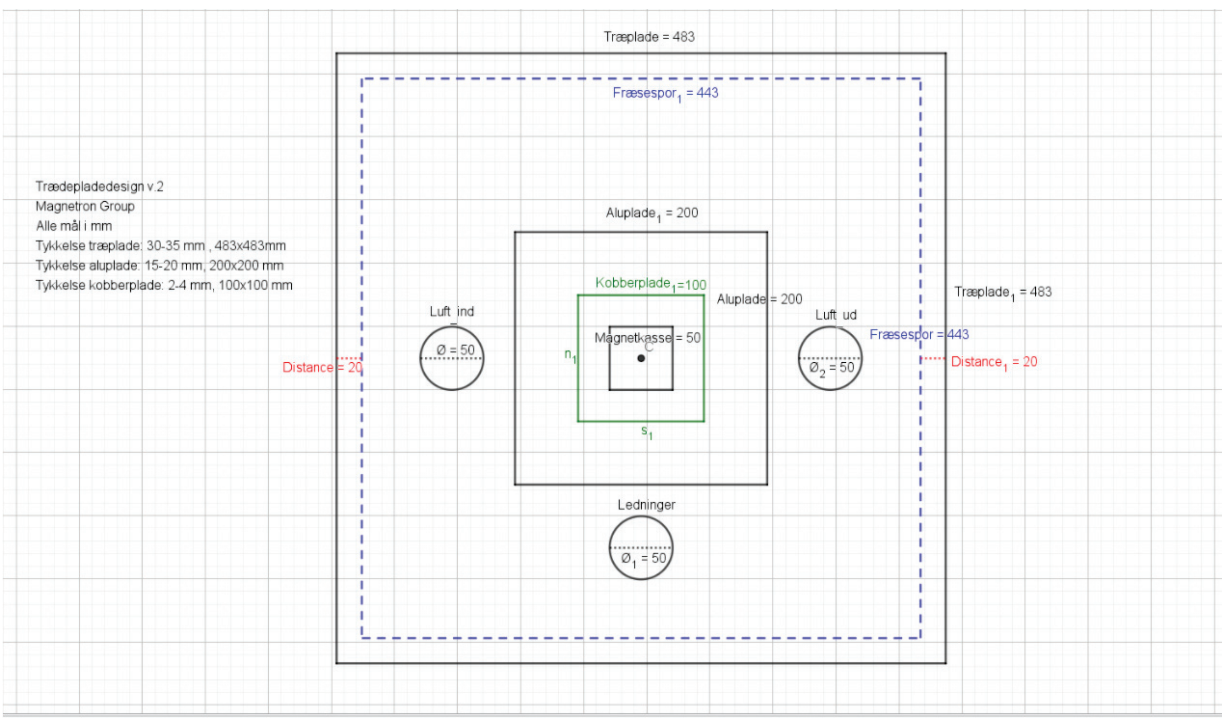
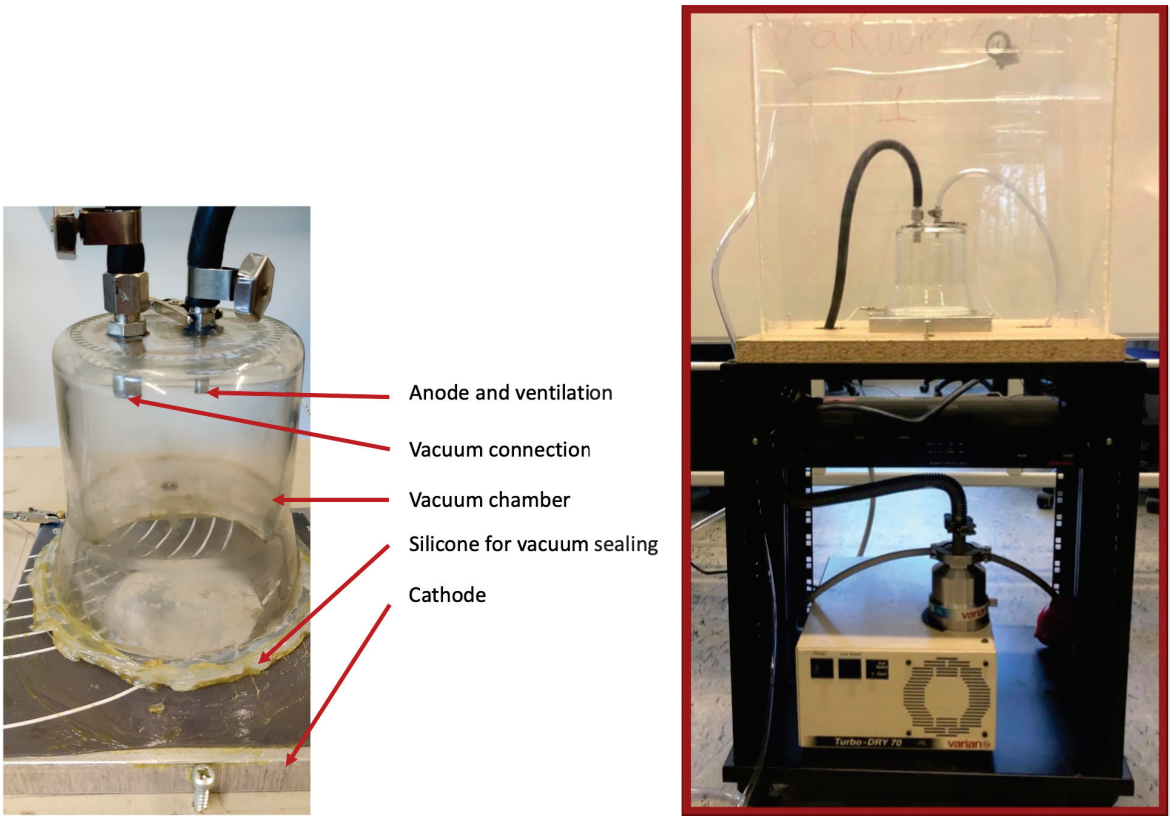


