The Continuing Story of Secondary Electron Yield Measurements from TiN Coating and TiZrV Getter Film

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18th August 2004

Abstract

In the beam pipe of the positron Main Damping Ring (MDR) of the Next Linear Collider (NLC), ionization of residual gases and secondary electron emission will give rise to an electron cloud which can cause the loss of the circulating beam. One path to avoid the electron cloud is to ensure that the vacuum wall has low secondary emission yield and, therefore, we need to know the secondary emission yield (SEY) for candidate wall coatings. We report on the ongoing SEY measurements at SLAC on titanium nitride (TiN) and titanium-zirconium-vanadium (TiZrV) thin sputter-deposited films, as well as their effects on simulations.

1 Introduction

Beam-induced multipacting, which is driven by the electric field of successive positively charged bunches, arises from a resonant motion of electrons that were initially generated by photons, by gas ionization, or by secondary electron emission from the vacuum wall chamber. These electrons move resonantly along the surface of the vacuum chamber, occasionally getting "kicked" by the circulating beam to the opposite wall. The electron cloud density depends on characteristics of the positively charged circulating beam (bunch length, charge and spacing) and the secondary electron yield energy spectrum of the wall surface from which the starting electrons arise. The electron cloud effect (ECE), started by multipacting, has been observed or is expected at many storage rings [1]. The density of the cloud, hence its space charge, if sufficient, can lead to a loss of the beam or, at least, to a drastic reduction in beam luminosity.

The SEY of technical surfaces, needed to mitigate multipactor, ECE or space charges, has been measured in the past at SLAC [2] [3] [4], at CERN cf. Fig.1, [5] [6] [7] and in other labs [8] [9] [10] [11].

In this paper we are following up on experiments carried out at SLAC and previously reported in [12]. We present various measurements of the SEY of titanium nitride (TiN)

thin film, as well as the titanium-zirconium-vanadium alloy getter film ($\text{Ti}_{30}\text{Zr}_{18}\text{V}_{52}$ and $\text{Ti}_{27}\text{Zr}_{31}\text{V}_{42}$, concentrations are in at%) deposited on stainless steel (SS) and aluminium (Al) substrate. The chemistry of the NEG film was checked using the XPS (x-ray photoelectron spectroscopy) technique [12]. Some implications for electron cloud build up simulations, in presence of a beam, are also discussed.

Figure 1: SEY of baked technical surfaces, 350°C for 24hr [13]

2 Experiment Description and Methodology

The system and experimental methodology used to measure the secondary electron yield have been thoroughly described in [12].

The system is composed of two coupled stainless steel UHV chambers where the pressure is in the low 10^{-10} Torr scale in the measurement chamber and high 10^{-9} Torr scale in the "load lock" chamber, Fig.2. Samples, individually screwed to a carrier plate, are loaded first onto an aluminium transfer plate in the load lock chamber, evacuated to the low 10^{-8} Torr scale, and then transferred into the measurement chamber.

After all samples (up to ten or so) are transferred into the measurement chamber, one sample at a time is loaded, on its individual carrier plate, onto a manipulator arm (Vacuum Generators Omniax[®]). Two thermocouples are available to measure the temperature near the sample, during irradiation or during a sample bake. The back of the samples are heated by electron bombardment, achieved by biasing a tungsten filament negatively [12].

Sample temperatures are compared to the thermocouple temperatures by using a black body-calibrated infrared pyrometer ($0.8 \mu\text{m}$ - $1.3 \mu\text{m}$ bandpass) which is corrected for absorption by the 7056 glass viewport of the measurement chamber and the sample emissivity (ϵ) of 0.2 - 0.4. This technique was used to measure accurately the temperature of the samples during their bakeout or activation [12].

