LOW SECONDARY ELECTRON YIELD CARBON COATINGS FOR ELECTRON CLOUD MITIGATION IN MODERN PARTICLE ACCELERATORS

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Abstract

Electron-cloud is one of the main limitations for particle accelerators with positively charged beams of high intensity and short bunch spacing, as the SPS at CERN. The Secondary Electron Yield (SEY) of the inner surface of the vacuum chamber is the main parameter governing the phenomenon. The effect could be eliminated by coating the vacuum chambers with a material of low SEY, which does not require bake-out and is robust against air exposure. For such a purpose amorphous carbon (a-C) coatings were produced by magnetron sputtering of graphite targets. They exhibit maximum SEY between 0.95 and 1.05 after air transfer to the measuring instrument. After 1 month of air exposure the SEY rises by 10 - 20 % of the initial values. Storage in desiccator or by packaging in Al foil makes this increase negligible. The coatings have a similar X-ray photoelectron spectroscopy (XPS) C1s spectrum for a large set of deposition parameters and exhibit an enlarged linewidth compared to HOPG graphite. The static outgassing without bake-out depends on deposition parameters and is in a range from 1 to 10 times higher than that of stainless steel (StSt). Instead, the electron stimulated desorption is lower than for stainless steel and is leaded by CO.

INTRODUCTION

The electron cloud build-up in high energy particle accelerators is driven by the SEY of the beam pipe inner surface. Due to the heating temperature limitation in the SPS, the goal is to find a material with very low initial SEY, which does not require thermal activation and is robust against air venting for maintenance. The SEY should remain sufficiently low, typically below 1.3 in the case of SPS, to avoid e-cloud build up.

EXPERIMENTAL

Thin Film Coating

The investigated samples are thin film coatings deposited by d.c magnetron sputtering, using a graphite cathode placed in the center of a cylindrical vacuum chamber. The length of the vacuum chamber is normally 500 mm whereas the diameter of the chamber is 100 mm. StSt after standard cleaning for UHV, are normally used as coating substrates for investigation of SEY. The discharge gas used for sputtering in this work is Ne, however, Ar and Kr have also been tested.

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The investigated coating parameter range is given in Table 1. Different combinations can be set up. To investigate the influence of coating parameters on the SEY, a number of various changes, such as, power, discharge gas pressure and substrate temperature, have been tested. The thickness of the coatings measured by Scanning electron microscope (SEM) is in the range between 50 and 1300 nm.

Table 1: Coating parameters for amorphous carbon coatings (magnetic field 150 Gauss).

Parameter choice	Power (W)	Discharge gas pressure (Torr)	Substrate temperature (°C)
Low	80	$4\cdot 10^{-3}$	150
Medium	250	$4\cdot 10^{-2}$	250
High	450	$9\cdot 10^{-1}$	350

Experimental Setups and Procedures

The measurements of SEY are carried out with an electron gun, which sends primary electrons (PE) of 50 - 2000 eV to the surface of the sample, and a collector for the emitted electrons. The collector is biased to +45 V in order to capture all secondary electrons, whereas the sample is biased to -18 V. All reported SEY measurements were carried out at normal PE angle of incidence. The electron dose was calculated to be below 1×10^{-6} C/mm^2 over irradiated areas of about 2 mm^2 for a full SEY measurement.

Each sample was measured as received after extraction from the deposition chamber and transfer to the SEY measurement apparatus through air. The time in air during the transfer is approximately 2 hours. The precision of the measured SEY values is estimated to ±0.03.

After the SEY measurement, an XPS spectrum is usually taken after a transfer under UHV from the SEY system to the XPS system.

The aging, or increase of the SEY during air exposure, is different for different coatings. The purpose of sample storage under controlled conditions is to find a way to avoid or suppress the aging of samples. The following storage procedures have been tested and compared after 1 month's time: Storage inside polymer box; wrapped into Al foil inside polymer box/polymer bag; in desiccators and in unbaked static vacuum (before closing the vessel, the sample was pumped down to 10^{-7} mbar.).

The outgassing rate in the unbaked state is important for the SPS on which the pumping speed cannot be increased.

The pressure decrease for several a-C coated tubes has been measured during the 100 hours of pumping and the results have been compared with a bare StSt tube as reference.

The detailed description of Electron Stimulated Desorption (ESD) measurements has been discussed in [1]. The system is baked at 300 °C for 24 hours without heating the sample and the a-C sample is measured unbaked and after 2 hours' heating at several selected temperatures. Electron energy is 500 eV with a bombarding current of 1 mA. The estimated bombarded area is about 200 cm^2. Each ESD measurement is taken after 100 s of bombardment.

