GRAPHENE COATING FOR THE REDUCTION OF THE SECONDARY ELECTRON YIELD

Taaj Sian[1,2,3], Yue Lin[1], Reza Valizadeh[2,3], Oleg B. Malyshev[2,3], Guoxing Xia[1,3], Cristina Valles[1], Geliang Yu[1] and Ian Kinloch[1]
[1]University of Manchester, Manchester, UK
[2]ASTeC, STFC Daresbury Laboratory, Warrington, UK
[3]Cockcroft Institute, Warrington, UK

Abstract

Secondary electron emission is a limiting factor for a performance of many instruments ranging from small gauges and detectors to waveguides and charged particle accelerators. Several methods have been developed to reduce this effect, e.g. use of a coating of a material with low Secondary Electron Yield (SEY). This paper describes the effect of graphene coatings on a stainless steel substrate to achieve low SEY surfaces. The SEY were taken on a dedicated facility using an electron gun and a Faraday cup, the electron energies were varied between 80 eV and 1 keV with a bias of -18 V on the sample. The maximum SEY (δ_{max}) was decreased from 2.4 for bare stainless steel to 1.4 with a graphene coating.

INTRODUCTION

Secondary electron emission limits the performance of accelerators by playing a significant role in Electron Cloud (EC) build up. The primary electrons are produced by residual gas ionisation and photoelectron production from the wall of the beam pipe by sychotron radiation. Then the primary electrons are accelerated towards the positively charged beam, after the beam passes these electrons may reach and interact with the opposite side of the beam pipie, producing secondary electrons and this effect leads to the build up of an electron cloud and electron multipacting [1].

The build up of EC in a particle accelerator causes: increase in the emittance, beam instabilities, presure rises and additional load on the cryogenic system [2]. Multipacting is also problematic in RF cavities and waveguides as it absorbs the RF power and may lead to damage of the surface. The electrons can also desorb gas from the cavity surface increasing the pressure in the cavity. The electrons can also heat the cavity walls thus increasing the heat load on the wall, which is especially problematic with superconducting cavities [3]. The SEY as a function of primary electron energy can be described with its maximum value δ_{max} and corresponding primary electron energy which lies in the range between 200 and 400 eV for commonly used vacuum chamber materials such as copper, aluminium and stainless steel. It is important to reduce δ to below 1 in the whole range of primary electron energies for EC mitigation [4].

The SEY of a material depends upon the atomic number of material, surface chemistry, the surface topology and to a lesser effect on the work function of the material. By coating the substrates with graphene we change the surface material to a material with a lower atomic number as well as the surface chemistry. Carbon is a known low SEY material and is already used in its various forms; for example, coating copper with amorphous carbon by DC magnetron sputtering has been found to reduce the δ_{max} from 2.4 to 1.1 for 'as received' samples and coating with Highly Ordered Pyrolytic Graphite (HOPG) reduces δ_{max} to 1.26 [5]. Graphene has unusual electrical, mechanical and thermal properties [6] and since it is a form of carbon it should result in a low secondary electron yield. In this paper we report the results for using a graphene coating for SEY mitigation.

EXPERIMENTAL

Sample Preparation

The stainless steel substrates were 30 mm × 10 mm. In order to ensure homogenous deposition of the graphene film, the stainless steel substrates were carefully ground, then polished down by using 1 µm diamond paste followed by OPS colloidal silica (22-28 nm, pH 9-10). The graphene was prepared by means of electrophoretic deposition (EPD) described in Ref. [6]. The clean graphene was first dispersed in deionised water in an ultrasonic bath for 1 h to get stable suspension of graphene. Hydrochloric acid was then added until the suspension reached pH 3. This caused the graphene to become positively charged. The suspension was then loaded into a glass beaker and two gold coated conductive glasses were placed 5 mm apart to be used as electrodes. An electric field was applied and the graphene sheets were desposited onto the surface of the negative electrode. Six samples were coated with graphene varing deposition time between 1 and 10 minutes and the bias on the sample between 3 and 6 V, see Table 1 [6].

Measurement Procedure

The samples were attached to a sample holder using 2400 circuit works conductive silver epoxy then placed into an oven at 120 °C for 20 minutes an finally cooled in air. Each sample was then loaded onto the transfer arm in the load lock chamber and the chamber was pumped down to 2×10^{-8} mbar which took approximately 4 hours. The sample was then transferred into the SEY measurement chamber. The bias was then applied to the sample and the SEY measurement was started. After the SEY measurements were completed,

the samples were transferred to the surface analysis chamber for X-ray Photoelectron Spectroscopy (XPS) analysis.

Table 1:The Graphene Deposition Parameters for the Samples

Sample	Bias (V)	Time (min)
S1	3	3
S2	3	10
S3	6	1
S4	6	3
S5	6	5
S6	6	10

Setup

A schematic of the experimental setup is shown in Fig. 1. The measurements were performed using an electron source focused upon a sample with a negative bias with respect to the Faraday cup that is held at ground potential. The bias was applied to the sample to repel the secondary electrons into a Faraday cup which was used to collect the secondary electrons. The electron source was able to emit electrons from 10 eV up to 1 keV. The primary electron current was of the order of 10 nA to ensure negligible conditioning effects. The pressure in the testing chamber was 1×10^{-8} mbar during the SEY measurements.

The sample to ground current was measured using a Keithley 6485 picoammeter, the Faraday cup to ground current was measured using a Keihley 486 picoammeter. Equation 1 was used to calculate the SEY at each energy. The accuracy of the SEY measurements was within 6%.

