ELECTRON ENERGY DEPENDENCE OF SCRUBBING EFFICIENCY TO MITIGATE E-CLOUD FORMATION IN ACCELERATORS

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Abstract

Recently built and planned accelerators, base their ability to reach design parameters, on the capability to reduce Secondary Electron Yield (SEY) during commissioning, hence mitigating the potentially detrimental effects of e-cloud driven machine limitations. This SEY reduction (called “scrubbing”) is due to the fact that the electrons of the cloud, hit the vacuum chamber wall, modifying its surface properties and reducing its SEY. This may minimize any disturbing effects of the c-cloud to the beam. “Scrubbing” has been studied in laboratory experiments as a function of impinging electron dose only by bombarding surfaces with 300-500 eV electrons, but no scrubbing dependence on the bombarding electron energy has ever been discussed. The actual energy of electrons of the cloud hitting the wall in real accelerators has never been measured accurately, while simulations predict very low electron energies (<50 eV). For this reason and given the peculiar behaviour observed for low energy electrons [1] we decided to study this dependence accurately. Here we present some preliminary results calling for a more intense experimental effort to clarify the role of electron energy and scrubbing efficiency and their eventual implications to machine commissioning procedures.

INTRODUCTION

During operation, the internal walls of modern particle accelerators are subjected to Syncrotron radiation irradiation and/or electrons bombardment [2]. Such phenomena do affect the surface properties such as the secondary electron yield, SEY, i.e. the number of emitted electrons per incident electron. The reduction of the SEY is advantageous for the operation of particle accelerators and it is called surface conditioning or beam scrubbing [3,4]. In fact the design luminosity of present and future particle accelerators such as the Large Hadron Collider (LHC), can only be achieved if the SEY of the beam vacuum walls is strongly reduced by surface conditioning during its initial operations or commissioning, hence mitigating the potentially detrimental effects of e-cloud instabilities. The understanding of the conditioning process may therefore help to optimise the conditioning required to reach the LHC design parameters.

Surface scrubbing can be studied in various ways [5,6], for instance by measuring the electron dose dependence of SEY yield. All the available experiments found in literature have been performed by bombarding technological metal surfaces with electron beams of fixed energy as 300-500 eV[1,7-9] and 2.5 keV[10,11]. These experiments showed that even after a low electron exposure of about 10^{-6} C·mm^{-2} the SEY of technological surfaces starts to decrease significantly, reaching its lowest value after about 10^{-2} C·mm^{-2}. By measuring the amount of molecules desorbed from bombarded surfaces [8] and by monitoring the variation of Carbon Auger peak intensity as function of electron dose with Auger Spectroscopy, the origin of SEY reduction versus dose is explained as a two steps process, involving a surface cleaning caused by primary beams and an accumulation of carbonaceous species coming probably from the material itself [10,11].

Despite these investigations are useful to elucidate the origin of conditioning in accelerators, they are not complete and other studies are required to clarify the scrubbing dependence on the bombarding electron energy since this parameter is missing. Furthermore the actual energy of the electron of the cloud (EC) hitting the walls in real accelerators has never been measured accurately, while simulations, which study EC formation and evolution, predict very low electron energies (<50 eV)[12]. For this reason and given the peculiar behaviour observed for low energy electrons [1], we decided to study this dependence accurately. In this contribution we present some preliminary results obtained bombarding surfaces of the actual Cu sample used in the LHC beam screen with electron beam in the range of primary energies 20-500 eV. Our measurements seem to show that scrubbing efficiency depends on the impinging energy of the electron beams. Such results, if confirmed by further experiments performed by bombarding with electrons of energy even lower than 20eV, could have significant implications to machine commissioning procedures.

EXPERIMENTAL

The experiments were performed in a UHV μ-metal chamber with less than 5mGauss residual magnetic field at the sample position, pumped by a CTI8 cryo-pump to ensure a vacuum better than 10^{-10} Torr after bake-out. Ion pumps are not used due to their detrimental stray magnetic field, which can be a serious problem when dealing with very low energy electrons.