Figure 3: Technical drawing of the wooden plate on which the magnetron system was mounted.

The custom made vacuum chamber mainly consisted of a glass jar purchased from IKEA. For electric feed through, vacuum suction and ventilation, two holes (the ventilation and the electrical feed through were attached through the same hole) were drilled in the bottom of the jar. The students investigated the technique to drill in

glass and used play dough with water to successfully drill the holes. With support from the technical staff, two feed trough pipes were glued to the jar using a special epoxy. The vacuum chamber is illustrated in Figure 4a. The vacuum chamber was encapsulated by a Plexi glass for safety reasons, it was unknown whether the glass jar would implode when evacuating it to vacuum. The students purchased five Plexi glass plates and glued them together. The complete custom made DC magnetron sputtering system is shown in Figure 4b and was ready to be tested.



(a) (b)

Figure 4: (a) The magnetron sputtering chamber including an aluminium cathode and a steel anode. (b) The complete magnetron sputtering system.

4. TEST PROCEDURE AND RESULTS

The students were asked to prepare a test procedure for each system component and the order in which to test the system. They created an extensive test procedure which is reduced to the main steps and illustrated with the flow chart in Figure 5. Initially, the pumps were turned on and the chamber evacuation to vacuum was in process. However, the pumps did not reach full speed due to air leaks between the glass jar and the cathode. The students located the issue, which was caused by a curvature in the glass jar, resulting in the air leaks. To resolve the issue, a silicone paste, usually used for aquariums, was applied to the glass jar and hardened in an oven for 24 hours.

After applying the silicone paste, the pumps reached full speed and the chamber was evacuated to vacuum. There was no pressure gauge available in this project, so the students were given the task to estimate the base pressure of the setup.

