ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPS25

# IMPROVING THE UNIFORMITY OF MAGNETRON SPUTTERING TITANIUM FILM FOR NONLINEAR INJECTION KICKER

C.S. Huang†, W.Y. Lai, B.Y. Chen, C.J. Lin, C.K. Kuan, and T.C. Tseng,
National Synchrotron Radiation Research Center, Hsinchu, Taiwan, R.O.C.

*Abstract*

The design and manufacturing of the Nonlinear Injection Kicker is one of the upgrade project for the Taiwan Photon Source (TPS). In accordance with the requirements of the developed ceramic vacuum chamber, it is necessary to apply a uniform titanium coating on the inner surface of the ceramic substrate to reduce the impedance and image current observed by the stored electron beam. Therefore, titanium films must be sputtered onto a 30 cm × 6 cm ceramic substrate, and these films must exhibit excellent uniformity. Based on our tests of sputtering titanium films on ceramic substrate, the uniformity of the titanium film can be controlled within 5%. The adhesion between the ceramic substrate and the titanium films meets the highest level of ASTM-D3359 5B standard, with an adhesive strength reaching 40 MPa. This paper describes the detailed manufacturing processes and testing results.

## INTRODUCTION

Sputtering is a surface coating technique, and its main principle involves using the target material as the cathode, with the substrate serving as the anode. In a vacuum environment, a working gas is introduced as the ion source, and then DC or AC voltage is applied between the two poles, inducing the phenomenon of glow discharge. Positive ions in the plasma are attracted to the cathode target material due to its negative voltage, resulting in bombardment of the target material surface. Atoms from the target material gain kinetic energy and escape the target surface, entering the plasma zone. Finally, it is deposited on the substrate by diffusion to form a thin film. This technology is commonly used in the manufacturing of optical films, metal films, ceramic films, and other applications. [1-3]

The sputtering system used in this report has a total length of 4.36 meters, with a maximum component size of 1.2 meters in length and 0.10 meters in height, as shown in Fig. 1. It is equipped with two magnetic sputtering sources, a 1 kW DC power supply, and a 600 W RF power supply. Therefore, this equipment system can perform coating processes for both metallic and non-magnetic materials. During the coating process, the substrate is fixed on a moving platform, which is driven in reciprocating motion by a stepper motor rotating gear.

The development and manufacturing of the Nonlinear Injection Kicker aim to improve the injection efficiency of the electron beam compared to the four injection kickers currently used in the TPS. The purpose of this report is to use DC magnetron sputtering technology to deposit titanium thin films on two ceramic substrates sized 30 cm x 6 cm. The requirement for uniformity is set at 5% to meet the specifications of the vacuum chamber used in the Nonlinear Injection Kicker. As the sputtering system is equipped with a 4-inch rotary stage designed to enhance the uniformity of the coating substrate, as shown in Fig. 2. Because the size of the substrate for Nonlinear Injection Kicker is larger than 4 inches, the rotary stage of the sputtering system cannot be used. Therefore, a system performance upgrade is necessary to improve the uniformity of large-area substrates. After numerous tests, the required film thickness and uniformity have been achieved. Details are as follows.

Figure 1: The sputtering system.

Figure 2: Rotating stage for samples under 4 inches.

## EXPERIMENTAL

This experimental procedures for the application of titanium coatings on 30 cm x 6 cm ceramic substrates. Additionally, the design of coating masks to enhance coating uniformity is also discussed. The main steps of sputtering include the following:

1. Establishing a Vacuum Environment: Coating deposition in a vacuum environment is crucial. This is because in high vacuum conditions, reducing the number of gas molecules prevents reactions with the target material and substrate, ensuring high purity throughout

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPS25

the deposition process. In this experiment, a cryogenic pump is used to evacuate the vacuum to less than 2E-6 Torr, indicating the completion of the vacuum preparation for coating deposition.

2. Preparing the Target and Substrate: First, clean the substrate thoroughly, and check the surface to ensure there are no dust particles on the surface. The substrate will as the anode and is the object to be coated. The 99.99% titanium target material as the cathode and is the material to be sputtered onto the substrate.
3. Adding process gas: In this experiment, argon (Ar) is introduced as the process gas, with a process pressure set at 3 mtorr, to form plasma in the vacuum environment. These process gases aid in plasma formation and also influence the characteristics of the sputtering process.
4. Applying Voltage: Apply DC voltage between the cathode (target material) and the anode (substrate). This induces the phenomenon of glow discharge, resulting in plasma formation. The power range in this paper of 120 to 200 watts.
5. Sputtering of the Target Material: Glow discharge attracts positive ions from the plasma to the cathode (target material), causing them to bombard the surface of the target material. This process results in the atoms of the target material gaining kinetic energy and being ejected from the target surface.
6. Atomic Deposition: Ejected target material atoms diffuse in the plasma zone and eventually deposit onto the substrate surface. These atoms form a thin film, achieving coating on the substrate.

