EXPERIMENTAL EFFORTS AT LNF TO REDUCE SECONDARY ELECTRON YIELD IN PARTICLE ACCELERATORS

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Abstract

A common effort in most accelerator centres is to develop new technologies to produce and test beam pipe inner walls of particle accelerators with an as low as possible Secondary Electron Yield (SEY). This item, in fact, is crucial in controlling Electron Cloud formation and in reducing its effects that are well known to be a potential bottle-neck to the performances obtainable from present and future accelerators. Frascati has a longstanding experience in qualifying materials in terms of surface parameters of interest to e-cloud issues. We are routinely measuring SEY, its dependence from electron energy, temperature and scrubbing. We are about to be ready to study not only the Photo Electron Yield (PEY), but more importantly, to characterize in situ the surface chemical composition and eventual modifications occurring during electron or photon irradiation by using synchrotron radiation beamlines in construction at DAΦNE. Our experimental measurements of the relevant parameters can be also confidently compared to simulations, performed by running the EC codes, in order to elucidate the final consequences on machine performances. Such a combined characterization effort is also suggesting ways to produce low SEY materials coatings. This issue is particularly important in view of the possible construction in Italy of a Super-B high luminosity collider [1], where e-cloud issues are foreseen to be a potential bottleneck to operational machine performances.

INTRODUCTION

In accelerator rings beamlines with positively charged beams, an electron cloud [2] may be initially generated by photoelectrons or ionization of residual gas and increased by the surface secondary emission process. If an electron cloud (EC) forms, it may couple with the circulating beam and cause beam instabilities, tune shift, and vacuum pressure rise, ultimately affecting the machine performances. Electron cloud detrimental effects have been observed at many storage rings [3] and are expected to be a serious issue for future machines like ILC-DR and Super-B.

EC build-up and evolution depend strongly on the surface properties of the accelerator walls such as Secondary Electron Yield (SEY), defined as the number of emitted electrons per incident electron and commonly denoted by δ. Generally for metal surfaces used in accelerators, the value of SEY ranges from 1 to 3 in the 0-500 eV energy range, and reaches a maximum (δ_{max}) around 200 eV. The SEY of technical surface materials for accelerator vacuum chambers has been extensively measured in the past years at CERN [4, 5], KEK [6, 7], SLAC [8, 9, 10] and other laboratories [11].

A low SEY is essential for the operation of particle accelerators, since their design luminosity and performances relies on a SEY value of about 1.3 or less. Clearly, an industrial surface with such a low yield should be stable in time and during operation, and have the necessary requirements in terms of vacuum compatibility, impedance, surface resistance, etc.. Up to now, unfortunately the significant effort done by many laboratories to find suitable surface coatings or systems, has not yet given satisfactory and conclusive results. LHC, for instance, does not count on a specific low yield material coating but on the experimental evidence that the SEY of the chosen Cu surface is strongly reduced by surface conditioning during initial operations (or commissioning). In this framework, the understanding of the conditioning process is needed to predict the conditioning time and beam parameters required to reach accelerator design performances. To this scope we have measured SEY reduction (scrubbing) not only versus the dose (the number of impinging electrons per unit area on sample surfaces) of the impinging electrons, but also versus their energy, with special attention to low energy primary electrons (<50 eV) which have been recently shown to have peculiar behavior in terms of reflectivity [4]. Such studies, performed on Cu prototype of the beam screen adopted for the Large Hadron Collider (LHC), have shown that scrubbing efficiency depends not only on the dose but also on the energy of incident electron beams [12,13].

So, while it is clear that scrubbing is one possible solution to obtain low SEY beam pipe accelerators, it seems very useful to study the actual chemical phenomena occurring at the real surfaces and causing the observed SEY reduction. Such careful surface analysis can not only clarify some important functional aspects related to the scrubbing process, but also can individuate new strategies in producing stable low SEY materials.

In this context Surface science techniques and synchrotron radiation spectroscopies are ideal tools to perform “in situ” characterization of the chemical composition of a relevant surface material and its eventual modifications occurring during electron or photon irradiation. To convince ourselves that such research line could indeed give significant insight to the scrubbing

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process itself, before having access to the XUV beamlines in construction at DAΦNE [14] we performed preliminary experiments at Elettra focussing on the relation between the SEY and the surface condition of representative LHC samples. We correlate the SEY reduction obtained by electron bombardment with the surface chemical composition by using photoemission spectroscopy. Such characterization suggests also ways to produce low SEY materials.

EXPERIMENTAL

The measurements were performed at the BEAR beamline at ELETTRA in Trieste. This is a bending magnet beamline, which can provide a monochromatic beam with energies ranging from 3 to 1600 eV with a resolving power between 2200 and 5800 [15], and a white light with a spectral distribution similar to that of LHC. The actual energy resolution in our experiments was about 100 meV at 300 eV, this value being experimentally derived by measuring the exciton line-width at the C K edge on a diamond sample.

