RESEARCH ON LOW SECONDARY ELECTRON YIELD MATERIALS FOR FUTURE ACCELERATORS*

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Abstract

For future accelerators, such as SPPC (SEY$_{\max}$ <1.2), the build-up of electron cloud generated in the beam pipes considerably affect the stability of particle beams. Therefore, it is critical to look for steady and low secondary electron yield (SEY) material for future high intensity accelerators.

INTRODUCTION

Secondary electron cloud limits the performance of high-energy and high-intensity charged particle accelerators, radio frequency wave guides and detectors. For example, the beam-induced electron multipacting build up on the beam path will hinder the beam stability, energy, emittance etc. Electron cloud effects (ECE) such as multipacting, heat load, in particular inside cold superconducting magnets, vacuum instability, have been observed in many machine, e.g. APS, KEKB, PS, SPS, CESR etc. This is a serious technical risk for LHC and future colliders. Therefore, searching low SEY materials is a very critical problem.

Many research institutions, such as Cornell [1], KEK [2, 3], CERN [4-6], LNF-INFN [7], etc., have done a lot of research on low SEY materials. The chosen of low SEY material is generally based on the threshold value for e-cloud appearance and other limiting conditions of the certain machine.

For SPS, the threshold value for e-cloud appearance in the SPS with the LHC beams is 1.3 [8]. The strategy against e-cloud for LHC includes TiZrV getter coated beam pipes in the warm sections, Cu-coated LHC beam screen with a sawtooth surface on the outer wall (at 4-20 K) in the cold arc, the pumping slots in the beam screen are shielded, a-C film coating with $\delta_{\max}$ about 1 and surface conditioning. Nonetheless, increase of SEY can occur because of contaminants on the a-C sample surfaces [4]. Moreover, traces (~6% monolayer) of silicon were detected on the a-C coated samples that were present during pre-installation 150 ℃ vacuum bake out of the a-C coated vacuum chamber, resulting in significant increase in secondary electron yield (SEY) [9].

However, for SPPC (super proton proton collider), the threshold value is 1.2 [10]. A stable low SEY material (SEY$_{\max}$ <1.2) is needed to reduce ECE for SPPC.

THE COMPARISON OF LOW SEY MATERIALS

Amorphous Carbon (a-C)

CERN has produced amorphous carbon (a-C) using DC magnetron sputtering method. The SEY on the a-C samples after long term exposure to various atmospheres, different surface treatments, such as conditioning by electron beam, annealing under vacuum and ion bombardment on the sample surfaces have been investigated by CERN [4].

According to [4], The C1s peak areas of a-C without external substrate heating, show a percentage of 73% sp^2 and 27% sp^3. While, for a-C C1s produced with external substrate heating at 350℃, the peak areas corresponding to sp^2 and sp^3 bonds are 85% and 15%, respectively.

The peak SEY of various amorphous carbon film coatings are compared and shown in Table 1. According to Table 1, in most of the cases, the SEY$_{\max}$ of a-C is about 0.9~1.2. However, the SEY$_{\max}$ of a-C after 1 year air is 1.24 and the SEY$_{\max}$ of a-C under 8 months air exposure in polymer box is 1.51. Also, the SEY$_{\max}$ of a-C coated MBB (Magnetic Bender of B-type) magnet after one year operation is 1.33. Therefore, for SPPC, a-C is not the best choice.

Table1: Peak SEY Comparison of Various Amorphous Carbon Film Coatings

Test organization	Electron beam dose or other parameters	Peak SEY
Cornell [1]	0.01~100/Amp·hr	1.0
CREN [4]	52 nm/ thickness	1.06
	390 nm/ thickness	1.02
	150℃/substrate temperature, low pressure	1.07
	150℃/substrate temperature, high pressure	0.98
	350℃/substrate temperature, low pressure	0.97
	350℃/substrate temperature, high pressure	0.9
	CKr4	1.33
	CNe8	0.92
	CNe13	1.0
	CNe13 2 weeks in air	1.14
	C strip	0.92
	a−C on rough Zr	0.96

