THE VARIATION OF THE SECONDARY ELECTRON YIELD AND OF THE DESORPTION YIELD OF COPPER UNDER ELECTRON BOMBARDMENT: ORIGIN AND IMPACT ON THE CONDITIONING OF THE LHC

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Abstract

The operation of most radio-frequency components in accelerators rely on the conditioning obtained usually by gradually increasing the power fed into these devices. This effect is related to the reduction of the desorption yields and of the secondary electron yields of surfaces exposed to electron bombardment. In LHC, similar decreases will also limit the detrimental consequences of the electron cloud phenomenon on the beam stability, the power deposited in the cryogenic system and the gas density. The parallel evolution of the desorption yield and of the secondary electron yield will be discussed and compared to the changes to the surface composition as observed by surface analytical techniques. The possible origin of the secondary electron yield decrease will also be discussed at the light of these new results.

1 INTRODUCTION

In modern vacuum systems, the interaction of energetic particles with solid surfaces is playing an increasing role. This is related to the growing presence of charged particles necessary to carry out numerous processes like sputtering for thin film deposition, implantation for the modification of chemical compositions, or e.g. Auger or SIMS methods for chemical analysis. In high energy accelerators this type of interaction is responsible for the ion induced pressure instability in proton storage rings[1] and for the photon induced desorption which is the most important gas source in electron-positron storage rings [2]. Apart from the desorption of gas, the impact of energetic particles on surfaces stimulates also the emission of charged particles, the most numerous one being electrons. These electrons, in the presence of electromagnetic fields, can multiply if appropriate conditions on the geometry of the system, the frequency of the field and the secondary electron yield (S.E.Y.) of the surface are fulfilled. This detrimental effect is known as multipacting and is commonly encountered in RF devices. More recently such an effect developed in the CERN SPS [3] when the first LHC type beams were injected. It has been called "e^- cloud effect" and results in a large gas desorption and in an alteration of the emittance of the proton beam. Apart from the gas desorption induced by the electronic bombardment of surfaces and the subsequent reduction of the desorption yields, it has been shown [4] that this e^- bombardment produces also an important decrease of the S.E.Y. These phenomena are frequently used in accelerators to operate radio frequency devices and are known under the generic term of "conditioning". Such conditioning will be required to achieve the operation under nominal conditions of the LHC and of its injector the SPS. In an attempt to provide the necessary data to evaluate the time needed to obtain conditioning and to judge, during the running in of the accelerators, the degree of conditioning achieved, measurements will be presented relating the desorption properties and the electron emission of copper surfaces. Furthermore, as the origin of this important effect is not yet completely understood, surface investigations will be shown which could contribute to elucidate the origin of conditioning in accelerators.

2 MODIFICATIONS INTRODUCED BY THE ELECTRON BOMBARDMENT OF A COPPER SURFACE

Before investigations, the copper surfaces are cleaned by immersion in an alkaline detergent (NGL Cleaning Technology 17.40) followed by rinsing in demineralised water and ethanol.

The bombardment of a copper surface by electrons with an energy of a few hundreds of electron volts, leads to a decrease of the S.E.Y. [5] as can be seen from the figure 1. These curves were reproducibly obtained in

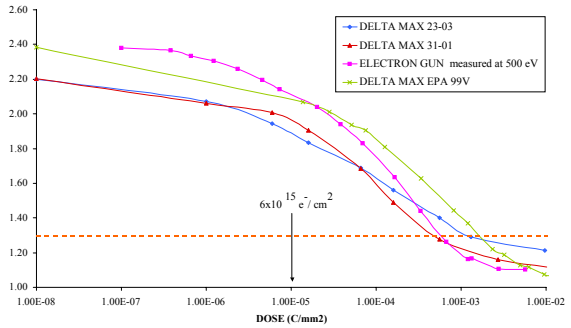


Figure 1: The variation of the secondary electron yield with the incident electron dose

different systems, using various types of electron sources. For example, the curve labelled EPA 99V was obtained using as primary electrons, photoelectrons, accelerated towards a biased sample i.e. without any heated filaments

for the generation of electrons. After the impact of an electron dose equivalent to some 10^{-6} C/mm^2 ($7x10^{14}$ e$^-$.cm^{-2}) , the S.E.Y. starts to decrease and reaches, after the accumulation of 1 mC.mm^{-2}, a value lower than 1.3 secondary electrons per primary electron. In parallel to this decrease of the S.E.Y., the desorption yield decreases by several orders of magnitude as can be seen in figure 2 where both the decrease of the electron induced desorption yield (E.D.Y.), normalised to one for the initial value and of the normalised S.E.Y. are plotted versus the