The experimental station has been described elsewhere [16]. Briefly, the UHV analysis chamber is equipped with a 6-degrees freedom manipulator, covering both the entire azimuth and polar angle ranges, with an angle resolution better that 1/100 degree.

The samples studied, co-laminated Cu for the LHC beam screen, were introduced into the measurement chamber without any treatment and characterized by photoemission and absorption spectroscopies. It was necessary to polarize the sample to a negative bias voltage since the transmission function of the CMA, used for the photoemission measurements is not constant at low energies. The bias voltage was chosen as that voltage that maximizes the transmission function of the CMA at low energies.

Absorption measurements were performed in the total electron yield (TEY) mode. As the radiation impinges on the sample, the absorption spectra are given by the ratio between current intensity flowed through the sample and the current intensity of a W mesh monitoring the radiation flux.

The SEY (δ) is determined from: $\delta = I_e/I_0 = (I_0 - I_S)/I_0$ where I_e is the current due to electrons emitted by the sample; I_0 is the impinging electron current and I_s is the drain current measured from sample to ground, both measured with a Keithley picoammeter.

The SEY has been measured before and after the irradiation with a source of electrons made of a filament with barium oxide, which being not collimated, allows a more uniform bombardment on a larger zone of the sample surface and can provide a large current on the sample. During the bombardment the filament was biased at –390 V and the sample at + 50 eV, in order to collect the total amount of electrons emitted by the filament. Therefore the electrons hit the sample with an energy of 440 eV. Electron dose is determined from: $D=Q/A=I_0t/A$, where Q is the total charge incident per unit area on sample surface, I_0 is the impinging beam current and t is time period for which the sample was exposed to the beam. Unit chosen here for dose are Cmm^{-2}. All SEY and doses have been performed at normal incidence.

RESULTS AND DISCUSSION

In Fig. 1 we present the overview photoemission spectra measured on the LHC sample before (as received sample) and after the electron bombardment. These spectra have been acquired with a photon of energy 650 eV.

The as received sample was conditioned with a dose of $10\mathrm{mCmm}^{-2}$ at the energy of 440 eV. As it was shown in previous papers [12, 13], this electron dose is sufficient to reduce the maximum value of SEY yield, δ_{max}, from 2.1 to ~1.1 (not shown).

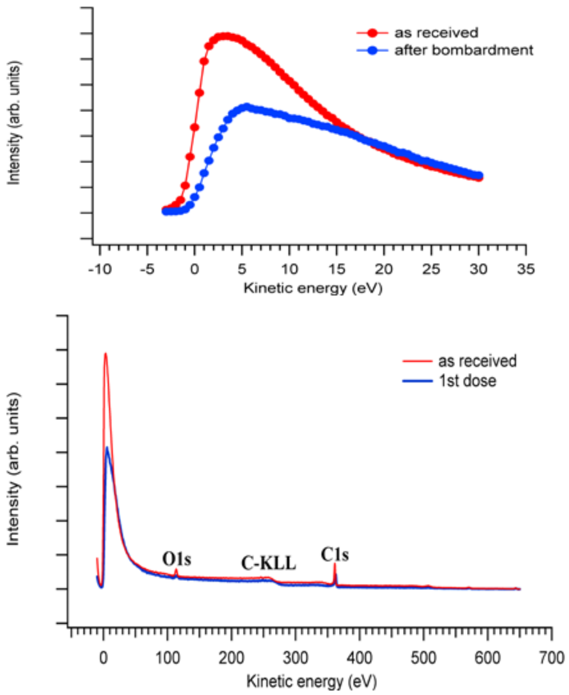

Figure 1: Top: Photoemission overview spectra of the sample (as received) and after electron bombardment. Bottom: peak of secondary electrons before and after the bombardment with electrons.

In the photoemission spectra we can distinguish the high peak of secondary electrons, centered at 3 eV, the O1s core level peak due to oxygen atoms at the kinetic energy of ~ 110 eV (labelled with A), and the broad KLL Auger line at the kinetic energy of ~ 258 eV (labelled with B) and the C1s core level peak at the kinetic energy of ~ 358 eV (labelled with C) due to C atoms.

It is clear that electron irradiation causes a decrease of the secondary electron peak, as better evidenced in the bottom side of Fig.1. This reduction is due to the chemical modification induced by electron bombardment on the surface of the sample.

In order to better observe the changes in the contaminants induced by electron bombardment, Fig. 2 shows the O1s and C1s spectra measured at higher energy resolution. The behavior of these peaks shows that there is not only a pure reduction of the intensities due to the cleaning of incident electrons, but there is also a changing in the chemical state of these contaminants. This is particularly evident in the case of carbon, whose C1s peak after the exposure to the electron beam is shifted toward higher kinetic energies, indicating that the carbon impurities (mainly hydrocarbons) have changed to graphitic carbon.

