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PRODUCTION AND SECONDARY ELECTRON YIELD TEST OF AMORPHOUS CARBON THIN FILM*

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Abstract

Amorphous carbon (a-C) thin film applied to vacuum chambers of high-energy particle accelerators can decrease secondary electron yield (SEY) and suppress electron cloud effectively. A dc magnetron sputtering system to obtain a-C film has been designed. With the apparatus, a-C thin film can be deposited onto the inner face of stainless steel pipes ultimately which is uniform and high-quality. Moreover, researches on its secondary electron yield are also conducted and it is found that a-C has a low SEY (<1.2) measured by the secondary electron yield test equipment in National Synchrotron Radiation Laboratory. The results indicate that a-C is an outstanding surface material for vacuum chambers of modern particle accelerators.

INTRODUCTION

The build-up of electron cloud is one of the main limits to get high-quality beam and high luminosity for modern particle accelerators, such as SPS, Cornell Electron Storage [1, 2]. Coating the vacuum chambers with thin films which has a low secondary electron yield is considered to be an excellent means to mitigate e-cloud [3]. Many laboratories have been doing research on amorphous carbon thin films and found that a-C coatings showed a good performance in the application of accelerators [4-6].

The main aim of our work is to design a set-up to obtain a-C thin films on the interior surface of a thin and long vacuum pipes. Scanning Electron Microscope (SEM) and X-ray Photoelectron Spectroscopy (XPS) were used to investigate the characters of a-C thin films. The SEY of the coatings were also been measured.

EXPERIMENTAL SET-UP

Coating System and Methods

A dc magnetron sputtering system was designed to coat amorphous carbon thin film onto the interior wall of stainless steel pipe, using a graphite cathode placed in the center of the pipe. The schematic diagram of DC magnetron sputtering coating system which mainly consisted of solenoid, cathode, vacuum gauge, power supply, gas flow control system, is shown in Fig. 1.

The StSt pipe used as a main vacuum chamber which is 86mm in diameter and 500mm in length is connected to an auxiliary chamber by Con-Flat flanges. The pumping system is a 300 l/s turbo molecular pump unit, connected to the auxiliary chamber. The discharge gas is high-purity neon whose flow rate can be adjusted by a mass flow controlling system. The magnetic field during sputtering is 150 Gauss provided by a coaxial solenoid coil. A high voltage dc power supply is used to ignite and sustain the discharge. Silicon wafers <111> were mounted onto interior wall of the StSt pipe for investigation of film thickness, morphology, composition, and SEY. Thermocouples were applied to the pipe for temperature measurement.

Before deposition, Si substrates were ultrasonically degreased and cleaned in acetone and ethyl alcohol for 10 minutes, respectively. Then they were immersed in the dilute HF solution, washed with deionized water and dried by purging with nitrogen gas.

Generally speaking, amorphous carbon film coating process was mainly divided into three steps. Firstly, leak detection was carried out for the whole vacuum set-up. Secondly, the turbo molecular pump unit was set to pump. Thirdly, the flow valve was opened to let working gas Ne into the vacuum chamber. When the pressure was close to a suitable value, DC power supply was turned on and glow discharge started.

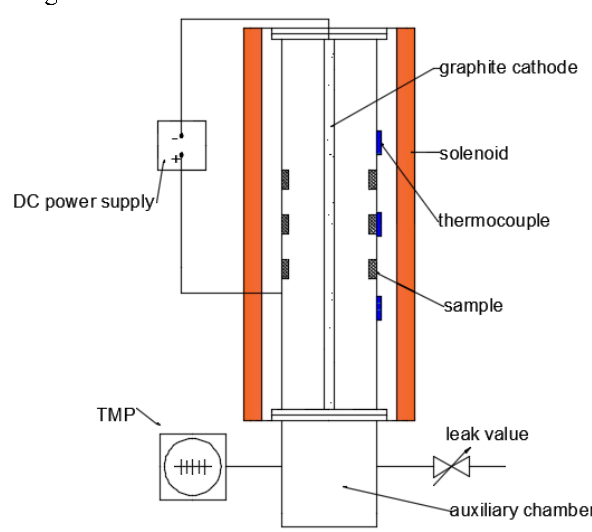

Figure 1: Schematic diagram of DC magnetron sputtering coating system.

