SEY OF AL SAMPLES FROM THE DIPOLE CHAMBER OF PETRA III AT DESY

D.R. Grosso, M. Commisso, and R. Cimino#, LNF-INFN, Frascati Italy,
R. Flammini, CNR-IMIP, Monterotondo, Italy,
R. Larciprete, CNR-ISC, Rome, Italy,
R. Wanzenberg, DESY, Hamburg, Germany

Abstract

At the synchrotron radiation facility PETRA III, tune spectra have been measured with some characteristics which are typically observed at other storage rings in connection with electron cloud effects. For some bunch filling patterns, an increase of the vertical emittance has been observed. To estimate such effects with the available e-cloud simulation codes, the detailed knowledge of the SEY (Secondary Electron Yield) of the Al chamber is required. To the purpose, representative PETRA III Al samples were studied in detail at the INFN-LNF Surface Science Laboratory. XPS (X-ray photoelectron spectroscopy) and SEY measurements were performed as a function of electron conditioning. The SEY of the "as received" samples shows a value of δ_{max} = 2.8 at E_{max}=300 eV. Surface bombardment with electrons (scrubbing) of 500 eV kinetic energy, reduces the SEY to values between δ_{max} = 1.8 to 1.5 (depending on the actual sample analyzed), with, respectively, E_{max}=325 to 250 eV. The XPS characterization of the sample surface shows clearly that the SEY variation is closely related to the amount of oxygen present on the surface.

INTRODUCTION

At DESY the PETRA ring has been converted into a synchrotron radiation facility, called PETRA III [1]. The main design parameters are summarized in Table 1. The commissioning with beam started in April 2009, and regular operation for users started in summer 2010 [2]. PETRA III is presently running in a top up operation mode with positrons since PETRA III is sharing the same preaccelerator chain with the light source DORIS, which is running with positrons to avoid problems with ionized dust particles. For the operation mode with a large number of bunches and a short bunch to bunch distance (8 ns) a vertical emittance growth has been first observed in May 2010. Furthermore, tune spectra have been measured with some characteristics which are typically observed at other storage rings in connection with electron cloud effects. A summary of the measurements and results from simulations of electron cloud build-up are given in Ref. [3]. In 2010 two filling schemes with 40x4 and 60x4 bunches were established for user operation, see Fig. 1, which showed no emittance growth with a total beam current of 100 mA. Already in 2010 there was an indication that there is some conditioning effect which allows using filling schemes with smaller bunch to bunch spacing without a vertical emittance growth. In 2011 it was possible to use a filling scheme with 240 equidistant bunches and a bunch to bunch spacing of 32 ns for user operation, see Fig. 1.

Table 1: PETRA III design parameters

Parameter	PETRA III	
Energy / GeV	6	
Circumference /m	2304	
Emittance (horz. / vert.) /nm	1 / 0.01	
Bunch length / mm	12	
Total current / mA	100	
Number of bunches	960	40
Bunch population / 10^{10}	0.25	12
Bunch separation / ns	8	192

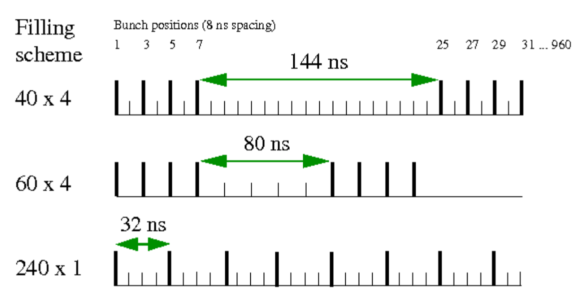

Figure 1: Bunch filling schemes of PETRA III.

The integrated beam current has increased from about 133 Ah on May 1, 2010 to 577 Ah on May 1, 2011, see Fig. 2. The filling scheme with 40 x 4 bunches was used in May and June 2010 while the scheme with 60 x 4 bunches was used from Aug. to Dec. 2010, where the integrated current was about 230 Ah. After the winter shutdown 2010/11 it was possible to use the filling scheme with 240 equally filled bunches for regular user operation. This corresponds to an integrated current of more than 425 Ah.

In order to investigate the increase of the vertical emittance observed, e-cloud simulation codes are employed. These codes rely on some physical parameters, like the SEY (Secondary Electron Yield) value.

