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CARBON-BASED COATINGS FOR ELECTRON CLOUD MITIGATION IN SRF PHOTOCATHODES

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Abstract

Multipacting is a common issue in the context of cathode units of superconducting radiofrequency photoinjectors (SRF-guns) utilized in linear accelerators under resonant conditions. During the past three years, we developed a coating along with a corresponding in-situ characterization process in order to realize SRF-gun surfaces featuring low secondary electron yield (SEY). Important aspects that have been accounted for are the homogeneity and adhesion of the coatings deposited on the cylindrical SRF-gun mantle. Furthermore, the correlation between SEY and crystallinity, morphology, and contamination was studied in detail. The SEY maximum can be tuned between 1.5 and less than 0.7 depending on the deposition conditions. In this work, we recap the results and present a general strategy for the effective mitigation of electron cloud multiplication.

INTRODUCTION

The unwanted resonant electron multiplication in high-frequency structures is called multipacting (MP). This phenomenon arises at the cathode module of superconducting photoinjectors for linear accelerators and prevent its operation [1]. Principally, there are four strategies for MP mitigation on a srf-gun:

1. DC-biasing of the coaxial cathode system [2],
2. structuring the cathode surface on a micrometer-scale [3],
3. geometrical optimization of the system [4],
4. coating the cathode by a low secondary electron emission yield material.

This work focusses on the fourth strategy of coating the srf-gun mantle with a low SEY carbon coating. Carbon has been shown to have a SEY below 1 [5, 6]. The latter is the requirement for effectively suppressing the electron multiplication. Compared to other methods, a coating system is cost effective, applicable to 3D structures and clean in terms of vacuum compatibility.

One of the main concerns in an accelerator is the pollution of the system by particles. A coating must provide a good adhesion to its substrate material in order to make sure that no delamination happens. An area-wide or even a partly delamination of the coating would be disastrous. Therefore, increasing the adhesion of the coating is one of the main topics of this research.

In this study, the prototype was based on the design of the FELBE srf-gun used at HZDR. This design uses two different metals, namely the cathode body and the cathode plug. The former is made of copper, the latter is made of molybdenum sitting on the very tip of the cathode body [7]. In conjunction with aforementioned adhesion requirements the two substrate materials Cu and Mo making things even more challenging. Both materials do not react chemically with carbon thus do not form any chemical bonds. Hence, the adhesion of carbon on both metals will be poor. Still, to go for a good adhesion a titanium interlayer was implemented. On the one hand, Ti easily forms metallic bonding with Cu and Mo. On the other hand, Ti chemically reacts with carbon forming chemical bonds (TiC). This increase the adhesion dramatically and makes the top coating somewhat independent from the actual substrate material. The following results are based on this interlayer concept.

In this contribution, we show the dependencies of deposition parameters on microstructure and the resulting SEY.

EXPERIMENTAL

Carbon coatings were prepared on coin-shaped Cu and Mo samples with a diameter of 25 mm and on cylindrical srf-gun dummy-samples having a diameter of 10 mm and length of 100 mm. The latter have been prepared to mimic the FELBE srf-gun at HZDR. To coat the mantle of the cylinder-shaped samples a new substrate holder was engineered. With this, it is possible to coat a fully assembled FELBE-style srf-gun homogenously (Fig. 1).

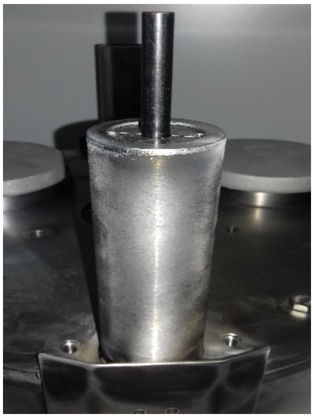

Figure 1: Coated srf-gun dummy sitting in its specially designed coating sample holder system.

Before deposition, samples have been cleaned in ethanol ultrasonically and rinsed in distilled water. Additionally, various surface pre-treatments like polishing, sandblasting, wet chemical etching and plasma etching have been investigated in order to get different roughness, a good cleanliness and contamination free substrate surface.