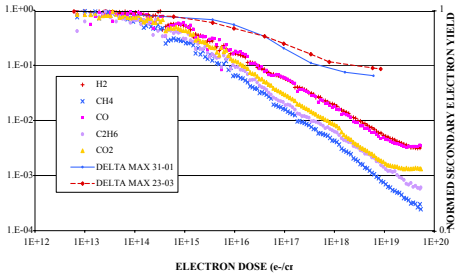
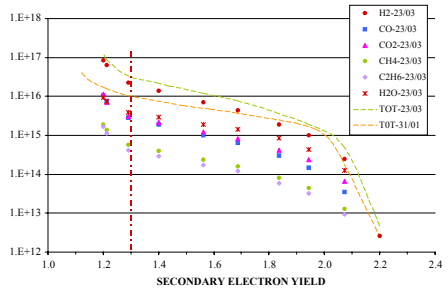


Figure 2 : The evolution of the normalised desorption yield and of the normalised secondary electron yield with the electron dose

electron dose. These curves demonstrate that the decrease of the E.D.Y. starts at a smaller dose (approximately 10^{14} e$^-$.cm^{-2}) than the decrease of the S.E.Y. Furthermore the desorbed gas composition changes with the dose: CO_2 E.D.Y. decreasing at a faster rate than the one of CO and H_2. After an electron dose of 10^{18} e$^-$. cm^{-2}, the S.E.Y. reaches its minimum while the E.D.Y. continue to decrease by at least an order of magnitude.

3 RELATION BETWEEN DESORPTION YIELD AND SECONDARY ELECTRON YIELD

These measurements also allow establishing relations between the amount of molecules desorbed from the bombarded surface and the decrease of the E.D.Y. and S.E.Y. In order to predict for the operation of the LHC, the amount of gas desorbed during the conditioning period, it is possible to use the preceding measurements to evaluate the total number of molecules desorbed to achieve a given S.E.Y. This is shown in figure 3 where the quantity of the various desorbed gases is plotted as a function of the S.E.Y. achieved during conditioning. During two separate experiments the total amount of gas released to obtain a S.E.Y. of 1.3 was greater than 10



monolayers, hydrogen being the most abundant gas released (~20 monolayers) followed by H_2O, CO and CO_2 (some monolayers). Hydrocarbon species are also released mainly in the form of CH_4, C_2H_6 (less than one monolayer).

Figure 3 : The amount of various gases released during the conditioning of an as received copper surface

As the pressure is a routinely measured quantity in accelerators it is useful to establish an analytical formula relating the E.D.Y. and hence the pressure to the S.E.Y. Using the data collected during two sets of experiments, the fit formulae given in the figure 4 were obtained. This graph confirms the initially slow variation of the S.E.Y.

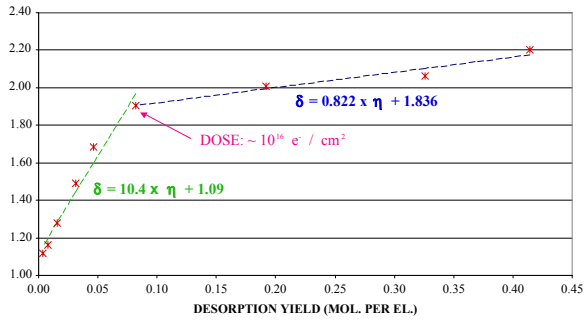


Figure 4 : The variation of the secondary electron yield (δ). versus the desorption yield (η) and the corresponding analytical expressions

against the E.D.Y. up to a value corresponding to a dose of 10^{16} e$^-$.cm^{-2}. At that dose (E.D.Y. lower than 0.1 mol./e$^-$), the S.E.Y. decreases at a faster rate to its residual value (lower than 1.3) reached for a desorption yield lower than 0.01 mol./e$^-$

4 MODIFICATION OF SURFACE COMPOSITION AND CONDITIONING EFFECT

It has been shown that the decrease of the S.E.Y. during an electron bombardment is a phenomenon accompanied by a large release of gas due to electron induced desorption. It is hence tempting to attribute this effect to the cleaning of the surface related to the electron stimulated desorption. Nevertheless experiments have shown that the S.E.Y. obtained after electron bombardment (here ~1.2) is smaller than the one obtained on a clean (in-situ glow discharge cleaned) copper sample (1.4) as can be seen on the figure 5 (curve marked with crosses). Furthermore if a fully conditioned sample (S.E.Y. ~ 1.2, curve marked with triangle) is exposed to an ion bombardment of increasing dose, the S.E.Y. increases from its original value to a value corresponding to the clean copper value (1.4) after an argon ion dose of $4x10^{17}$ ions.cm^{-2}. It is hence difficult to attribute all the effect to a simple cleaning of the copper surface.