The sample is mounted on a close cycle Sumitomo cold finger manipulator specially designed to obtain a stable temperature on the sample between 8 and 400 K. The data here shown were performed at room temperature. The samples studied were all part of the final production of co-laminated Cu for LHC beam screen, hence are representative for the real surface “seen” by the proton

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beam in the machine. The electron beam was set to be smaller than 0.25 mm ^{2} in transverse cross-sectional area and stable in current for energies between 10 and 500 eV, as confirmed by a line profile and by stability tests done using a homemade 1 mm slot Faraday cup. Unfortunately it has been observed that the beam move slightly in position during energy scans, forcing us to manually irradiate with the same doses the neighbouring areas of the sample around the measuring spot. Such rastering procedure, although time consuming, ensure that the SEY measurements were done on a uniformly irradiated area for every bombarding electron energy. To measure low-energy impinging primary electrons, a negative bias voltage was applied on the sample. Such bias allows us to work at very low primary energy (close to zero eV) while keeping the gun in a region where it is stable and focused. Our set-up has been chosen among different bias and geometrical conditions to guarantee the absence of any spurious effects on the measured data caused by the possible presence of electric field lines induced by the sample bias.

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 as measured by a positively biased Farday cup (75V). I_s is the drain current measured from sample to ground (applying on it a negative bias voltage –75V) with a Keithley picoammeter. I_0 was set to be as low as possible (about few nA at 500eV) to avoid giving any significant scrubbing dose during SEY measurements. 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 imping beam current (generally of few μA while dosing the sample) and t is time period for which the sample was exposed to the beam. The area is determined assuming that the electron beam hits the surface sample with a circular spot. Unit chosen here for dose are Cmm^{-2}. All SEY and doses have been performed at normal incidence. Given some uncertainty on the irradiated spot and on the adopted rastering procedure doses have to be considered within 20% of their quoted values. The data acquisition system is a customized LABVIEW program which allows to scan beam energy from lowest to highest value and to acquire beam and sample current in order to calculate SEY.

RESULTS AND DISCUSSION

In fig. 1(a) and (b) we present the variation of SEY curves versus incident beam energy for a LHC sample type as a function of the electron dose. These curves are obtained bombarding the sample with an incident energy of 500 (a) and 50 eV (b) at normal incidence. The curves are consistent with those found in literature [1,9], showing respectively a maximum and a minimum value, which depend on the actual sample and on its conditions (temperature, scrubbing...).

In these curves it is clear that that secondary electron yield decreases with the increase of the electron dose for every primary impinging energy. After the impact of an electron dose equivalent to some 10-6 C.mm-2, δmax (the maximum value of the SEY) decreases until it stabilizes at a value close to 1.15 for doses greater than 1x10-3 C.mm-2, as indicated by the reference doted line.

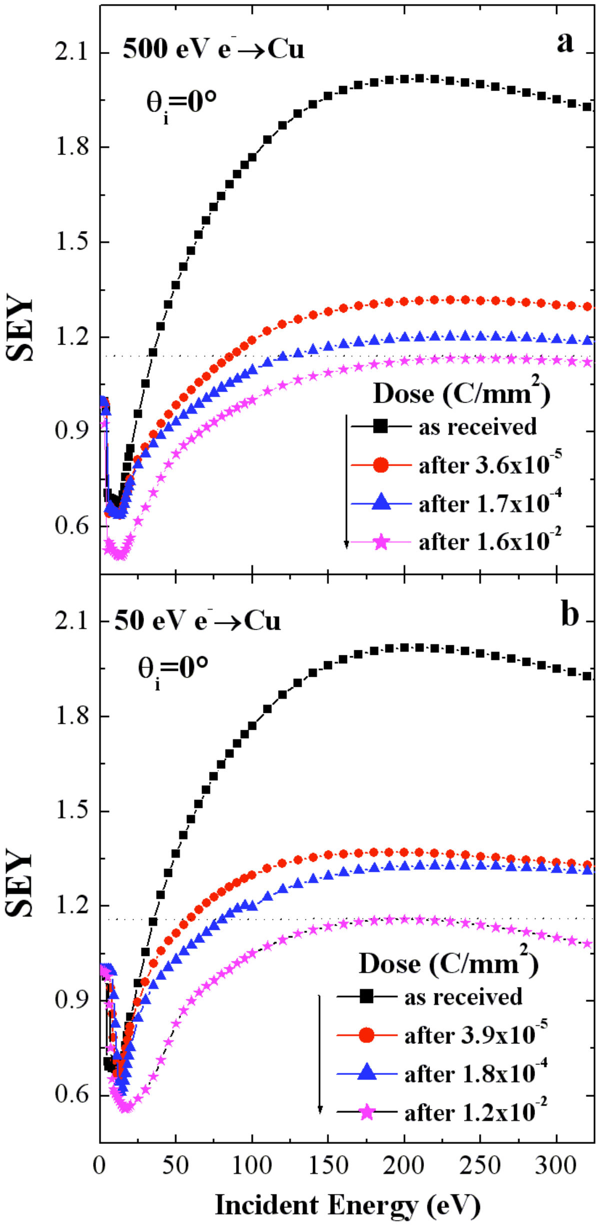

Figure 1: SEY measurements for 500 eV a), and 50 eV b) impinging electron energy at normal incidence

Furthermore the corresponding energy, E_{max}, shifts versus lower values with doses.