Figure 2: Experimental system used for SEY measurements and surface analysis. Fourth and first authors also shown

A good way to monitor the activation process of the TiZrV non-evaporable getter (NEG) is to record the decrease of the surface oxygen concentration with XPS. During the NEG activation, the surface goes from an oxidized state to a partially metallic state. During XPS measurement the x-ray generated photoelectron current leaving the surface of the sample is measured to be ~ 27 nA, over an area of 16 mm^2 . The backside of the NEG sample was heated, directly via a hole in the plate holder, by electron bombardment. It has to be noted that hot Zr is pyrophoric, This is also true for Zr-based alloyed getter like St707TM ($\text{Zr}_{70}\text{V}_{24.6}\text{Fe}_{5.4}$). However, one sample of $\text{Ti}_{27}\text{Zr}_{31}\text{V}_{42}$ getter, prepared by SAES getters[®], of about 1 micron thick did not ignite in air when heated up to 350°C .

The electronic circuit for SEY measurement is that presented in Fig.3 [4]. The energy of the computer-controlled electron beam coming from the gun is decoupled from the target measurement circuitry. However, the ground is common to both. The target is attached to a bias voltage supply and an electrometer connected in series to the data gathering computer through an Analog Digital Converter (ADC). Measurements were made with a Keithley 6487, a high resolution picoameter with internal variable ± 505 V supply and IEEE-488 interface. The 6487 has several filter modes which were turned off for our measurements. The integration time for each current reading was $167 \mu\text{s}$, which is the minimum value for the instrument. The current was sampled one hundred times; the mean and standard deviation were returned from the picoameter to the computer.

The SEY (δ) definition is determined from equation (1). In practice equation (2) is used because it contains parameters measured directly in the experiment.

Figure 3: Electronic circuitry used to measure the secondary emission yield

$$\delta = \frac{\text{Number of electrons leaving the surface}}{\text{Number of incident electrons}} \quad (1) \quad \delta = 1 - \frac{I_T}{I_P} \quad (2)$$

Where I_P is the primary current (the current leaving the electron gun and impinging on the surface of the sample) and I_T is the total current measured on the sample ($I_T = I_P + I_S$). I_S is the secondary electron current leaving the target. The reproducibility of the experiment is around 2%. More details on the methodology can be found in [12]

Due to experimental reasons, some of the curves of SEY have been obtained with a beam impinging at 23° from normal incidence and at normal incidence, also labelled "0deg". The effect on the SEY from such angles of incidence is plotted in Fig.4. A relationship between the SEY for different angle of incidence can be deduced from equation (3) [4]

$$\delta_\theta = \delta_\perp e^{\alpha X_m (1 - \cos(\theta))} \quad (3)$$

Where θ is the angle of incidence of the incoming electron beam, X_m the average depth of escape of the electrons and α the secondary electron absorption.

Figure 4: Variation of the SEY in function of the incidence of the primary electron beam

3 Results and Comments for TiN thin films

The TiN coating, made at Brookhaven National Laboratory (BNL), was deposited onto 6063 aluminium alloy substrates (TiN/Al), and onto type 304 stainless steel substrate (TiN/SS), following the same recipe described in [9]. According to BNL, the expected film thickness is around 1000 Å. We measured the actual sample thicknesses using XRF (x-ray fluorescence) [12]. Results using a 157.6 nm thick TiN/Al reference are presented in Fig.5.

This reference cannot be used with the TiN/SS, since at 5.5 keV the incident x-rays can still fluoresce the Cr contained in the SS, which then fluoresces the K_{α} line of the Ti, thus giving an unwanted extra contribution to the Ti signal. A finely polished SS coupon was coated at BNL, with a thin film of TiN. The thickness of the film was measured via a stylus profilometer. This TiN/SS sample was used as a reference for XRF techniques on TiN/SS samples.

Samples of TiN/Al are referred to by number from 1-6. Sample of TiN/SS are letter-named as follows:

a	b	c	d	e	f
COIN2R	COI1L	InjBELL1	InjBEIR1	E3L	RFS2R

SEY measurements results of the six different "as received" TiN/Al samples are displayed in Fig.6. SEY measurements for the TiN/SS samples are displayed in Fig.7. Note that sample a) is not measured, due to the fact that it fell off the transfer plate. The electron beam current impinging onto the sample surface is of the order of 2 nA over an area of less than a mm². Typically the beam size is between 0.2 mm to 0.4 mm in diameter. The low current is necessary in order to minimize surface conditioning during SEY measurement. The size of the beam can be checked by using a fluorescent screen, or is inferred from secondary electron microscopical imaging (available on the measurement system and used to precisely choose the point of SEY measurement).

