SIMULATION OF THE TRAJECTORY OF ELECTRONS IN A MAGNETRON SPUTTERING SYSTEM OF TIN WITH CST PARTICLE STUDIO*

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Abstract

In the process of magnetron sputtering deposition, electromagnetic fields have an important influence on the trajectory of particle movement and the properties of the TiN thin film in many cases. Even for simple geometries, the analytical prediction for charged particles trajectories is extremely cumbersome, so numerical simulations are essential to obtain a better understanding of the possible effects and helpful to optimize the design of experimental facility and experimental process. A software of CST PARTICLE STUDIO™ has been used to simulate the effect of magnetic and electric fields on electrons trajectories in the process of film coating. According to the simulation results, the improvement measures of the system design and experimental process have been achieved. The author put forward the improvement measures on film coating process according to the simulation results. The result shows that it is feasible and convenient to use three dimensional tool in the simulation of trajectory of electrons in a magnetron sputtering system.

INTRODUCTION

Each In the past few decades, TiN thin film causes great interest because of its low secondary electron yield (SEY), good electrical conductivity, stability of performance, ability to block hydrogen permeation, etc.[1-3]. The properties and coating process of TiN thin film have been studied in NSRL [4], DESY [5], BNL [6], KEK [1], etc. However, for some irregular type ducts, such as the racetrack type (Fig. 1) ceramic chamber in accelerators, the shape of the ceramic pipeline will induce new and considerable technological difficulties for the uniformity of TiN coating which is important for the vacuum and beam stability in the pipeline.

Ceramic vacuum chamber is the key equipment of the electron storage ring injection system. The light injection chamber at Hefei Light Source II (HLS II) consists of four ceramic vacuum chambers whose inner surface are coated with thin conductive metal wall, and the length of each vacuum chamber is 350 mm. When the interior wall of ceramic vacuum pipeline is coated by mental film, consideration must be given to both the pulsed magnetic field and the continuity of the current in the vacuum chamber wall, in order to reduce the storage ring beam coupling impedance. Typically TiN or Ti are chosen as the metal coating material of the ceramic vacuum chamber while the sheet resistance of the film should be 0.3-0.8 Ω/sq. It has an extremely valuable research that how to get the mental film which has high quality and meets the requirements of the physical design of the storage ring, such as mitigating the electron cloud instability [7].

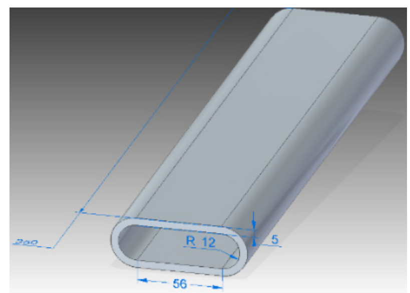

Figure1: A diagram of a ceramic vacuum pipeline.

APPARATUS AND METHODS

Coating System Description

The TiN films are deposited onto the interior wall of ceramic vacuum pipeline which is described in Fig. 1, using a DC Magnetron Sputtering technique. The deposition system which is shown in Fig. 2 consists of observation window, 300 l/s turbo molecular pump, DC power supply, vacuum gauge, coating vacuum chamber and gas flow control system. Argon gas and nitrogen are introduced into the sputtering system through an adjustable leak valve. The typical sputtering parameters are: 900-V cathode voltage, 5×10^{-1} torr gas pressure, 5:1 nitrogen and argon gas flow ratio and 30-mA sputtering current.

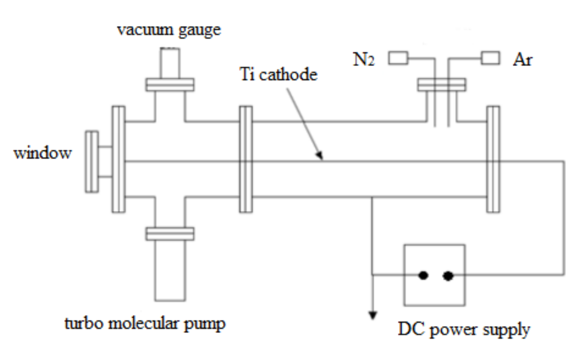

Figure 2: Schematic diagram of DC sputtering coating system.

