

RESEARCH ON SECONDARY ELECTRON EMISSION CHARACTERISTICS OF DIAMOND-LIKE CARBON THIN FILMS

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Abstract

In modern particle accelerators, the build-up of electron cloud is a main limiting factor for the achievement of high-quality beam. Among the techniques to mitigate it, coating the internal walls of the beam pipes with a thin film which has a low secondary electron yield (SEY) is considered to be one of the most effective means. From several earlier studies, it was found that diamond-like carbon (DLC) thin films are potential coatings. This paper is mainly about the research on secondary electron emission characteristics of DLC thin films. The secondary electron emission (SEE) tests were done at temperature of 298 K and vacuum pressure of 2×10^{-9} Torr. Here, we obtained the characteristics of the SEE from DLC film coatings with different thickness under ultrahigh-vacuum (UHV) conditions. The maximum secondary electron yield (SEY), δ_{\max} , of the DLC thin films under different primary electron doses were also obtained, respectively.

INTRODUCTION

For modern high-energy accelerators, electron cloud which is typically initiated by ionization of residual gas or from electron generation when stray beam particles strike the chamber is considered as one of the main limitations to obtain high luminosity and high quality beams, especially for proton and positron rings. Many laboratories have been dedicated to eliminate electron cloud occurring in the beam pipes so far, such as CERN [1], SuperKEKB [2], SLAC [3]. In practice, solutions to suppress electron cloud mainly include: (a) modifying the vacuum chamber surface with grooves or slots [4]; (b) modifying the vacuum chamber surface by laser ablation engineering [5]; (c) coating vacuum chamber surface with a thin film layer with lower secondary electron yield (SEY) than the vacuum chamber itself [6]; (d) different combinations of above. A thin film coating is considered as the most natural way among the methods. From many studies, DLC thin films is a potential material.

In the present study, secondary electron emission characteristics of DLC thin films with various thickness have been investigated conditioning different electron bombardment dose. In addition, X-ray Photoelectron Spectroscopy (XPS) have been used to investigate the characters of DLC thin films.

EXPERIMENTAL

SEY Measurement Set-up and Procedures

A secondary electron emission test system has been designed to measure the SEY of materials, which mainly consists of an ultra-high vacuum chamber, a pretreatment vacuum chamber, TMP pumping system, magnetic transmission system, power supply system, data acquisition and processing system. The main vacuum chamber is installed with a Kimball Physics EGL-2022 electron gun directed towards the sample at a 90 degree. The electron gun provides an energy spectrum of 50 eV to 5000 eV on the samples at Emission Current Control (ECC) mode. A Keithley 2400 pico-Ammeter is connected to the sample which can apply bias voltage and indirectly measure the SEY of the sample during the test. It has an accuracy of 0.024%. The vacuum chamber is grounded during SEY measurements. The pretreatment vacuum chamber is used for pre-pumping to greatly shorten the experiment period. The electron dose during the test was 1×10^{-8} , 2×10^{-8} , 5×10^{-8} , 1×10^{-7} C·mm⁻², respectively. All the measurements were performed at 298 K and the pressure is about 2×10^{-9} Torr.

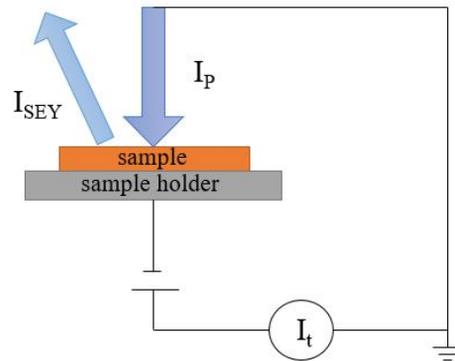


Figure 1: Schematic diagram of the SEY measurement.