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The coatings have been synthesised by DC magnetron sputtering. A two-step coating process was used to create an interlayer of Ti before depositing the carbon top-layer. Ti source was a 400 x 150 mm² Ti target. Carbon source was a graphitic target of same size. After pumping down to a base pressure of $5x10^{-7}$ hPa a pre-sputtering of both targets was carried out to clean targets from any possible contamination. During pre-sputtering cathode-shutters where closed protecting substrates from unwanted deposition or contamination. Then, the Ti interlayer was deposited using Ar as process gas at $8x10^{-3}$ hPa and target power of 3500W for 10 minutes. The subsequent carbon top-layer was deposited using Ar, Kr, N_2, C_2H_2 and mixtures of these. Substrate temperature, substrate bias, pressure and power have been varied to elucidate their effect on the SEY. In order to find the main dependencies, the parameters have been studies using a statistical experimental planning. The range of process parameters are summarized in Table 1.

Table 1: Process Parameter for Carbon Coating Synthesis

Parameter	Range
Temperature	60 – 650 °C
Pressure	
Power	3500 – 5000 W
Bias	0 – 300 V

The coated samples have been analysed by scanning electron microscopy (SEM) and SEY-measurements to investigate the surface morphology and SEY, respectively. The SEY measurement have been performed in a SEY setup that has been constructed based on the design used at CERN. A more detailed description can be found elsewhere [6]. In this study, all samples left the deposition chamber under normal laboratory conditions and have been stored wrapped in aluminium foil.

RESULTS AND DISCUSSION

SEY Measurements of Substrates

A comparison between different substrate materials (Cu, Mo, Nb) and surface conditions with an optimized carbon coating is shown in Fig. 2. The Nb "as received" curve is a representative for all metal substrates tested here. As received samples are technically clean but anyhow, hold various contaminations like oxidation layers, hydrocarbon and water adsorbates. In other words, the measurement does not show the SEY of the material itself but its surface layer, which differs from the actual bulk material in the first some tenth to one hundred nanometres.

Ultrasonically cleaning of samples in ethanol does not improve the SEY very much as shown in the corresponding curve (Fig. 2). Indeed, cleaning a sample which formerly had a SEY lower than 1 will increase the SEY to values higher than 1 [6]. This is because of many residues are left on the sample surface after evaporation of the liquid.

A good method for cleaning sample surfaces is by ion irradiation. In this study, Ar-plasma treatment of all three metals shows good results. This treatment has been done inside the SEY-measuring system under UHV conditions ($5x10^{-10}$ hPa). Therefore, the SEY-measurements show the SEY of the pure metal. It can also be seen that all three metals have maximum SEYs equal or higher than 1.2.

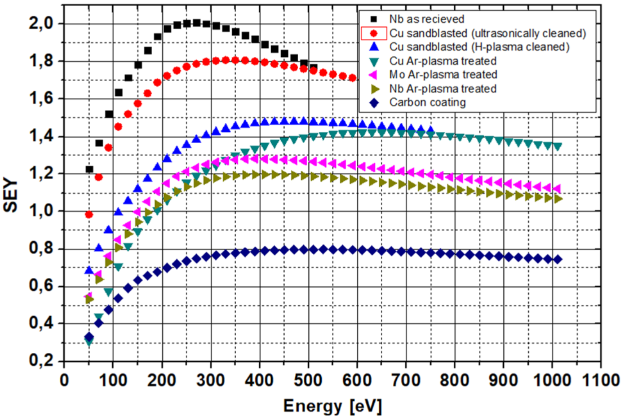

Figure 2: SEY measurements of various substrate materials treated by different methods.

SEY Measurements of Carbon Coatings

Figure 3 shows SEY measurements of three different carbon coatings deposited using different process gas mixtures. A gas mixture of noble gas (Ar, Kr) shows the best result and consequently, is used in all the following processes. One common PVD carbon coating is diamond like carbon (DLC). For its synthetization C_2H_2 is utilized. However, the corresponding curve of a DLC coating shows SEY > 1.1 and consequently, not followed any further. Another approach is the use of nitrogen in the gas phase. The corresponding curve shows a maximum SEY of 1 which makes C-N coatings an interesting alternative for low SEY applications. However, this branch has not been investigated further in this study.