The chemical changes induced by the electron bombardment are also reflected by the absorption spectra taken on the oxygen and carbon K-edges, reported in Fig.3. The absorption spectrum of the oxygen shows only a reduction of signal, but not great changes in the shape. This suggests that the electron bombardment causes some oxygen desorption from the sample surface but does not significantly modify its chemical environment. Modifications of the C K-edge are more evident. Very important is to note the increase of the peak at 285 eV: this feature is generally considered a strong fingerprint of the formation of π bonds between carbon atoms, hence suggests a transition to a flat rearrangement of carbon atoms on the substrate surface. This is a clear signal of a graphitization of the carbon on the surface.

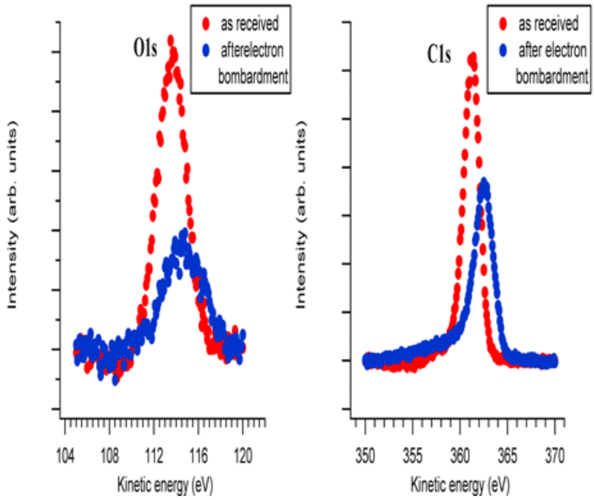

Figure 2: O1s (left) and C1s (right) core level spectra measured before and after electron bombardment.

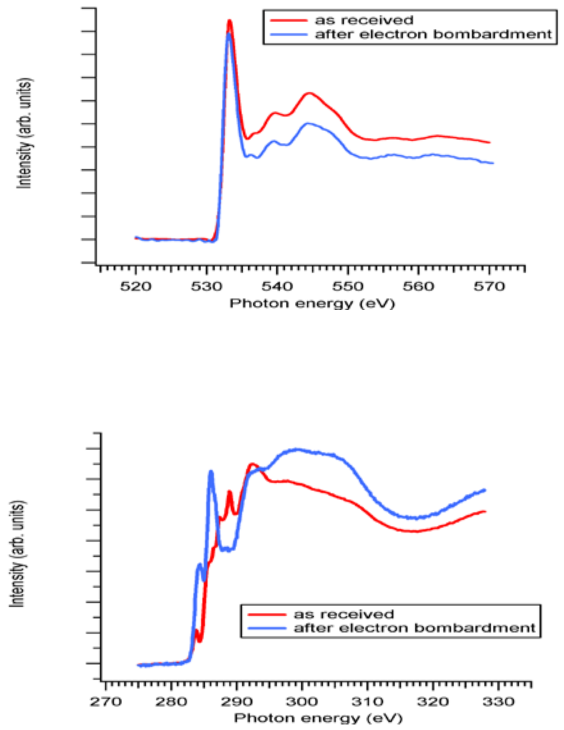

Figure 3: Absorption spectra measured at the K-edges of oxygen (top) and carbon (bottom).

Both photoemission and absorption measurements confirm that the electron bombardment results in the graphitization of the carbon impurities on the copper surface. At the same time, δ_{Max} of SEY curves (not shown) [12, 13], decreases to ~1.1 after the electron doses. Similarly, graphitization and decrease in SEY were also observed in other materials [17] after the irradiation with primary electron beams of 5 keV [7, 9]. Thus we conclude that the electron beam-induced graphitization results in the decrease of the SEY.

These results show that the SEY reduction can be confidently associated to the formation, on the surface, of a graphitic layer and suggest new researches directed to develop novel technologies to produce and test innovative materials, such as graphitic coatings, with low intrinsic SEY to be used in accelerators to mimic what is actually happening during scrubbing. This line is also consistent with carbon coatings techniques under development at CERN and in other Laboratories. Such Carbon coatings may allow to suppress e-cloud effects down to comfortable levels. Some experimental efforts are already undergoing at LNF and in other accelerator centres like CERN, SLAC, CESR-TA and KEK-B and will be subject of future publications.

CONCLUSION

We report preliminary experimental results on the relation between the surface properties of LHC samples conditioned with a dose of electrons at 440 eV and the reduction of SEY. Photoemission and absorption measurements performed on samples before (as received) and after electron irradiation, confirm that the electron bombardment results in the graphitization of the carbon impurities on the copper surface. As a consequence of this chemical modification we observe a SEY decreasing to 1.1. This opens up the possibility of producing stable graphite films to lower SEY values of industrial materials to the desired values.

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