The behaviour of the SEY curves at low primary energy (<30 eV) is largely independent of δ_{max} and of the degree of scrubbing, showing a SEY value close to unity in all cases, which is consistent with previous experimental studies [1].

Fig 2 shows the behaviour of δ_{max} as a function of the electron dose for various measurements performed using different primary electron energies. The curve obtained while conditioning the sample with 500 eV has been

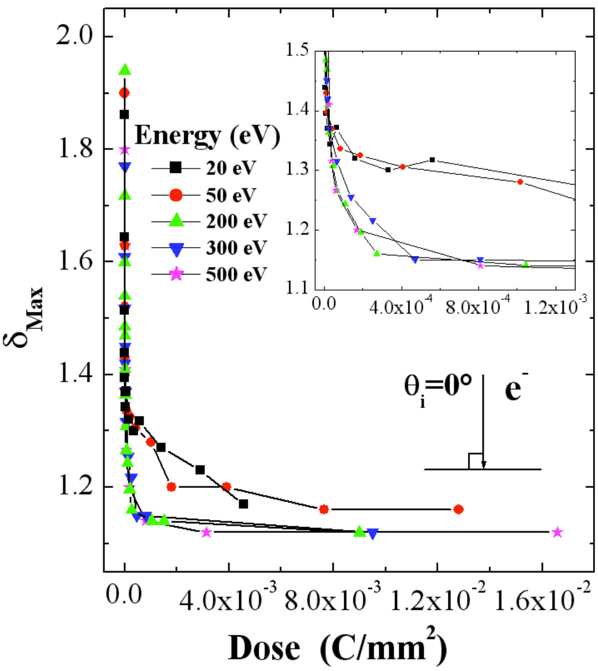

Figure 2: δ_{max} versus dose for different impinging electron energies at normal incidence.

performed for reference to various works reported in literature [8].

Our measures show that an electron dose, between $8\text{x}10^{-4}$ and $2\text{x}10^{-3}$ Cmm^{-2} is required to reach a SEY lower than 1.3, while the minimum of the SEY (close to 1.15) is obtained for an electron dose close to 10^{-2} $\text{C}\cdot\text{mm}^{-2}$ (fully conditioned sample). These measures agree well with available results from the literature [1,8,11]. We notice also that when sample is conditioned with an incident energy of 200 eV and 300 eV, the reduction of δ_{max} versus electron dose is similar to 500 eV electron bombardment. As shown in the inset of fig.2, the situation is different for samples conditioned with primary electron energies of 50 and 20 eV. In those cases one can observe that the δ_{max} reduction versus incident dose proceeds with a much slower rate with respect to 200-500 eV. In addition the final value of δ_{max} obtained at the dose of 10^{-2} Cmm^{-2} is different. These measurements have been reproduced on different Cu beam screen samples showing that the conditioning behaviour does not depend on the slightly different initial condition of the sample (i.e. δ_{max} on “as received” samples). This difference in efficiency with respect to electron energy is consistent with experiments performed in EPA at CERN while conditioning a copper sample with photoelectrons with energies between 100 and 820 eV [5,13].

Our measure seems to indicate that the efficiency of scrubbing depend on the energy of the irradiating beams. Therefore the time required to obtain a fully scrubbed surface is consequently different especially when low energy electron beams are considered. These new information need further investigation especially at very low impinging electron energies, and might be useful in evaluating the impact of electron cloud in large accelerators in order to improve both the commissioning procedures and the input parameters of simulations.

CONCLUSION

We reported new experimental results obtained by bombarding a LHC type samples with primary electron beams of different energies. Our data show that scrubbing efficiency depends on the energy of irradiating beams. Further studies, exploring in details the peculiar behaviour of impinging electrons of very low energy (<20 eV) could have significant implications to machine commissioning procedures.

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