Figure 5: TiN/Al thickness measured by XRF (7 keV x-ray energy) of four BNL samples and TiN/SS thickness measured by XRF (5.5 keV x-ray energy) of six BNL samples

Figure 6: SEY of six TiN/Al sample as received, measured at normal incidence

Figure 7: SEY of five TiN/SS sample as received, measured at 23° incidence

SEY results from TiN/Al, from a primary beam impinging at normal incidence, have already been discussed in [12], hence we will focus on the TiN/SS. The SEY of the as-received TiN/SS samples varied from 1.7 to 2, when bombarded by a primary beam impinging the surface at 23° from normal incidence. The thicker film samples display the lower values for the SEY. These SS samples have been coated at the same time, in the same setup, following the recipe described in [9]. As already pointed out in [12], the roughness of each sample, or the chemistry of the surface, Table.1, might be a factor influencing the spread in the SEY curves. The irregularity in the SEY, at near maximum, for sample TiN/SS #INJbell and TiN/SS #E3L can be due to a non uniform spot emitting secondaries from two different yields. We have experimentally excluded any artefact in the measuring hardware system.

Sample	Ti At%	N At%	Contamination
INJBEIR1	14	15.4	-
INJBELL1	20	23.75	-
RFS2R	14.5	14.9	Sodium
E3L	13.4	13.06	-
CO111L	16	14.6	Sodium

Table 1: XPS survey of TiN/SS sample

At energies above 2 keV, electrons penetrate through the ~ 150 nm of the TiN film and reach the substrate, suggesting that the bend in the SEY plots (TiN/Al and TiN/SS) seen at this energy is due to a subfilm backscatter effect from the substrate. Backscattering of electrons from a SS surface is also more efficient than from an Al surface.

Surface conditioning of two TiN films, deposited on Al and SS substrate, using ~ 130 eV electrons, was carried out. In the NLC positron damping ring the average energy of electrons from the cloud was computed to be 130 eV, Fig.8. The effect of the electron bombardment on the SEY of the TiN/Al and TiN/SS is shown in Fig.9. These results are similar to results obtained on other bulk surfaces, such as copper [6].

TiN/Al samples provided by Lawrence Berkeley National Laboratory (LBNL or LBL), of a deposited thickness of 150 nm, were also studied, Fig.10. The as-received samples have a δ_{max} of 1.8 to 1.9.

The effect of a sample bake of 150°C for 2 hours, then an additional 5 hours on one of the samples, was also investigated. The heat treatment reduces the δ_{max} to respectively 1.7 and 1.6, Fig.10. A similar reduction from an as received TiN sample was obtained at CERN [6]. The SEY dropped from an initial δ_{max} of 1.6 to a δ_{max} of 1.45. From our test, a total of 7 hours bake does not much further reduce the SEY than the 2 hours bake. Results of higher temperature treatment can be found in [2] and [6]. The sample was then left in vacuum up to 12 days, at a pressure $\sim 5 \cdot 10^{-10}$ Torr, causing the 7 hours bake benefit to be lost. The SEY curve of the sample left 12 days in the vacuum is almost identical to the 2 hours bake curves, see Fig.10. After 14 hours in vacuum, the SEY curves lies in between the 2 hours bake and the 7 hours one. For clarity of the figure, this last result was not plotted.

Finally, this sample after being baked at 150°C then left in vacuum for 12 days, was submitted to an electron conditioning of energy 130 eV. The maximum reduction

Figure 8: Simulation of the energy spectrum of the electron cloud in the field free region of the damping ring

obtained, after a dose of $5743 \mu\text{C}/\text{mm}^2$, is also displayed in Fig.10 as well as Fig.11, labelled : TiN/Al#1(LBL-Baked 150C). Comparison with the "as received" sample is also plotted in Fig.11 with the legend TiN/Al#2(LBL-as received). Electron conditioning is as efficient as lowering the δ_{max} for a TiN film, as it is on other technical surfaces.