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Design of Ti Cathode

The cross-section of shaped ceramic vacuum chambers in the system is a special type of racetrack with a small aperture. In order to obtain a uniform thin film, a few titanium wires which are horizontally mounted as cathode target in the experiment have been used. Obviously the coated film could not be uniform with one or two titanium wires as cathodes because of the non-rotational symmetry. So three cathodes had been considered firstly. Due to the complexity of the calculation process, the analysis of sputtering rates(***S***) on different locations of the inner surface of ceramic vacuum chamber had been achieved by using the Matlab software.

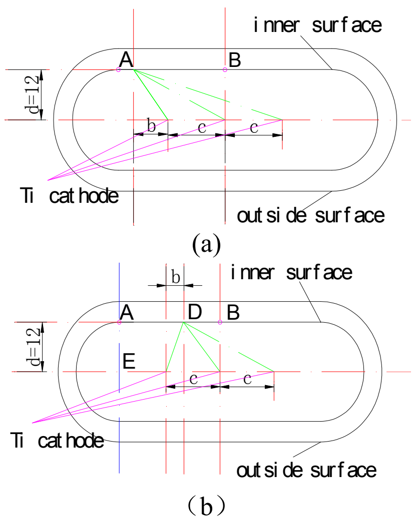

Figure 3: The sputtering rate analysis of one point on the inner face of a ceramic vacuum pipeline. (a) The point is in the right of the left Ti cathode in the horizontal direction, where c is the distance between the Ti cathodes, b is the distance of horizontal direction between the left Ti cathode and the point on the inner surface. (b) The point is in the left of the left Ti cathode in the horizontal direction.

The left side of ceramic vacuum pipeline had been simulated according to the characteristics of symmetry. In case (a), the larger b, *S* is smaller in point B. In case (b), $0 \leqslant b \leqslant c$, in point D, $\boldsymbol{S}=\boldsymbol{S}_1+\boldsymbol{S}_2+\boldsymbol{S}_3$

$$\boldsymbol{S}_1=\frac{\pi Kd}{2\left(b^2+d^2\right)},\boldsymbol{S}_2=\frac{\pi Kd}{2\left[\left(c-b\right)^2+d^2\right]},\boldsymbol{S}_3=\frac{\pi Kd}{2\left[\left(2c-b\right)^2+d^2\right]}$$

where *K* is constant. ***S*** take a great value when b=c for point B and ***S*** increase with c for point A. Above all, point E is an appropriate location for left Ti cathodes considering the homogeneity of the film thickness. On base of computation, the ratio of the maximum and the minimum film thickness is about 1.4:1 for c=28. Meanwhile the average thickness of the TiN film in point A and B is 20.6 nm 27.9 nm in dc sputtering experiments, which means that the average thickness ratio is 1:1.35. Hence the results are in good agreement with the experimental data.

CST SIMULATIONS

Different kinds of models such as analytical models, continuum or fluid models, hybrid models, particle models, have been used to simulate gas discharge in film coating process [8-10]. Nevertheless, these models are complex and time-consuming. CST PARTICLE STUDIO may be a good choice to understand the influence of electromagnetic field distribution on charged particles' motion simply. The DC sputtering coating system which has been defined in CST PARTICLE STUDIO is shown in Fig. 4. In addition, the ceramic gasket in Fig. 4 is for fixing the Ti cathodes.

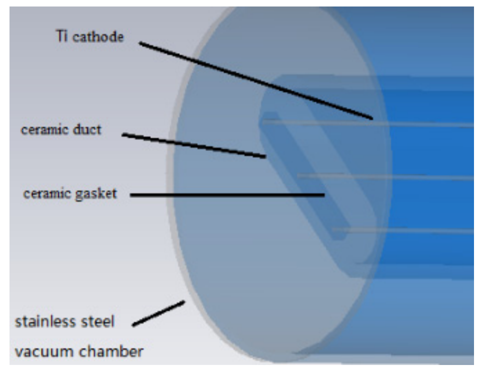

Figure 4: The model of DC sputtering setup.

Electrostatic Solver

The electrostatic solver has been used for simulating the electric field distribution. According to the experiment parameters, Ti cathode voltage is set as 900 V. The electric field strength (***E***) is shown in Fig. 5. The ***E*** near the ceramic gasket where exits higher energy ions bombardment, is much higher than in other place, therefore the temperature of the stainless steel vacuum chamber near the ceramic gasket is the highest. On the other hand, the voltage drop near the Ti target cathode is equal to the cathode dark space in glow discharge.