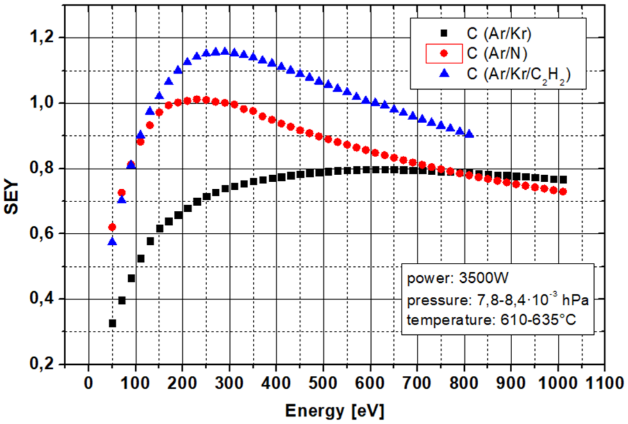

Figure 3: SEY measurements of three carbon coatings synthesised at different process gas mixtures.

Sticking to a Ar:Kr-ratio of 4:1, Fig. 4 and Fig. 5 are showing the results for substrate temperature, target power and substrate bias, respectively. It can be seen that a

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combination of high target power alongside with the application of a substrate bias leads to a reduction in SEY. This combination shows to be important since applying a higher target power without substrate bias does not show a significant change in SEY (Fig. 4).

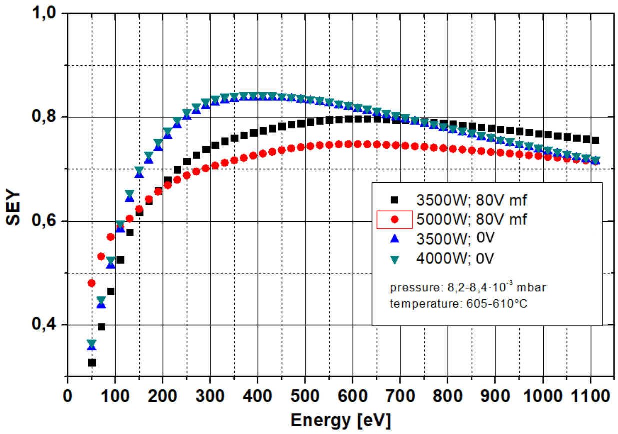

Figure 4: Influence of target power and substrate bias on SEY.

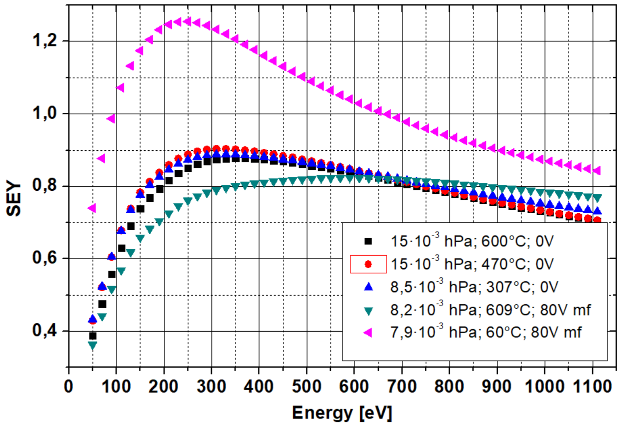

Figure 5: Influence of substrate temperature and substrate bias on SEY.

Most significantly, the substrate temperature turns out to be the most important parameter. As can be seen, a low substrate temperature (60°C) yields a very high SEY > 1.2. Whereas, temperatures of 307°C and above yield SEY ≤ 0.9 (Fig. 5). This can be improved by applying a mid-frequency (MF) substrate bias of 80V. In the following, the substrate temperature, pressure and target power were set to 600°C, 8.0-8.5x10^{-3} hPa and 4000 W, respectively.