## DISCUSSION AND CONCLUSIONS

Large-area coatings must exhibit uniformity to meet the requirements of various applications, thus demanding careful parameter optimization throughout the coating process. This study improves the uniformity of titanium coatings deposited by DC magnetron sputtering. Parameters including sputtering power, mask design and substrate positioning are tested and adjusted to improve coating uniformity.

The testing in the early stages, titanium coating was used a 24 cm x 4 cm glass substrate, as show in Fig. 3. Three 2 cm x 2 cm glass substrates were fixed at the front, middle, and rear positions for sputtering process. The thickness obtained at the three positions is as follows: P1: 103.9 nm, P2: 87.09 nm, P3: 82.5 nm, the uniformity was about 11.7%. These results did not meet the specifications required for the ceramic vacuum chamber.

In order to enhance the uniformity of the coating, different sputtering powers are tested while simultaneously measuring the film thickness distribution on the sample. Our goal is to find optimal sputtering parameters. Testing was using 40*25mm glass substrates, as shown in Fig. 4. Following the completion of the coating process, thickness measurements were taken at 10 positions vertically on average. The experimental results, as shown in Table 1, indicate poor uniformity, with thinning observed starting approximately one-third from the bottom of the sample (around positions M7 to M10).

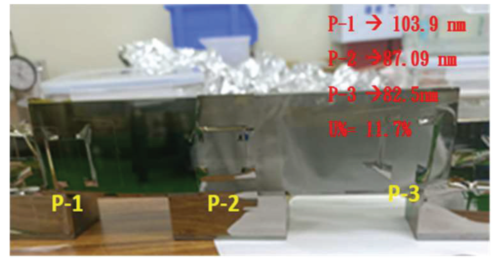


Figure 3: Test of Ti sputtering on 24 cm * 4 cm glass substrate.

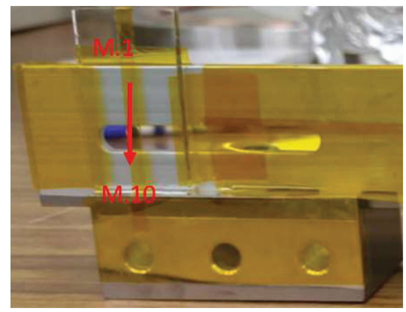


Figure 4: The thickness distribution at different sputter power.

Table 1: Results of Thickness Measurement in the Vertical Direction

| Position | 60W (nm) | 120W(nm) |
|---|---|---|
| M.1 | 97 | 202 |
| M.2 | 92 | 212 |
| M.3 | 90 | 221 |
| M.4 | 94 | 206 |
| M.5 | 95 | 201 |
| M.6 | 92 | 188 |
| M.7 | 88 | 169 |
| M.8 | 87 | 158 |
| M.9 | 80 | 152 |
| M.10 | 74 | 141 |
| U% | 12.94 | 21.62 |

Using an outer shell mask with dimensions of 6 cm wide x 6 cm high, and a 2 cm spacing from the glass substrate for coating, as shown in Fig. 5. The thickness of the coating decreases abruptly near the edges, resulting in an even greater difference., with no improvement in uniformity.

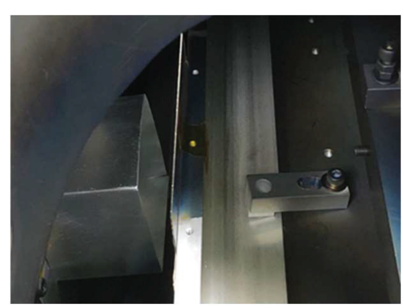

Figure 5: Coating test for the outer shell of the mask.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPS25

Since previous tests did not improve uniformity, we have sputtered large-area substrates to directly assess the condition of the coating film. Based on these results, we will design a mask to be used during the coating process to improve the uniformity of the coating, as shown in Fig. 6.

Figure 6: Design and fabrication of the coating mask and installed in the system.