RESULTS AND DISCUSSIONS

The SEY versus primary energy curves for the as-received a-C thin films produced with the various coating parameters, such as power and pressure and normal substrate temperature, i.e. no external heating applied, are shown in Fig 1.

The maximum SEY (δ_{max}) of a-C is between 0.95 and 1.05 and the primary electron energy E_{max} at which the maximum yield is obtained around 300 eV.

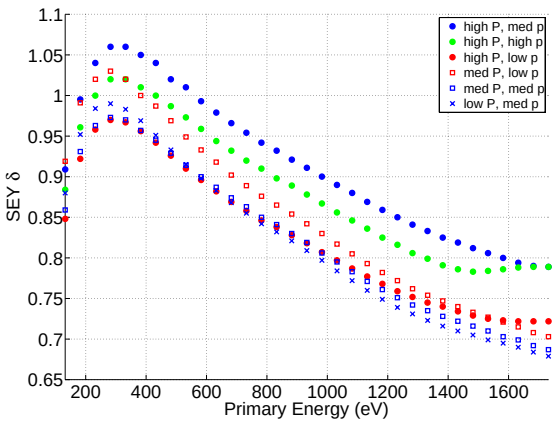

Figure 1: The SEY as a function of PE for a-C produced with the different coating parameters: power (P) and pressure (p).

The SEY were observed to be independent on the thickness of the film, which is above 50 nm. No measurable influence of the pressure of the discharge gas during the coatings could be seen on SEY, either.

External heating has been applied during the deposition in order to investigate the role of the substrate temperature on surface structure and morphoulogy. The investigated samples were produced with medium power.

Figure 2 shows the measured SEY versus PE for the thin films produced with external heating at 150°C, 250°C and 350°C, respectively. Different discharge gas pressures have also been applied in order to investigate the influence of this parameter.

As seen in Fig 2, there is a clear difference between the shapes of the SEY curves produced at different temperatures. For the samples produced in 150°C and 250°C, the shape of the curves looks similar to the samples produced without external heating (compared with Fig 1). However, the shape of the SEY curves produced in 350°C is flatter. In addition, δ_{max} is obtained at a higher E_{max} at 500 eV instead of 300 eV.

SEM has been employed in order to investigate the difference in morphology. In Fig 3, the sample produced in 350°C shows a more pronounced roughness compared to the samples in 150°C and 250°C. A high substrate temperature during the coatings seems to increase the roughness on the surface.

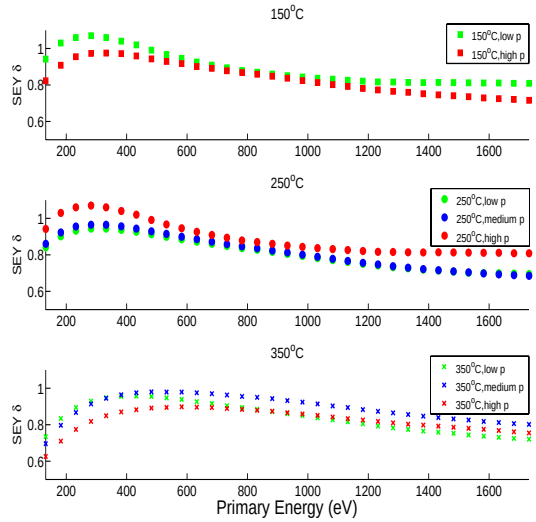

Figure 2: Variation of the SEY with the coating temperature. All the coatings were produced with the same power and various pressure (p).

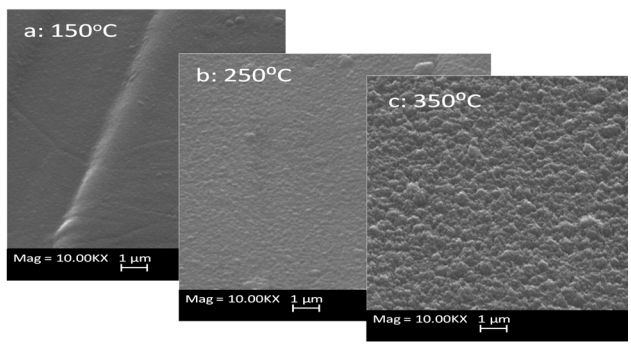

Figure 3: SEM of a-C produced with various temperatures. a: 150°C b: 250°C c: 350°C.

The storage test under controlled conditions has been performed and the results in term of SEY are shown in Fig 4. By storing the sample in desiccator, the SEY increase seems to be suppressed completely. Storage in unbaked static vacuum does not seem to be a good solution for the a-C coatings. The rapid increase in the unbaked static vacuum could be explained by water dominated adsorption.

The complete understanding in this type of SEY influence is still in progress.