When an electron beam hits the surface of a sample, it will emit electrons which are called secondary electrons. The secondary electron yield is defined as the ratio of the number of secondary electrons emitted from a surface, I_{SEY} , to the number of electrons incident to that surface, I_p . The SEY values are calculated by the following equation:

$$\delta = \frac{I_{SEY}}{I_p} = 1 - \frac{I_t}{I_p}, \quad (1)$$

where I_t is the total current which is measured by applying -20 V bias voltage that excludes all low energy secondary

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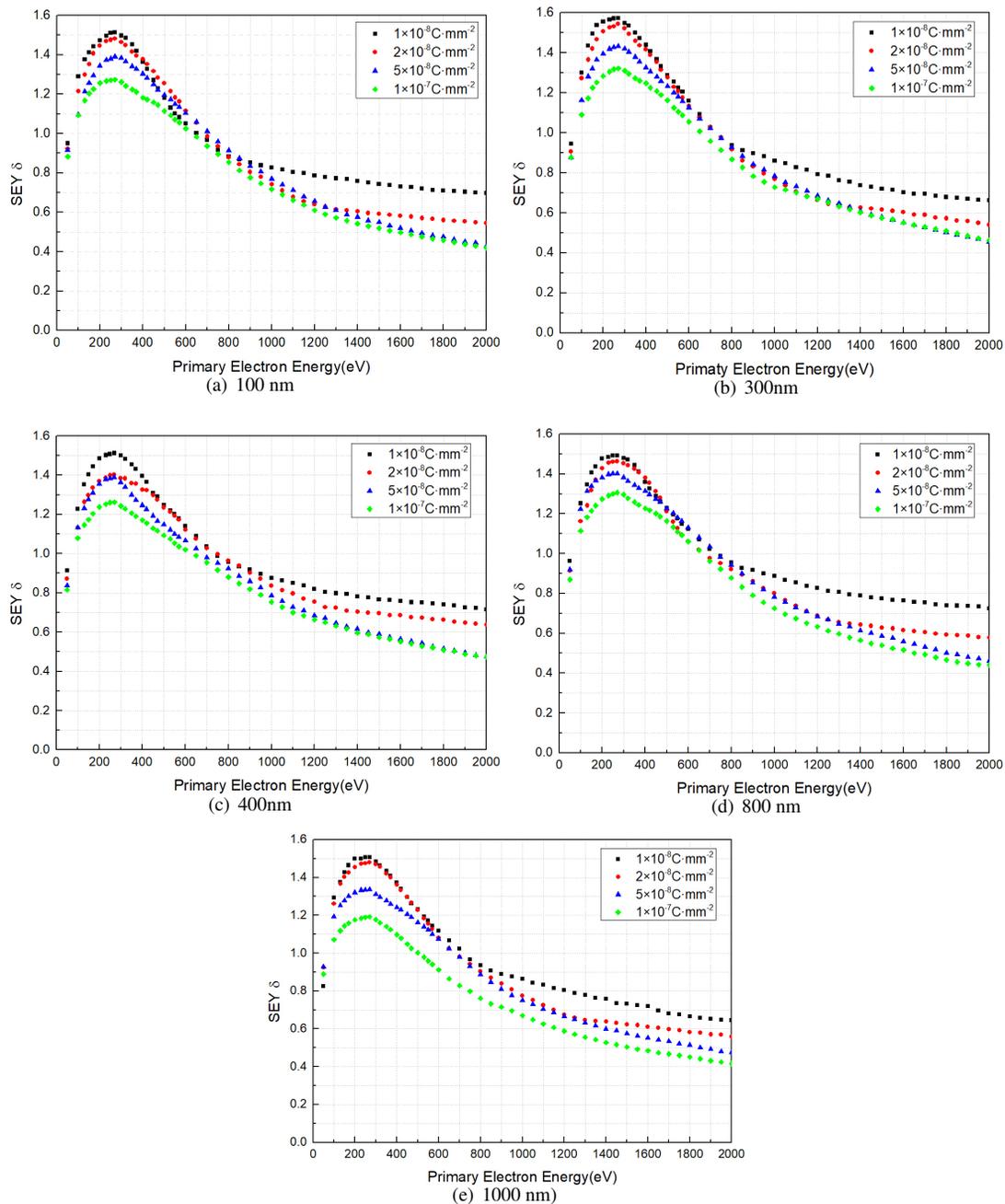


Figure 2: SEY results as a function of primary electron energy for DLC thin films produced with various thickness: (a) 100 nm, (b) 300 nm, (c) 400 nm, (d) 800 nm, (e) 1000 nm, and conditioning electron bombardment with a dose of 1×10^{-8} , 2×10^{-8} , 5×10^{-8} , $1 \times 10^{-7} \text{ C}\cdot\text{mm}^{-2}$.

electrons. I_p is measured by applying a +100 V bias voltage that could reacquire all secondary electrons. The schematic diagram of the SEY experiment is illustrated in Fig.1.