The SEY(δ) is defined as the number of the total emitted secondary electrons per incident electron. The SEY is important since it may strongly affect bunch stability and emittance conservation [4]. Its measured value can than be inserted in e-cloud simulation codes in order to test its impact on machine performances [3]. As an example, for the LHC (Large Hadron Collider) at CERN, a δ_{max} < 1.3 [4], is required to reach machine design parameters. Given the PETRA III machine performances reported in [2,3], an experimental measure of a representative surface of the real Al chamber used in the machine is indeed very important to understand the clear origin of the observed emittance growth. We also followed such representative Al sample simulating the machine operation, i.e. exposing them to electron scrubbing. Such data will be presented here, and discussed in relation with XPS measurements.

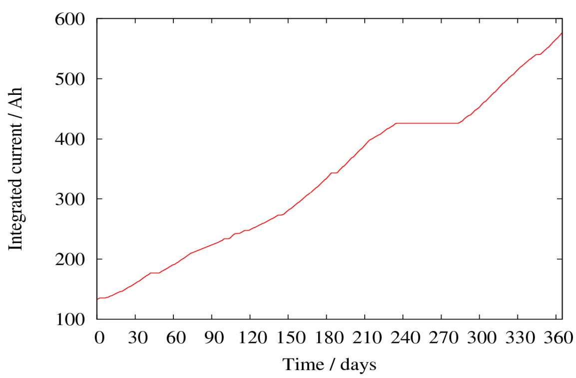

Figure 2: Integrated beam current of PETRA III during one year (May 1, 2010 to May 1, 2011).

EXPERIMENTAL

The data were acquired with a dedicated experimental apparatus which is described elsewhere [5]. Briefly, XPS and SEY measurements were performed at the INFN-LNF laboratory of Frascati (RM), under UHV conditions (base pressure between 2 10^{-9} and 2 10^{-10} mbar). The UHV system includes an XPS analysis chamber and a chamber for in-situ preparation of the samples. The two experimental chambers are UHV connected. Photoemission spectra were acquired with an Omicron EA125 electron analyzer. Non monochromatized Mg Kα photons (hv =1253.6 eV) were used to induce the photoemission. The SEY spectra were measured in normal incidence geometry and at room temperature. The full experimental set-up for the SEY measurements has been described elsewhere [6].

RESULTS AND DISCUSSION

Figure 3 shows the comparison between three SEY spectra recorded in different conditions on Al technical samples cut from the inner walls of the Petra III storage ring. The curve labelled a) is a representative SEY spectrum acquired on one of the "as received" samples, i.e. just mounted and inserted into the analysis system. As can be seen from the figure, and from other data (here not shown), the SEY recorded on the "as received" sample shows a maximum value of δ_{max} ranging between 2.7 (as in fig.3) and 3.0.

To simulate the effect of the e-cloud, presumably present in the machine, an electron conditioning (scrubbing) is performed. The treatment consists in an electron bombardment at various electron doses at kinetic energy of 500 eV. The total amount of electron dose reached the value of $1.2x10^{-1}$ C/mm^2. The curve labelled b) represents the SEY spectrum after such electron "scrubbing". It is seen that the δ_{max} value has decreased from 2.7 down to 1.8 for this sample held at a base pressure in the low 10^{-9}mbar during experiment and dosing.

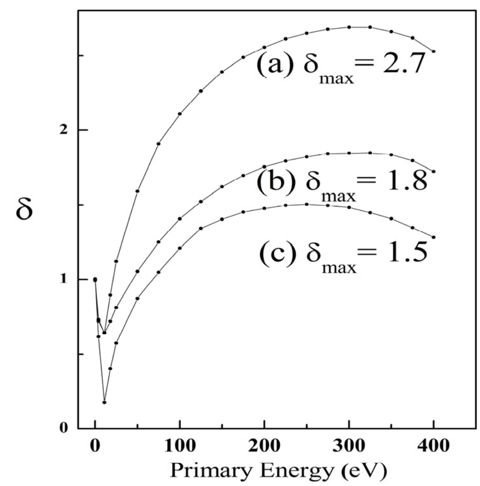

Figure 3: SEY curves measured on the Al samples (a) “as received”, and (b,c) after electron scrubbing with a dose of 1.28×10^{-1}C/mm^{2}at 500 eV of kinetic energy. The curves (b) and (c) were measured on two different samples scrubbed in UHV at background pressures of low 10^{-9} mbar and low 10^{-10} mbar, respectively.