Having found the most appropriate parameter set, the next results show a substrate bias series of both SEM and SEY investigations. The SEM micrographs in Fig. 6 reveal the coatings' surface morphology dependency on applied substrate bias. With increasing bias, the morphology changes from dense to porous. Furthermore, at 150 V a fibrous growth can be observed. These fibres have a diameter of 10 to 80 nm. The free space between the fibres is in the same range. At very high substrate bias however, the fibrous structure is destroyed by the bombardment with high energetic plasma ions. Correlating these findings with the SEY measurements shown in Fig. 7, it becomes obvious that the structured surface morphology at 150 V is the most desirable one.

It should be mentioned, that correlating the SEY and surface roughness, e.g. R_a or R_q values, does not show any significance.

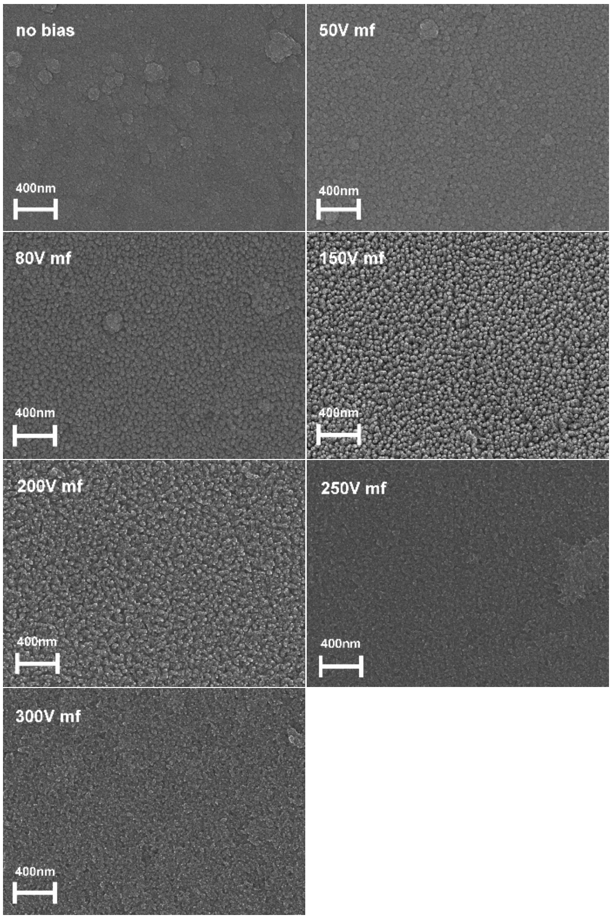

Figure 6: Plain-view SEM micrographs of carbon coatings deposited at different substrate bias voltages.

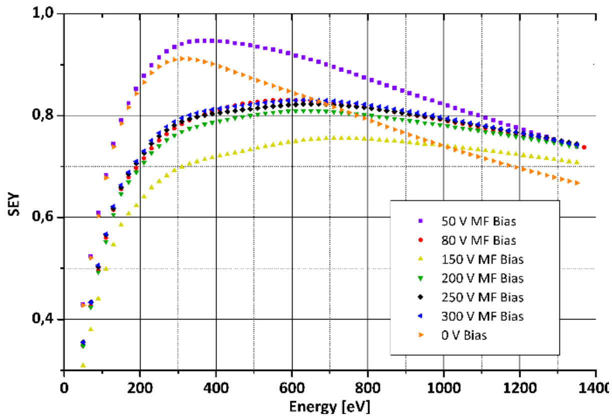

Figure 7: SEY curves of a substrate bias voltage series. This directly correlates with Fig. 6

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CONCLUSION

A parameter study of DC magnetron sputtered carbon thin films on metal substrates has revealed that the most important parameters for achieving a low SEY are the substrate temperature (600°C) combined with a substrate bias voltage (150°C). By controlling both parameters, it is possible to tailor the coatings´ morphology, which in turn makes it possible to adjust the SEY to low values around 0.8. By correlating the SEM micrographs of the samples' surface morphology and the SEY it becomes obvious that the SEY is strongly dependent on morphological changes.

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