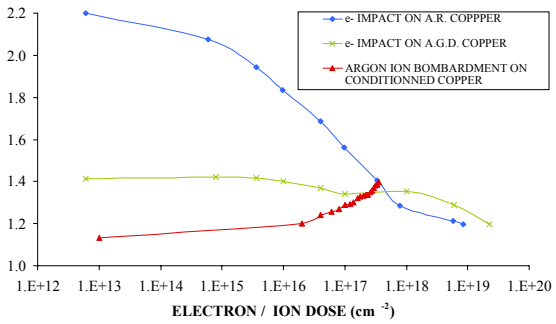


Figure 5: The variation of the secondary electron yield after ion/electron bombardment

To investigate further the origin of this effect, a copper sample has been investigated in a scanning Auger system[6]. The variation of various Auger peaks, characteristic of the copper surface have been recorded as a function of the electron dose delivered to the surface. They are shown on the figure 6. For small electron dose, the copper peak increases and the carbon and the oxygen peaks decrease, indicating a cleaning of the copper surface. These variations correspond to the release of the gas desorbed by the electron beam, as presented in the figure 2, the most abundant gas in the desorbed species: hydrogen, being impossible to detect with the Auger

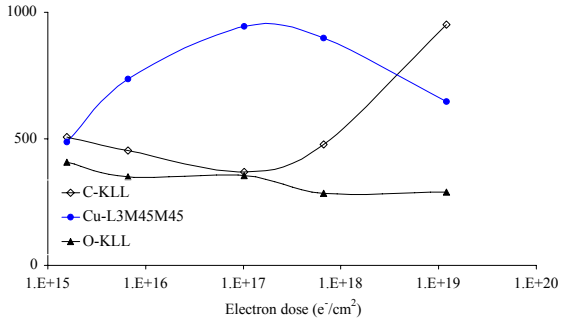


Figure 6 : Carbon (C-KLL), oxygen (O-KLL) and copper (Cu, $L_3M_{45}M_{45}$) Auger peak intensity on chemically cleaned copper as a function of the electron dose

method. For an electron dose close to 10^{-4} C/ mm^2 i.e. ($6.6x10^{16}$ e$^-$.cm^{-2}), the copper peak decreases and there is a marked increase of the carbon peak. This dose corresponds approximately to the dose at which the S.E.Y. reaches its minimum. In order to determine the origin of the carbon, experiments have been carried out under various partial pressure of carbon containing gases (CH_4, CO). For experimental reasons the data were obtained on samples with different initial preparations. It was shown that the composition of the residual gas does not change the different initial S.E.Y. The results are illustrated in figure 7. They show that neither the dose at which the S.E.Y. changes nor the ultimate S.E.Y. obtained are affected by changes of 4 orders of magnitude in the carbon concentration of the residual gas. Similar results have been published in [7]. The origin of the carbon present on the surface in the fully conditioned state is hence independent of the CH_4 and CO partial

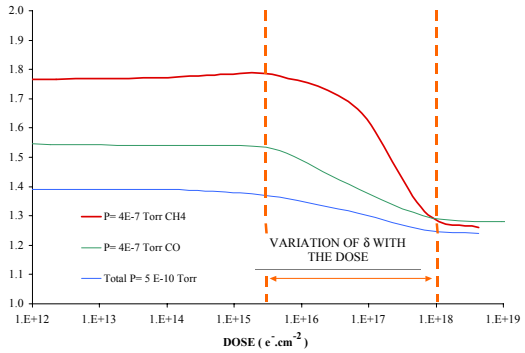


Figure 7: The variation of the S.E.Y. with the electron dose for various residual gas composition

pressure. The fact that the dose dependence of the S.E.Y. has been recorded in various vacuum systems equipped with totally different electron production mechanism (see for example figure 1) seems to indicate that the carbon necessary to the formation of a carbonaceous layer reducing the S.E.Y. below the value measured for clean copper is not coming from the residual gas but from the material itself.

5 CONCLUSION

The variation of the S.E.Y. with the bombarding electron dose is a process explaining the conditioning of devices affected by multipacting in accelerators. The origin of this process it linked in a first stage to the cleaning of the surface as indicated by the large decrease of the desorption yields and the increase of the copper peak in the Auger spectra. After this initial decrease, a further reduction (above an electron dose of $7x10^{16}$ e$^-$.cm^{-2}) seems to be linked to the formation of a carbonaceous layer as indicated by the carbon peak increase on the Auger spectrum. This effect has proven now to be effective in large room temperature systems like the SPS to reduce the density of the electron cloud and to reach the LHC nominal operation conditions in this accelerator.

6 REFERENCES

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