Amorphous carbon thin film was deposited without external heating during the whole coating process and the substrate temperature was left free to vary due to the discharge power. The surface temperature during coating can go up to 250 °C, from the thermocouples. The range of coating parameters are given in Table 1. Samples were

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produced in the same deposition condition with different deposition time leading to different thickness. The morphology of the samples were investigated by SEM to calculate the thickness.

Table 1: Discharging Parameters for Amorphous Carbon Thin Film

Power /W	Discharge Gas Pressure/mbar	Deposition Time/hour	Gas Flow/sccm
200	3.5-5.1×10^{-2}	Various	5

SEY Measurements

The measurements of secondary electron yield (SEY) were carried out with an apparatus showed in Fig. 2. It consists of an ultra-high vacuum chamber which is installed with a Kimball Physics EGL-2022 electron gun. The electron gun can provide primary electrons (PE) of 50-5000 eV towards the samples at a 90° angle. During the SEY test, the vacuum pressure was 1-2×10^{-7} Pa when the room temperature was 298 K.

The schematic diagram of the SEY test is shown in Fig. 3. The Faraday cap is biased to +70 V in order to collect all secondary electrons emitted from the sample. The electron dose during the test was 1×10^{-7} C/mm^2. The size of the samples was 10 mm × 10 mm × 0.5 mm. The precision of the SEY values is evaluated to 2.6%.

The SEY (δ) is ratio of the current of secondary electrons, I_{SEY}, to the current of incident electrons, I_P. It is calculated as:

$$\delta = \frac{I_{SEY}}{I_P} = \frac{I_F}{I_F + I_S} \tag{1}$$

where I_F is Faraday cup-to-ground current, I_S is sample-to-ground current. The most important values for a SEY curve are the maximum SEY, called δ_{max} and the corresponding primary electron energy, called E_{max}.

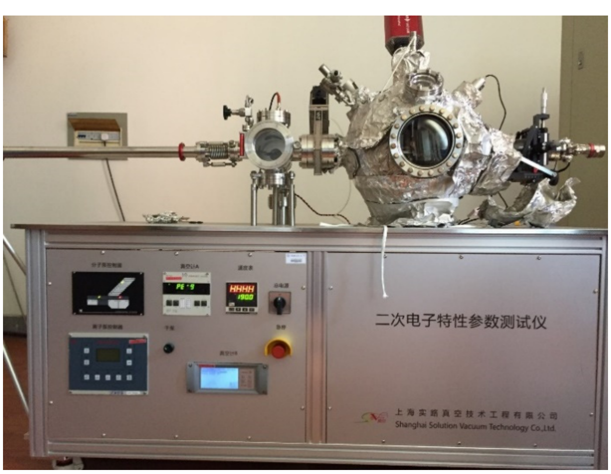


Figure 2: SEY measurement apparatus in National Synchrotron Radiation Laboratory.

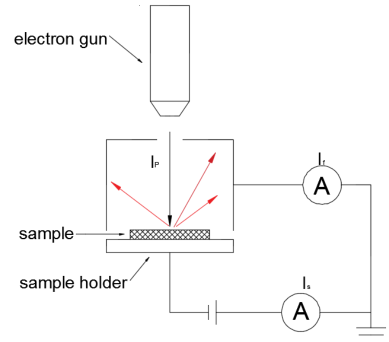
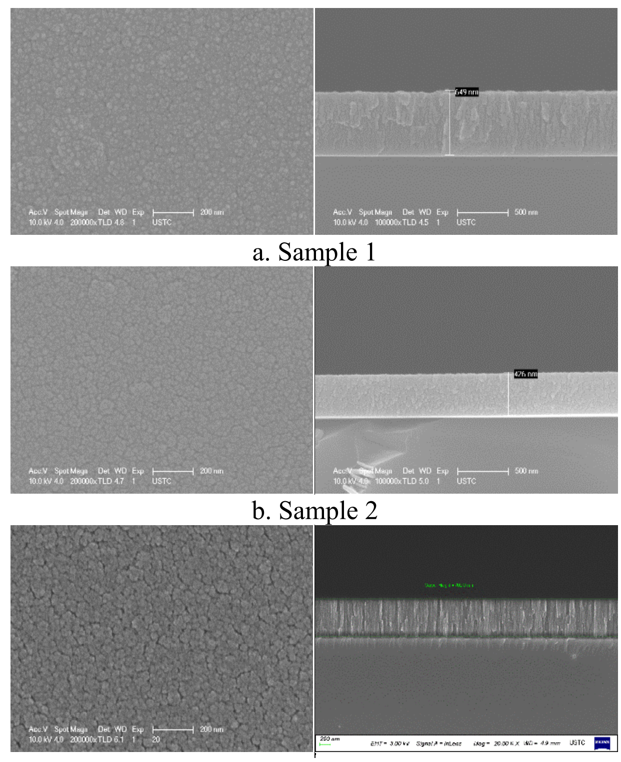


Figure 3: Schematic diagram of the SEY test.