XPS analysis of the coating shows that the C1s line has a larger FWHM compared to HOPG graphite. All the coatings show an oxygen surface concentration between 5 and 15 at.%, except for the coatings at 350°C which have lower oxygen content. No correlation between the O content of one various coating in the as received state and the SEY was found.

In Table 2, the water vapor outgassing rate for four a-C coated tubes with various coating parameters after 10 hours pumping is shown. The outgassing rate without bake-out is in a range from 2 to 10 times higher than that of bare StSt. The value depends on deposition parameters and it seems to be lower for coatings made at lower discharge gas pressure.

Figure 5 shows the typical graphs of ESD yields of a-C coating. CO has the highest ESD yield, followed by H_2 and CO_2. For heating temperatures higher than 120°C, the ESD yields of the a-C coated sample are lower than that of bare StSt. In the case of H_2 and CH_4, the a-C sample is at least 10 times better than StSt when heated. In the case of CO and CO_2, the a-C sample and the StSt ref have a similar behaviour.

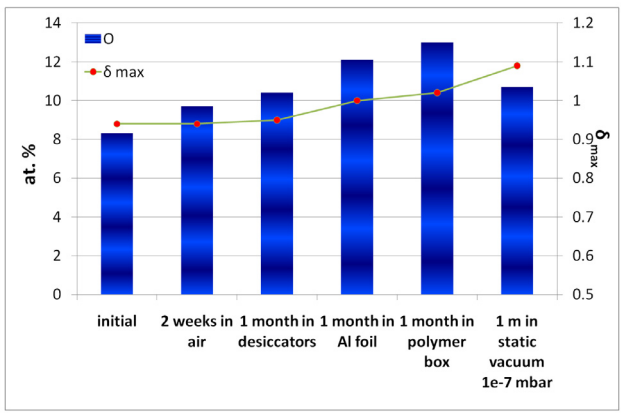

Figure 4: The comparison of O content measured by XPS and the SEY on the identical a-C samples stored under different conditions and was measured after 1 month.

Table 2: The outgassing rate (after 10-hour pumping) for four different a-C coatings with various deposition parameters. The pumpdown measurements were taken after 1-hour air venting.

	Power	Pressure	Q_{10h} (Torr l / s cm^{-2})
StSt			$8.9 \cdot 10^{-11}$
CNe19	low	medium	$2.0 \cdot 10^{-10}$
CNe20	low	medium	$5.9 \cdot 10^{-10}$
CNe34	low	high	$1.2 \cdot 10^{-9}$
CNe20	low	high	$1.3 \cdot 10^{-9}$

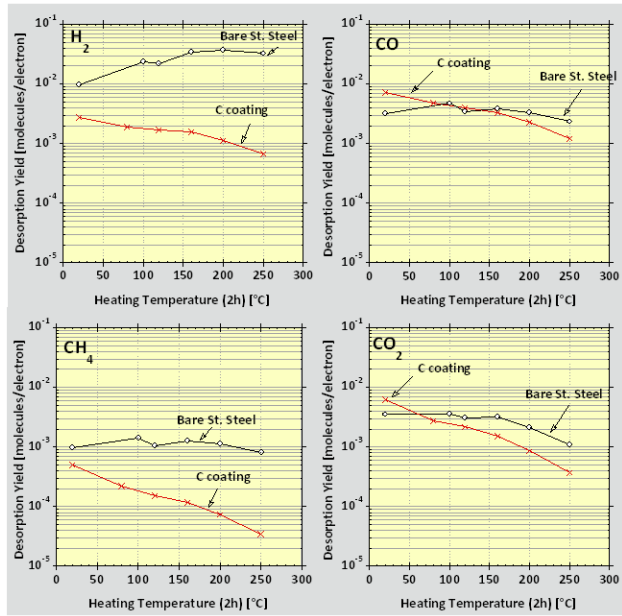

Figure 5: The electron stimulated desorption yield for a-C coating compared to those of bare StSt.

CONCLUSION

In the case of heating temperature limitations, as for the SPS, magnetron sputtered a-C films are a potential solution to eliminate e-cloud. The δ_{max} are generally in a range of 0.9 and 1.1 after air transfer to the measuring instrument.

Sample preparation affects the surface morphology. A high substrate temperature during the coatings increases the roughness on the surface. The effect of ageing can be influenced by storing the sample in different ways.

ESD yields are in general lower than those of the reference sample, except for the unbaked cases. For the unbaked samples, the total outgassing can be reduced by one order of magnitude by reducing the discharge gas pressure.

Study of the implementation of such coatings in real accelerators, with the final objective of coating the whole SPS ring (8 Km, about 1000 vacuum chambers) is still ongoing. The most recent results with the a-C coated dipole magnets in the SPS can be found in [2].

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