Figure 9: Electron conditioning of TiN/Al #2 (left) and TiN/SS #E3L (right) sample at 23° angle by an electron beam of 130 eV

TiN films are inert, but leaving them in vacuum after they have been exposed to electron bombardment leads to some recontamination. The SEY then increases, results on the δ_{max} versus the exposure time are plotted in Fig.12 for three samples. During this period, samples were inserted from the load lock chamber at a pressure of $\sim 10^{-8}$ Torr to the measurement chamber at a pressure $\leq 10^{-9}$.

Figure 10: TiN/Al from LBL after different processes, measured at 23° incidence

Figure 11: SEY max, measured at 23° incidence, during electron conditioning of TiZrV;
TiN/Al and TiN/SS

Figure 12: SEY max, measured at 23° incidence, during recontamination in a vacuum of few 10^{-10} Torr

4 Results and Comments for the NEG thin films

An alternative coating to TiN is sputter-deposited TiZrV getter. Two samples were tested, one TiZrV/SS of $\sim 2\mu\text{m}$ thickness, provided by CERN and one TiZrV/Al of $\sim 1\mu\text{m}$ thickness, from SAES[®] getters. This NEG, when activated, shows a drastic reduction of its SEY, Fig.13 and Fig.14. These results confirm what has been shown elsewhere [7]. It is also interesting to follow the behaviour of the SEY curves when the sample is exposed to a residual gas background of less than 10^{-9} Torr equivalent N_2 for an extended period of time. The SEY of the TiZrV/SS goes up with time when exposed to even such good vacuum, reaching 1.75 after 145 days, Fig.13. Fig.12, blue open circles, shows the evolution of δ_{max} for the TiZrV/SS (1.7), up to 50 days. Considering an average pressure of 10^{-9} Torr in the system for the 145 days the NEG was in vacuum, we computed an equivalent exposure of 12528 L^1 . Interestingly enough, it is claimed in [7] that the influence on the SEY of the NEG after exposure to 30 000 L of CO , CO_2 , H_2O and H_2 is rather small. δ_{max} will increase from 1.1 (CERN fully activated NEG) to 1.35 (max) while in UHV [7]. This behaviour has been discussed, but not understood, in [12]

Recent results obtained at CERN, in the framework of the electron cloud studies for LHC [14], seems to be in agreement with the fact that NEG, when saturated should, have a SEY below 1.4. In the CERN experiment carried out at the Super Proton Synchrotron (SPS), a section of the machine was replaced by a TiZrV NEG-coated chamber. After activation (200°C , 2 hours) the section was opened to an unbaked vacuum from the SPS. When the NEG saturated and was in the presence of an LHC-type beam, no electron cloud developed, suggesting that the SEY must be below 1.4. This CERN experiment is identical to our experiment. The contradiction between our results ($\delta_{max} = 1.8$) and the CERN one ($\delta_{max} = 1.4$) is still under study.

However, our CERN getter sample was then activated a second time (Fig.13, dotted line). This time the δ_{max} was 1.2. The value of δ_{max} upon recontamination in UHV goes up to

¹1L= 10^{-6} Torr.s

Figure 13: SEY of TiZrV/SS after different process, baking and electron conditioning

Figure 14: SEY of TiZrV/Al after activation and recontamination in the vacuum

1.4 and appears to have saturated, blue triangles in Fig.12, the last measurement having been taken at 60 days. We note that after electron conditioning and 34 days in a vacuum of a few 10^{-10} Torr, the δ_{max} is ≈ 1.4 (Fig.12, blue full circle). Thus, these two results are in agreement with CERN data.

It is also important to keep in mind that an activated NEG surface will not "remember" its previous surface chemical state. For example the chemical state of a surface which has been conditioned by 130 eV electrons, is "erased" as a result of activation.

Similar results were obtained for the SAES getter sample, TiZrV/Al. $\delta_{max} = 1.2$ after activation, reached 1.45 after having been left 18 days in vacuum, Fig.12 (red diamonds). During the 50 days the sample was in vacuum, Fig.14 and Fig.12, the δ_{max} seems to saturate, or, at least, to evolve very slowly.