RESULTS AND DISSCUSIONS

Film Properties



a. Sample 1

b. Sample 2

c. Sample 3

Figure 4: SEM images of 3 a-C samples obtained with various deposition time in the same deposition parameter. The deposition time for sample1, 2, 3 were 6, 4, 7 hours, respectively.

It can be discovered from Fig. 4 that the morphology of the coatings in the same deposition condition had a high consistency. The a-C thin films on Si substrates also showed good adhesion. The thickness of sample 1, 2, 3 is 649 nm, 426 nm, 709 nm, respectively. The deposition rate is calculated to be about 100 nm/h.

The XPS data of the a-C thin film is present in Table 2. And the C1s spectra of the coatings with various deposition time is showed in Fig. 5. From the XPS data, we can come to a conclusion that the a-C coatings show more graphite-like properties than diamond-like properties.

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Table 2: Summary of XPS Data for All the Coatings

Sample	Peak Binding Energy (eV)	FWHM (eV)	O Concentration (%)
1	284.8	1.32	12.38
2	284.8	1.63	15.46
3	284.8	1.49	12.3

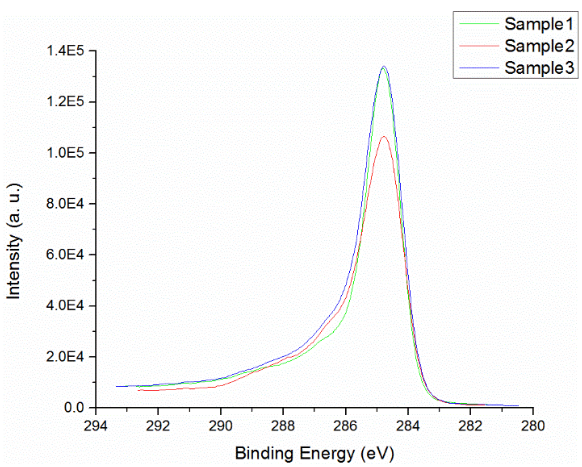

Figure 5: C1s spectra of different a-C coatings.

SEY of a-C samples

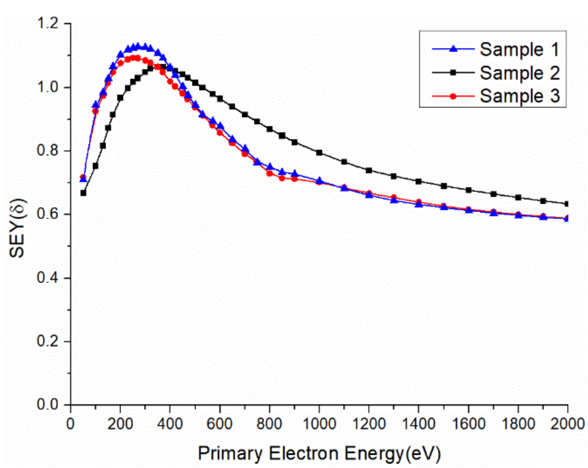

Figure 6: SEY of a-C coatings with different thicknesses.

As showed in Fig. 6, δ_{max} of the samples are 1.06, 1.12, 1.08 with different thickness 426 nm, 649 nm, 709 nm, respectively. All values are lower than 1.2, indicating that coating the vacuum chambers of high energy particle accelerators can decrease secondary electrons emission effectively. In addition, there is not a specific relationship between SEY and sample thickness.

CONCLUSION

In this study, amorphous carbon thin films have been deposited onto the inner face of the vacuum pipe by a dc magnetron sputtering apparatus successfully and efficiently. The coatings produced show an outstanding performance with a reliable low initial SEY and they do not require in-situ bake-out. Therefore a-C coatings are considered to be a potential surface material for modern particle accelerators. The ageing and recovery of amorphous carbon coatings is being investigated.

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