In Fig.3 the spectrum labeled c) has been recorded on another Al sample coming from Petra III, whose starting ("as received") value for δ_{max} was 3. After the electron scrubbing (same electron dose and kinetic energy of the previous sample but base pressure during the experiment in low 10^{-10} mbar), the δ_{max} suffered even a more important decrease down to 1.5 While this difference can be ascribed or to slightly different samples or to inequivalent initial conditions of the analyzed surfaces (as seen by their “as received” δ_{max} value), we are more ready to ascribe it to the effect of the different base pressure at which the scrubbing and the experiment were performed. Already in vacuum worse than the low 10^{-10} mbar the highly reactive Al surface can be modified by the interaction with the adsorbates dissociated by the electron beam. The occurrence of reactions at metal surface leads to new chemical phases which increase the final δ_{max} value for the fully scrubbed surface. A "fully scrubbed" sample is defined here, as the sample for which the SEY is unchanged upon a further electron conditioning. This preliminary observation will be discussed more in details in a forthcoming paper but calls for a more careful analysis when comparing scrubbing runs of very reactive surfaces like Al, at different vacuum pressures.

The comparison among the δ_{max} values of the "as received" and conditioned samples suggests that the Al samples heavily suffer the effect of surface contamination. Indeed, it is known from the literature, that a clean aluminum surface shows a δ_{max} around 1 [7].

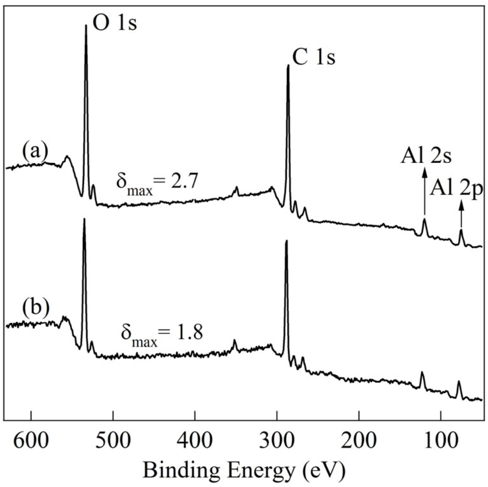

Figure 4: XPS spectra measured on the Al sample (a) "as received and (b) scrubbed with an electron dose of $1.2\ 10^{-1}$ C/mm^2 at 500 eV. The corresponding δ max values are also indicated.

In order to elucidate the possible relation between the surface contaminants and SEY values, the Al samples were analyzed by XPS to observe the evolution of the surface composition during the treatments. Figure 4 shows the XPS spectra acquired on the Al sample characterized by an initial δ_{max} value of 2.7 eV, before and after the exposure to the electron dose corresponding to a full scrub. Both spectra show, in addition to the Al 2s and Al 2p core levels, intense features corresponding to C1s and O1s peaks. Apart from carbon, oxygen and aluminum, only a negligible contamination due Ca atoms is observed at about 350 eV. The Al surface is mostly contaminated by compounds related to ambient air, like adsorbed water, hydrocarbons and carbonaceous oxides. It is noted here that hydrocarbons and water are known to increase the value of the SEY [8]. The large difference in the intensity between the carbon, the oxygen and the Al peaks suggests that the contaminants over-layer is very thick (50 Å [9]). The electron scrubbing acts as an electron stimulated desorption process, modifying the chemistry of the topmost layers and partially removing the surface contaminants. In this case the effect of the prolonged electron irradiation of the sample surface causes a preferential O desorption as the O1s peaks decrease by 22%, whereas the C1s looses only 14% of its intensity. The sample is then formed by the metallic Al substrate, the oxidized Al surface and finally a thick layer of contaminating species (water, CO, CO_2 and eventually $CaCO_3$). Therefore only these latter species are responsible for the SEY values, being the sampling depth only about 20 Å [10]. In this respect, the electron conditioning changes only the topmost layer properties, i.e. the properties of the surface contaminants, possibly changing their chemical nature and reducing their amount.

In agreement with [8], and due to the measured extreme reactivity of the Al surface, we think that Al chambers are not suitable for their e-cloud related performances unless coated with a more stable compound.

In the light of the above discussion, it is suggested to investigate the same samples upon sputtering-scrubbing cycles not only to simulate the actual presence of ions in the accelerator chambers but also to reduce the effect of "native" surface contamination and clarify the importance of vacuum dependent electron induced surface and SEY modifications.

CONCLUSION

We have reported on the SEY and on the effects of electron conditioning (at 500 eV of kinetic energy) of Al samples from the dipole chamber of PETRA III at Desy. For the first time, the SEY of the actual "as received" PETRA III Al chamber was measured. We show that the SEY value is severely affected by the contaminating species of the sample surface. It is shown here that the SEY decreases upon electron scrubbing, although its final SEY value, as measured in the Lab, could depend on the actual base pressure at which the experiments are performed. This suggests that some extra care is needed when comparing data measured on different set-ups. These data can be used in further simulations to improve the understanding of the observed effects at PETRA III.

This work was partially supported by INFN-NTA funding agency, within the IMCA project. We thank the group MVS at DESY for providing the Al samples.

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