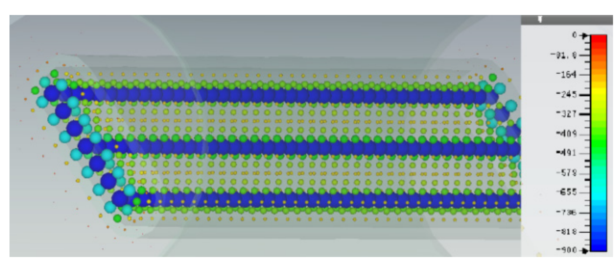

Figure 5: The distribution of electric field.

Magnetostatic Solver

The magnetostatic solver has been used for calculating the magnetic field strength of solenoid. In this model, the solenoid's voltage and current is set as 30 V and 3 A respectively with 500 turns according to the experiment parameters, thus the average magnetic field strength around the ceramic pipes is 3500 A/m. In accordance with the result in Fig. 6, the ceramic vacuum pipeline should be placed in 20 mm apart from solenoid port at least because of the well-distributed magnetic field which is helpful to form a uniform thin film.

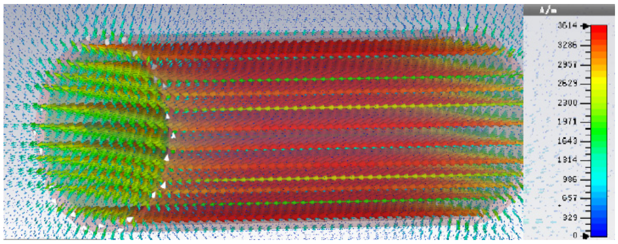

Figure 6: The distribution of magnetic field.

Solver & Particle Tracking

The particle tracking solver has been used to compute trajectories of electrons within electrostatic and magnetostatic fields. Moreover, the implemented gun-iteration enables the computation of a self-consistent electrostatic field which considers the reaction of the electrons movement to the electrostatic potential distribution. The surfaces of Ti cathodes as electron sources emit electrons in field emission model. For Fig. 7 and Fig. 8, the time of electrons' movement is 4.5 ns.

By comparison, the uniformity of electron energy distribution is better in the case of imposing both an electric and magnetic field in Fig. 8 than in Fig. 7 in which different colors represent different electrons' energy. In addition, magnetic field which increase the electron trajectory obviously in Fig. 8 can improve the sputtering rate. What is more, magnetron sputtering is lower voltage i.e. less than 700 V operation than simple DC sputtering i.e. about 900 V.

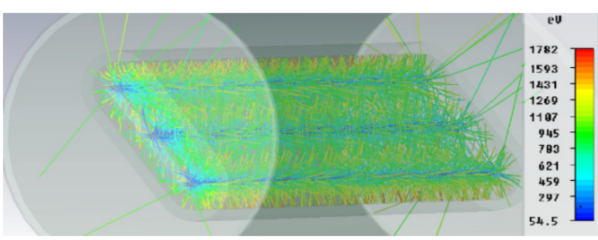

Figure 7: The trajectories of electrons in electrostatic fields.

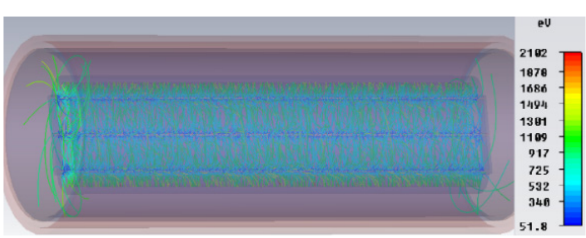

Figure 8: The trajectories of electrons in electrostatic and magnetostatic fields.

CONCLUSION

In short, the simulation of the effect of magnetic and electric fields on electron trajectory in the process of TiN film coating is a good way to optimize the design of configurations and properties of the film, such as the determination of cathodes location, the uniformity of film thickness. Based on the simulation results, preliminary experimental results of the runway ceramic pipeline film coating have been achieved. Furthermore, suitable sputter coating parameters would be found easily in the further work.

FUTURE PERSPECTIVES

To meet the objective of coating the inner surface of other types of pipe with a functional non-evaporable getter (NEG) film, the cathode configurations and coating parameters can be optimized with CST PARTICLE STUDIO in a similar way.

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