During the time the TiZrV/Al was kept under vacuum, other samples were loaded into the measurement system and a TiN/Al sample was baked. Hence, the TiZrV/Al has seen unbaked vacuum and thermally desorbed gas from the TiN/Al. The pressure rose to $6 \cdot 10^{-9}$ Torr and then decreased to $\sim 2 \cdot 10^{-9}$ Torr during the 2 hour bake of the TiN/Al. After five extra hours of bake, the vacuum was $\leq 2 \cdot 10^{-9}$ Torr.

These are important results, as it might be necessary for a TiZrV NEG, kept in an air environment for a while, to be activated twice to achieve its full properties. The same kind of behaviour is also seen for photocathodes, which often need two heat cleanings to reach their desired operational values.

4.1 XPS analysis of the C_{1s} and Ti_{2p} peak

XPS analysis was carried out to observe the evolution of the carbon chemistry from bake through conditioning as well as monitoring the effect of the recontamination when the NEG is left in UHV. In Fig.15 and Fig.16 are displayed C_{1s} photopeaks obtained by doing XPS at a 0.25 eV step. A few plots were taken with 1 eV step. All XPS spectrum have been obtained at room temperature.

Analysis of the XPS data obtained for the TiZrV/SS, after three different processes, is shown in Fig.15. On the left hand side, the NEG is baked at 210°C for 2 hours, then it is left in vacuum. The C_{1s} data shows 3 peaks : 283 eV 285 eV and 288 eV. An

Figure 15: XPS C_{1s} peak from CERN TiZrV/SS film, after different processes

amorphous/graphite C surface will show a single peak at 285 eV, binding energy (BE). An oxidized C (C-O) surface will create a peak at higher BE, 288 eV. During NEG activation a peak at 283 eV appears, as shown on the curve labelled : NEG at 180°C, Fig.15. This spectrum was taken at the end of the activation, when the NEG was still warm. The 283 eV BE peak is a typical metal carbide state, probably of Ti (Ti-C) and it should be present after a fully successful activation [7]. The XPS spectrum of the carbon from the TiZrV/SS, after the two activations, show the presence of carbide and amorphous/graphite carbon peaks.

After the first activation, Fig.15 left plots, the carbide at 283 eV BE disappear. The spectrum shifts to pure C and oxidized C, respectively at 285 eV and 288 eV BE; comparison of curves labelled "NEG at 180°C" and "NEG 11 days Vac". After 65 days in vacuum, the oxidized C peak increases. The SEY reflects this change in chemistry, and the δ_{max} reached 1.75 after 134 days, Fig.13.

After the second activation, right bottom plot in Fig.15, we do not see such changes. The carbide peak after 50 days in vacuum is still present. The broadening, results of the 1 eV resolution, of the "50 days in vac" spectrum is due to oxydation of the carbon. This oxydation being minimal, the δ_{max} saturated at 1.35, Fig.12 (blue triangles).

This scenario is reproduced with the SAES getter TiZrV/Al, Fig.16. The low BE peak after bake is the carbide (283 eV), and as the NEG pumped the residual gas, the carbon peak (285 eV) rose. Oxygen pumped by the NEG is probably bounded on the Ti and the Zr and not on the C. Monitoring the evolution of Ti $2p^{1/2}$ and $2p^{3/2}$, during all the processes the getters have endured, does not change the above picture. The SEY max of the TiZrV/Al, after one activation, does saturate at 1.5, Fig.12 (red diamonds). As a comment, the 283 eV peak is never present on a TiN thin film, neither from heating at 150°C neither from electron conditioning. Very special conditions can make it appear, for example, by bombarding a TiN film with N_2^+ ion in a 10^{-4} Torr atmosphere of ethylene (C_2H_4) [15].

The chemistry evolution from an activated NEG is reproducible Fig.15 (bottom right) and Fig.16. The fully activated NEG presents a carbide peak (283 eV) and a amorphous/graphite carbon peak (285 eV). When left in an UHV atmosphere, moderate carbon oxidation occurs and a peak at ~ 288 eV appears. The oxygen is gettered by the Ti or by the Zr. However, in one case the carbon did highly oxidize Fig.15 (left) and, as a

result, the SEY did not saturate below 1.4 as expected [7].