The bias of -18 V was applied to the sample using a circuit consisting of batteries and resistors. The 9 V batteries were used since the mains power supplies generate too much noise thus the primary electron current would need to be higher and so the sample would get conditioned throughout the measurement. The SEY δ can be defined as:

$$\delta = \frac{I_f}{I_p} = \frac{I_f}{I_f + I_s}, \quad (1)$$

where δ is the total SEY, I_f is the current on the Faraday cup, I_p is the beam current and I_s is the secondary electron current.

The surface chemistry and composition was determined by XPS was performed using an Al K alpha x-ray source in a vacuum vessel with an operating pressure of 5×10^{-9} mbar.

RESULTS

Figure 2 shows the SEY data as a function of primary electron energy for all the samples. To produce the different samples the deposition duration and the applied bias were modified. It can be seen that a longer deposition at the same bias led to a lower SEY. It can also be seen that a higher bias for the same deposition time also led to a lower SEY. The lower SEY in both cases indicates a thicker layer of graphene deposited on the samples.

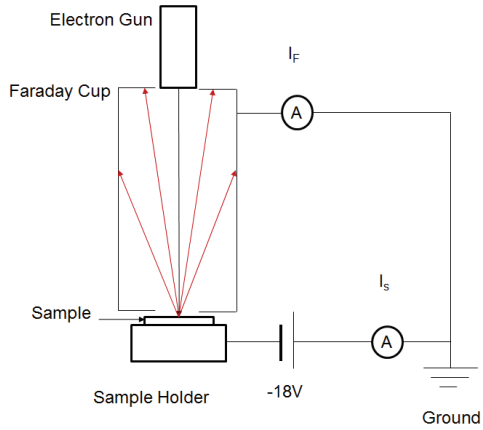

Figure 1: The schematic of the experimental set up to used to measure the SEY.

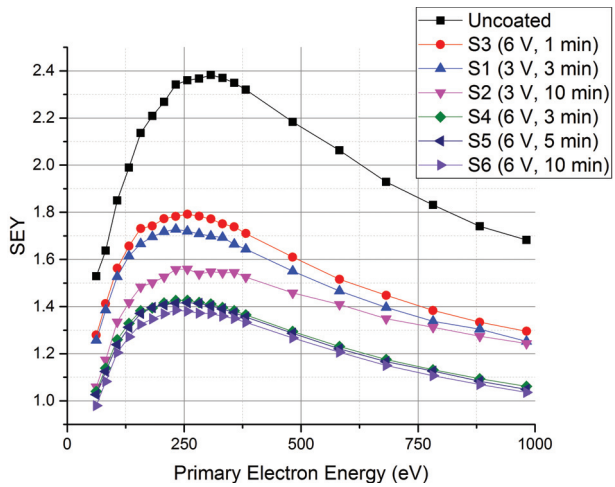

Figure 2: The SEY data for stainless steel coated with graphene using various EPD biases and deposition times.

Figure 3 shows the XPS wide scan of a graphene coated sample (S2) and an uncoated stainless steel sample. It can be seen that in the case of the graphene coated sample the surface is mostly composed of carbon (i.e. graphene) with a considerable amount of aluminium oxide impurity. The atomic composition of all the surface elements determined by casaXPS software is summarised in Table 2. The absence of any Fe signal in the spectra demonstrate that the graphene deposit is considerably thick. On S2 the surface was mostly composed of carbon (69%) as expected for a graphene coating. There was also a large amount of oxygen on the surface (21%). Although the surface of the uncoated sample was also mostly covered with carbon (57 %), it exhibited a large SEY value. It also contained twice as much oxygen.

DISCUSSION

The results presented in this study show that EPD coating of graphene can reduce the SEY of stainless steel samples. The δ_{max} was reduced from 2.4 (uncoated sample) to 1.8 (sample S3) by applying a thin coating (S3) and was reduced

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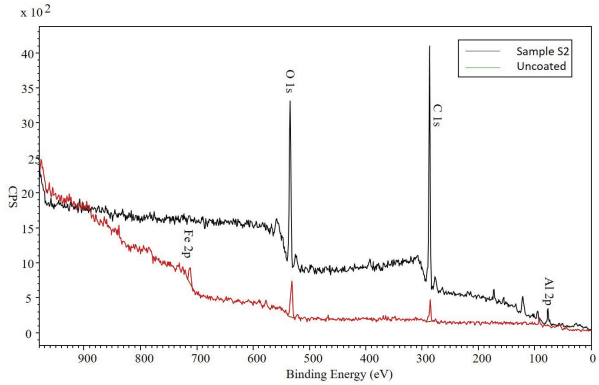

Figure 3: The XPS data comparison of sample S2 and the uncoated sample.

further to 1.4 (sample S6) by increasing the thickness of the graphene coating. The fact that the graphs for S4, S5 and S6 are very similar suggested the existence of a limit, which suggests that the thickness of the coating on the samples S4, S5 and S6 was large enough to supress the SEY from the stainless steel substrate. The presence of aluminium oxide as an impurity on graphene can represent the reason why the SEY was not reduced to levels already seen for both amorphous carbon and HOPG which have a lower δ_{max} of 1.1 and 1.26 respectively [7] however the amorphous carbon coating was on a copper sample which has a lower δ_{max} than stainless steel (2.4 and 3.5 respectivly) [7]. The source of aluminium oxide should be identified and suppressed in future studies.

Table 2: Quantification of the XPS Results

	Sample S2 (%)	Uncoated (%)
C 1s	69	57
O 1s	21	40
Al 2p	10	0
Fe 2p	0	3

CONCLUSION

Graphene coating by EPD on stainless steel has been shown to reduce the δ_{max} of 'as received' samples from 2.4 without coating to 1.8 with a thin coating. Further reduction to δ_{max} = 1.4 was achieved with thicker graphene coatings. Further reduction to 1.26 (reported for HOPG) may be achieved by reducing the aluminium oxide impurity in our future work.

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