Redesign a base support measuring 80 cm x 6 cm to evenly divide into five sections, each fixing a 6 cm x 2 cm glass substrate for Ti coating, as Fig. 7. and using the designed MASK for uniformity testing, the results are as shown in Table 2. The overall uniformity is approximately 5%, indicating an improvement from previous tests and meeting production specifications.


Figure 7: Coating test for 80 x 6 cm support with mask.

Table 2: Results of Thickness Measurement for 80 cm x 6 cm Support with MASK

| | Thickness (nm) | | | | |
|---|---|---|---|---|---|
| Position | P-1 | P-2 | P-3 | P-4 | P-5 |
| 0.5 | 197 | 202 | 201 | 211 | 211 |
| 1 | 209 | 207 | 200 | 203 | 206 |
| 1.5 | 211 | 206 | 205 | 207 | 213 |
| 2 | 196 | 209 | 211 | 203 | 200 |
| 2.5 | 194 | 212 | 208 | 200 | 195 |
| 3 | 210 | 205 | 208 | 202 | 199 |
| 3.5 | 211 | 207 | 206 | 204 | 198 |
| 4 | 196 | 210 | 201 | 200 | 194 |
| 4.5 | 194 | 208 | 212 | 202 | 195 |
| 5 | 211 | 200 | 198 | 201 | 201 |
| 5.5 | 213 | 201 | 198 | 202 | 195 |
| Thickness Avg. (nm) | 203.82 | 206.09 | 204.36 | 203.18 | 200.64 |
| U(%) | 4.66 | 2.91 | 3.43 | 2.71 | 4.73 |
| total U(%) | 4.67 | | | | |

Using these process parameters for titanium sputtering, which were sputtered onto ceramic substrates with two different surface roughnesses (Ra30nm and Ra183nm) for adhesion testing, as shown in Fig. 8. Adhesion strength was tested using two methods: the standard test methods for measuring adhesion by tape test (ASTM D3359), achieving the highest 5B. Following that, adhesion testing of the coating was performed using The ROMULUS Universal Tester, with results of approximately 40 MPa and 56 MPa, respectively. The adhesion of the titanium films also met the specified requirements.

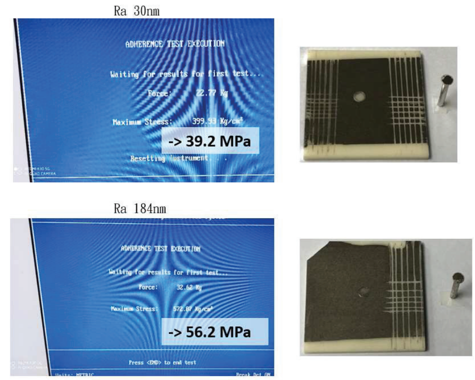


Figure 8: Adhesion testing on two kinds of ceramic substrate.

Figure 9 shows the deposition of uniform titanium films on two large ceramic substrates using DC magnetron sputtering technology and to ensure that the resulting thin films meet the specified uniformity requirements.

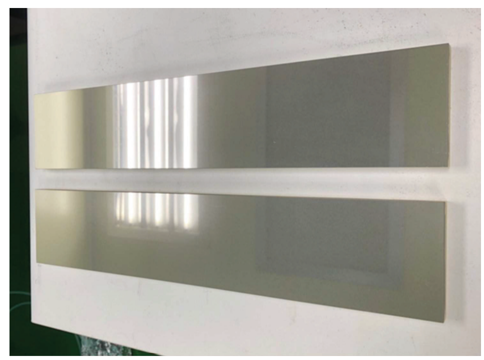

Figure 9: Coating test for large ceramic substrates.

## CONCLUSION

The experimental procedure detailed in this report involves achieving uniform titanium coatings on ceramic substrates through DC magnetron sputtering. After a series of tests, we continuously adjusted the process parameters and designed sputtering masks to ensure that the obtained thin films meet the specifications for film thickness and uniformity requirements. Finally, we achieved a coating uniformity level below 5%, meeting the requirements for Nonlinear Injection Kicker chamber applications.

## REFERENCES

[1] K. Wasa and S. Hayakawa, *Handbook of sputter deposition technology: principles, technology, and applications*, USA: William Andrew, 1992, pp.49-73

[2] B. Chapman, *Glow Discharge Process*, New York, USA: John Wiely and Sons, 1982.

[3] C. Christou and Z. H. Barber, “Ionization of sputtered material in a planar magnetron discharge”, *J. Vac. Sci. Technol. A*, vol. 18, pp. 2897-2907, 2000. doi:10.1116/1.1312370