Figure 16: XPS C peak of a TiZrV/Al film after bake and left in UHV

5 SEY of TiN and TiZrV at low primary electron energy : effect on simulations

5.1 SEY measurements

From the measurements obtained when running the electron gun by 2 eV increments on TiN and TiZrV from 0 eV - 300 eV [12], we have been able to probe, to some extent, the behaviour at low energy. We observed a dip at 10 eV for all the "as received" samples measured, Fig.17, 18 and 21.

For the "as received" TiN/Al the behaviour differs from the TiN/SS. In the latter case the SEY tends toward 1. In the case of the NEG and the TiN/Al, the SEY ranges between 0.5 and 0.7 as the primary energy tends to 0 eV. For activated NEG, there is no dip in the SEY curves, and the extrapolation to zero energy, brings the SEY to 0.4. From the NEG study, Fig.21, it turns out that the recontamination leads to the creation of the dip in the curves. However, for the second sample Fig.20 this seems not to be the case. Nevertheless it looks like at those low energies, few eV, the value of the SEY might be driven by the "oxide" layer. It might be possible that not only the chemistry of the "oxide" layer but also its morphology plays a role in the behaviour of the SEY. Again, roughness of the material can strongly affect the SEY.

Electron conditioning barely changed the state of the NEG surface chemistry, as revealed by the XPS in Fig.15. Hence, no vacuum recontamination effect could be seen, after an electron exposure on the SEY, at low energy (≤ 25 eV). The SEY curves of the TiZrV/SS after conditioning, Fig.22, are similar between a few days and 18 days in vacuum. The SEY at 2 eV being 0.8, and decreasing to ~ 0.57 around 10 eV, then increasing as the primary energy of the electron beam, increases also.

Figure 17: SEY of TiN/SS (BNL) at low primary electron energy, as received

Figure 18: SEY of TiN/Al (BNL) at low primary electron energy, as received

Figure 19: SEY of TiN/Al (LBL) at low primary electron energy, after several different processes

Figure 20: SEY of TiZrV/Al NEG (SAES), at low primary electron energy, after a 2hours bake at 210°C

Figure 21: SEY of TiZrV/SS NEG (CERN) at low primary electron energy, after the first activation

Figure 22: SEY of TiZrV/SS NEG (CERN) at low primary electron energy, after electron conditioning

5.2 Effect on simulations

Values of δ provided by experiments for energies below 20 eV should be used carefully when plugged into simulation. It was concluded from ref [16] that build-up and instability simulations run with different codes give results differing by a factor three to hundred. These differences depends on the modelling, including the modelling of reflection at low energy and of the spectrum of the re-diffused electrons. Moreover, the reflection of the primaries at primary energy close to 0 eV, can give very different results on the buildup of the electron cloud [16].

Figure 23: ECE depending of the parametrization taken at 0 eV, for GSI

Table 1: LHC parameters used for the simulations.

variable	symbol	value
Circumference	$2\pi R_0$	27000 m
Relativistic gamma	γ	7461
Bunch population	N_b	1.05×10^{11} p
Rms bunch length	σ_{z0}	0.075
Bunch spacing	L_b	25,50,75 ns
Beam sizes	$\sigma_{x,y}$	0.3/0.3 mm
Chamber size	a, b	22/18 cm
Photoelectron yield	Y	1.25×10^{-3} e ⁻ /(pm)
Chamber reflectivity	R	50% cosine distr.
Maximum SEY	δ_{max}	1.1, 1.2, 1.3, 1.4
Energy for max SEY	E_{max}	300 eV
E ⁻ reflectivity at 0 eV	$\delta(0)$	0, 0.5, 1

The result of simulations, for SIS18 at GSI [17], can be seen in Fig.23. The blue dashed curve is obtained by running the simulation with a $\delta_{0ev}=1$, according to [18], and the red curve is obtained with a $\delta_{0ev}=0$.

Applying the same simulation software for the LHC, with the parameters listed in Table 1, leads to the results summarized in Fig.24.