With a low pressure inside the chamber, the power supply was turned on and the applied power was steadily increased. We experienced heavy arcing at discharge voltages above 500 V, however it varied depending on the pressure in the chamber, which was directly related to the pump-down duration. We obtained, that with a distance of approximately 130 mm between the cathode and the anode (Figure 4a), it was not possibly to ignite a stable plasma. The distance between the cathode and anode was decreased by mounting a copper wire with a spiral geometry on the electrical feed through.

After numerous tests, the students successfully created a stable plasma in intervals of about 60-120 seconds. The purple plasma glow, arising from recombination of ions and electrons, is illustrated in Figure 6. This achievement was obtained in the end of the project and the students did not have the time to deposit thin films on substrates, however they build a functional dc magnetrons sputtering system.

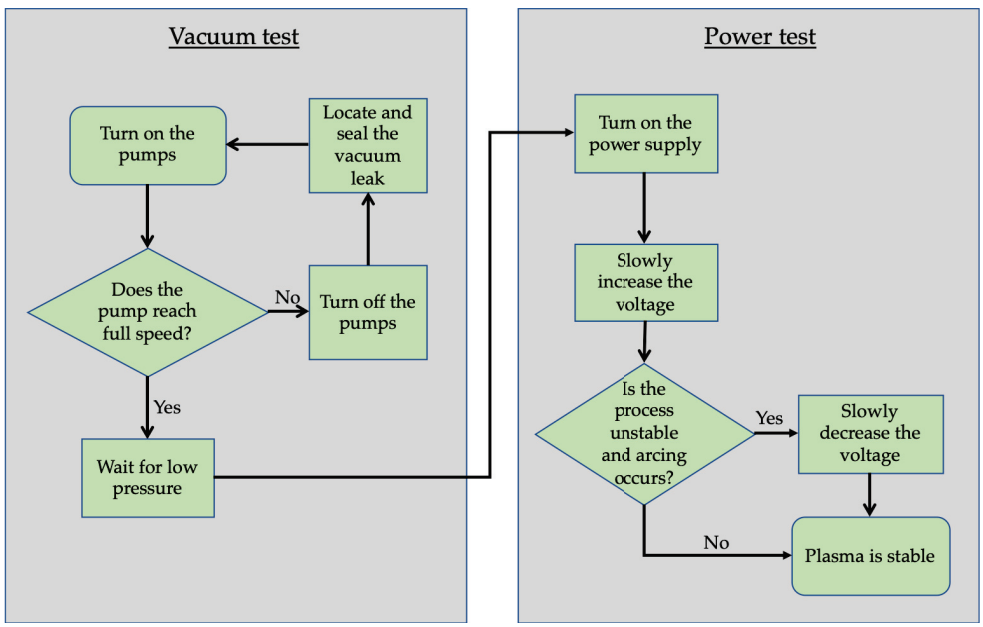


Figure 5: Test procedure for obtaining a stable plasma glow.

5. FUTURE WORK

The *Engineering work* course is held every year and the students of this project identified numerous areas, in which, the system could be improved. They suggested the following:

- Investigate if the magnetic field is strong enough to confine the plasma and secure stability of the plasma. This can be done by measuring the magnetic field with a Hall probe.
- Reduce the thickness of the aluminium plate to change the resistance in the cathode. Copper is a typical material used for magnetrons, however, purchasing a copper plate would used the full budget of 500 USD.