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	a–C after 1 year air	1.24
	1.72e–5 C/mm^2	1.2
	3.74e–2 C/mm^2	0.98
	a–C 8 months air exp. in polymer box	1.51
	a–C 10 min Ar+ ion bombard	1.03
LNF-INFN [7]	a-C/Cu	1.2
	1070 K/Annealing temperature	1.0

HOPG（Highly Oriented Pyrolytic Graphite）

The peak area of C1s peak corresponds to sp^2 content of 100.0% by definition of the HOPG. For freshly cleaved HOPG, it shows no oxygen contamination on the surface at all. While, for a-C film coatings, the oxygen content varied from 10%~20% [4]. As shown in Table 2, the SEY$_{max}$ of freshly cleaved HOPG is 1.25 and it is 1.30 under 1 week air exposure in polymer box. Hence, HOPG is not suitable for SPPC.

Table 2: Peak SEY Comparison of Low SEY Materials

Materials	Test organization	Electron beam dose or other parameters	Peak SEY
Carbon foil	CREN [4]	0.7-1.3 g/cm^3	0.92
HOPG	CREN [4]	2.27 g/cm^3	1.26
DLC	Cornell [1]	0.01~100/Am p·hr	1.8~1.05
C	CREN [4]	C on Cu black	0.95
Center part of DLC	CREN [6]	liner extracted from the SPS after 2 MD runs	1.45
DLC	KEK [3]	At 500 eV incident electron	1.2
HOPG	CREN [4]	freshly cleaved	1.25
		1 week air exp. in polymer box	1.30

Diamond-Like Carbon (DLC)

Diamond-like Carbon (DLC) coatings were used to avoid noise due to scattered light from the surface of tubes, without increasing outgassing rate [11]. In addition, CERN also studied the performance of DLC coating which shows a less effective reduction of the EC (electron cloud) current than a-C [6]. The peak SEY of DLC coatings tested by various organizations are shown in Table 2.

Graphene Films

The SEY of 6~8 graphene films with copper substrate were investigated by NSRL (National Synchrotron Radiation Laboratory) vacuum group. As shown in Fig. 1, the SEY$_{max}$ of 6~8 graphene films is 1.25. And the SEY$_{max}$ of Cu is 1.57. Therefore, graphene film coatings can reduce the SEY$_{max}$ of Cu. Due to the limitation of graphene preparation technology, the preparation process of graphene film on the inner face of beam pipes remains to be explored.

Graphene film has a stable physical properties and low secondary electron yield. Also, with the development of graphene preparation processes and technologies, graphene film with a number of layers may be implemented in the accelerator vacuum chamber to solve the problems related to electron cloud effect for future accelerators.

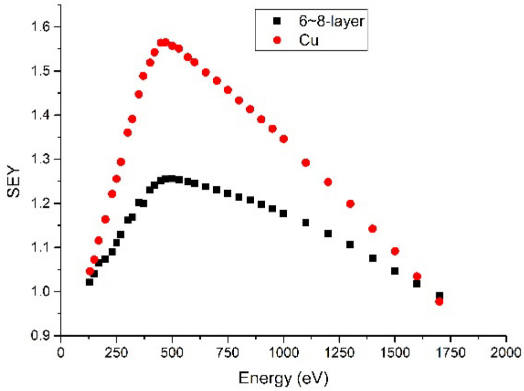

Figure 1: SEY curves of 6~8 layers graphene films with copper substrate and copper.

Laser Induced Micro/Nano Surface Structure

Reza Valizadeh et al. [12] proposed laser induced micro/nano surface structure (LIMSS) technology to obtain low SEY materials. The results show that LIMSS technology reduces the SEY of the copper, aluminium, and stainless steel to 1.12, 1.45, and 1.12, respectively. When the electron dose per unit is between 3.5×10^{-3} and 2.0×10^{-2} C•mm^{-2} and the electron energy is 500 eV, the δ_{max} further reduced to 0.76–0.78.

Laser Induced Micro/Nano Surface Structure is a promising technique for SPPC. But, it still needs a lot of experiments to test and verify before application.

CONCLUSION

In short, for SPPC, low materials (SEY$_{max}$ <1.2) or other surface treatment techniques are still needed to be studied in the future.

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