Figure 24: Buildup of electron cloud depending of the parametrization taken at 0 eV, simulation for LHC

The influence of the choice of the δ_{0ev} , at low energy, can be already seen for the LHC simulation using a δ_{max} as low as 1.2 and thus independently of the bunch spacing of 75 ns, 50 ns or 25 ns, Fig.24. The effect of the electron multipacting is more severe at 25 ns as it is expected. Using a δ_{0ev} of 1 will bring an artificial safety factor in the necessity of having a technical surface having a low δ_{max} .

For example, looking at Fig.24 for a 25 ns bunch spacing, a surface having a δ_{max} of 1.1 taking a δ_{0ev} of 1 will have the same electron flux as a surface having a δ_{max} of 1.3 with a δ_{0ev} of 0.5. The R&D on finding such a surface or process giving such a δ_{max} should not be considered easy. As a comment, we would like to mention that few pure elements have such a low SEY. Technical surfaces made of such elements are usually worse, since they easily oxidize. Aluminium and beryllium are, as examples, two of them; in their pure form their $\delta_{max} \leq 1$ and in their oxidized form, their δ_{max} is above 2.5, Fig.1.

6 Conclusion

We have reported on the status of the SEY experiments carried out at SLAC, including new results on as-received TiN and on thin film NEG TiZrV getters. Description of our experimental system can be found in reference [12].

In the case of the $2\mu\text{m}$ TiZrV/SS, provided by CERN, the influence of the activation and pumping recontamination was investigated. The maximum SEY δ increased from ~ 1.2 to ~ 1.4 after 40 days of exposure to a vacuum of $\sim 5 \cdot 10^{-10}$ Torr N_2 equivalent, and seems to saturate at this value. The second set of data after activation agrees with CERN results [7]. Saturated NEG and conditioned NEG have a δ_{max} below 1.4.

A TiZrV/Al sample, of $1\mu\text{m}$ thickness, from SAES, corroborated these results, i.e., the maximum SEY reached 1.5 after 46 days.

Conditioning the NEG with 130 eV electron beam, led to a δ_{max} of 1.3 at a dose of 1 mC/mm^2 .

The influence of conditioning has been shown for TiN on SS or Al substrates. Values of δ_{max} reached at a dose of 1 mC/mm^2 are 1.1 for both samples. Recontamination does not dramatically degrade the SEY, Fig.12.

Finally, some data taken for a primary beam energy between 0 - 25 eV were shown. Oxidized surfaces show the SEY going up where a clean metallic surface does not. Hence, simulation parameters are even more critical, as results will strongly depend on the chemistry at the surface. For a clean baked surface a $\delta_{0\text{ev}}$ of 0.5 seems reasonable. However, using a $\delta_{0\text{ev}}$ of 1 for a technical surface is sensible.

The electron conditioning results have been obtained in a laboratory system. In an accelerator, the electron cloud is going to be one of the element responsible for conditioning the walls of the vacuum chamber. When the SEY decreases, the efficiency of the electron conditioning decreases as well, reaching a limit where the recontamination from the accelerator vacuum dominates, making the electron cloud re-appear. However, in a dynamic vacuum, the contribution of photon and ion conditioning could be the key to avoiding the growth of the SEY, and thence the electron cloud.

In the future, we plan to study the influence of ion conditioning, as applied to the NLC damping ring. Different species of ions can be investigated, as well as different energies. For example, diatomic hydrogen at 3.5 keV and 500 eV as well as CO or N_2 at 500 eV. For now, roughness studies are ongoing on effects of grooves to lower the SEY. Results, for grooved clean "as received" aluminium and copper sample are encouraging. However, without a coating or some other treatment, the SEY for aluminium will not consistently go below 2.

7 Acknowledgments

We would like to thank P. He and H.C. Hseuh at BNL for providing the TiN samples on aluminium and on stainless steel and the EST group from C. Benvenuti at CERN for the TiZrV sample. We also thank A. Wolski, D. Lee and K. Kennedy at LBNL for the production of thin film samples, of TiN and TiZrV. Most valuable was the work of G. Collet and E. Garwin, SLAC, for converting and baking the XPS system for use on SEY measurements.

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