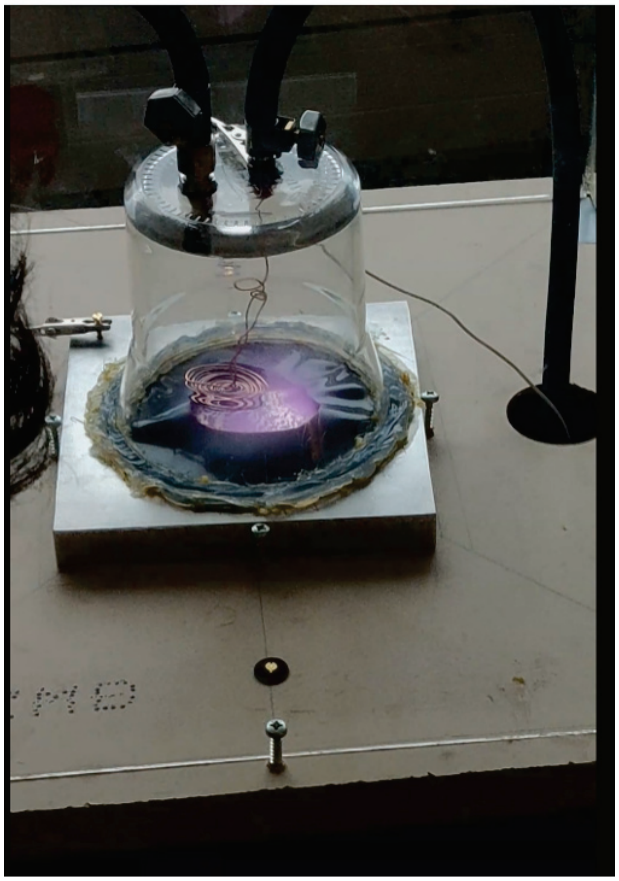


Figure 6: Functional custom made dc magnetron sputtering system with a stable plasma.

- Modify the geometry of the anode. The plasma stability was strongly influenced by the geometry of the copper wire added to the anode.
- Modify of upgrade the vacuum chamber. A low pressure was very important for obtaining a stable plasma. Removing the silicone paste and polishing the rim of the glass jar could reduce the air leaks in the system. Changing to a dedicated vacuum chamber would solve the leak issue, however, it would increase the budget significantly.
- Supplying the vacuum chamber with argon. The ventilation feed could be connected to a bottle of argon, which is the typical working gas in magnetron sputtering processes.
- Build a substrate holder for depositing thin film coatings. The holder can be part of the anode.

6. SUMMARY

A group of first year undergraduate students managed to build a functional custom made dc magnetron sputtering system. They obtained skills within project management, experimental work and technical documentation. They produced a detailed technical report and presented their work with a poster.

Based on the complexity of the project, the students were quick obtain knowledge about the project and they divided the tasks well between them. They prepared a test plan and executed it properly, which led to a stable plasma glow for a minute. Based on their results, they created a list of tasks which future students can continue working on.

REFERENCES

1. S. Massahi *et al.*, "The effect of deposition process parameters on thin film coatings for the Athena X-ray optics," *Proceedings of SPIE* , SPIE - International Society for Optical Engineering, 2021.
2. A. Vickery *et al.*, "Collimated magnetron sputter deposition for mirror coatings," *X-ray Optics and Instrumentation* **2008**, p. 792540 (9 pp.), 2008.
3. F. E. Christensen *et al.*, "Coatings for the nustar mission," *Proceedings of Spie–the International Society for Optical Engineering* **8147**(1), p. 81470U, 2011.
4. S. Massahi, *Industrialization of the mirror plate coatings for the ATHENA mission.* PhD thesis, Technical University of Denmark, 2019.
5. S. Svendsen *et al.*, "Performance and time stability of ir/sic x-ray mirror coatings for athena," *Proceedings of Spie* **11119**, pp. 107–116, 2019.
6. D. D. M. Ferreira *et al.*, "X-ray mirror coatings for athena: updated design, development status and performance," *Proceedings of Spie* , SPIE - International Society for Optical Engineering, 2021.
7. R. YT, "Home built desktop dc magnetron sputtering machine." `https://www.youtube.com/watch?v=c4Sic1DRXJI&ab_channel=YTrich`, 2013.