Sample Preparation

DLC thin films were produced onto silicon substrates by Plasma Enhanced Chemical Vapor Deposition (PECVD) with various deposition time, which leads to different coating thickness. Each sample was measured directly after extraction from the deposition chamber and transferred to

the SEY measurement system through air. The sizes of the samples are 10 mm × 10 mm. The composition of the thin films was investigated by X-ray Photoelectron Spectroscopy (XPS) to measure the type and content of elements.

RESULT AND DISCUSSION

SEY Curves of DLC Samples

Secondary electron emission characteristics of DLC thin films with different thickness are shown in Fig. 2, condition-

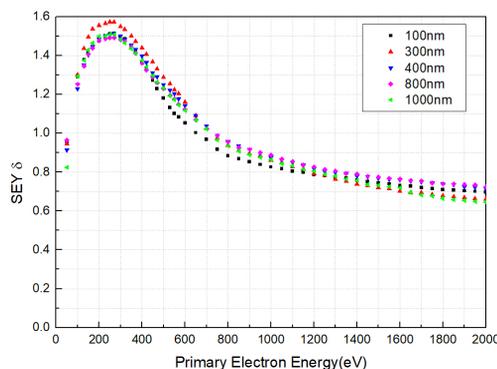


Figure 3: SEY measured versus PE energy for DLC thin films produced with different thickness.

ing with various electron dose. It can be discovered from Fig. 2(a) that δ_{\max} of the sample with a thickness of 100 nm decreased from 1.51 to 1.27 when the incident charge per unit surface (Q) increased from 1×10^{-8} to 1×10^{-7} C·mm⁻². In addition, similar results are observed for other samples. It can be seen that the maximum δ_{\max} of the samples with thickness of 300 nm, 400 nm, 800 nm, and 1000 nm are 1.57, 1.51, 1.49, 1.50, and the minimum δ_{\max} of them are 1.32, 1.28, 1.30 and 1.23, respectively, as shown in Fig. 2 (b), (c), (d), (e). Meanwhile, there is almost little changed for E_{\max} with the increase of the electron dose.

As seen in Fig. 3, δ_{\max} of the samples are 1.51, 1.57, 1.51, 1.49, 1.50 with different thickness 100 nm, 300 nm, 400 nm, 800 nm, 1000 nm, respectively. The corresponding primary electron energy E_{\max} at which the maximum yield occurs is around $E_{\max} = 270$ eV. DLC thin films have a max SEY value close to 1.5, which is far less than that of the materials commonly used in accelerator vacuum chambers, such as stainless steel [7], oxygen-free copper [8], suggesting that coating the vacuum chambers of high energy particle accelerators with DLC thin films is an effective method to suppress the electron cloud. Moreover, no clear correlation between SEY and thickness has been found.

The XPS data illustrates that oxygen has been found in all sample coatings which is the mainly impurity element and the concentration of oxygen ranges from 7.12-10.89 % in the various coatings (see Table 1).

Table 1: Summary of XPS Data for All DLC Thin Films

| Thickness (nm) | C concentration (%) | O concentration (%) | N concentration (%) |
|----------------|---------------------|---------------------|---------------------|
| 100 | 90.25 | 8.92 | 0.83 |
| 300 | 88.33 | 10.89 | 0.78 |
| 400 | 90.40 | 8.63 | 0.97 |
| 800 | 92.11 | 7.12 | 0.77 |
| 1000 | 91.19 | 7.93 | 0.88 |

CONCLUSION

DLC thin films prepared by PECVD generally have a secondary electron yield (SEY) close to 1.5 after air transfer to the measuring instruments. This can possibly be implemented as a promising solution for suppressing electron cloud effect for accelerator vacuum chambers. No measurable relationship between the SEY value and the thickness was observed. The max secondary electron yield (δ_{\max}) decreased as the incident electron dose increasing while the corresponding primary electron energy E_{\max} did not change too much. Large magnet devices are not required in the production of DLC thin films, without site constraints and DLC thin films do not need activation. Therefore, DLC thin films are more suitable for the curved section of vacuum pipe coatings. In conclusion, DLC thin films are believed to be a reliable solution for the electron cloud mitigation for the high-energy accelerators.

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