Summary of SLAC'S SEY Measurement On Flat Accelerator Wall Materials *

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Abstract

The electron cloud effect (ECE) causes beam instabilities in accelerator structures with intense positively charged bunched beams. Reduction of the secondary electron yield (SEY) of the beam pipe inner wall is effective in controlling cloud formation. We summarize SEY results obtained from flat TiN, TiZrV and Al surfaces carried out in a laboratory environment. SEY was measured after thermal conditioning, as well as after low energy, less than 300 eV, particle exposure.

1 Introduction

Multipactoring and the ECE have been detrimental to the functioning of onboard space devices as well as klystrons and accelerators. In the latter, the ECE was characterized and dealt with at the CERN ISR (Intersecting Storage Rings) [1, 2]. With the construction of high current colliders, e.g., the B factories, or accelerators producing a high amount of photons per (e^+, H^+) bunch, multipacting and the ECE are again being studied extensively [3].

Methods to suppress multipacting or the formation of electron cloud (EC) are still similar to the ones used for radio frequency (RF) components. One can allow the secondary electron to be produced and then get rid of them afterwards. For example by the use of electron clearing electrodes or, by use of low magnetic field solenoids that return the secondary electrons to the surfaces from which they have been produced. When photons are responsible for the creation of the EC, it is also possible to confine the photoelectrons to a place which is non-detrimental to the accelerator, for example in an ante-chamber.

Finally, one may modify the surface to produce less than one secondary electron per incident electron. This can be done, for example, by using a rough surface, by using an emission suppressing coating, or by cleaning the surface in-situ (thermal treatment, plasma glow discharge etc...) to remove high SEY adsorbed gas and oxide layers. These remedies can also be mixed together to give the best results for solving the problem in an existing machine or to be applied in a forthcoming accelerator where the ECE problem is expected to occur. Of course, lowering the circulating beam intensity can retard cloud formation but that also affects luminosity. In this summary, we report SEY measurements obtained at SLAC on flat surfaces, aluminium, TiN, TiZrV Non Evaporable Getter (NEG) and TiCN.

2 SEY experimental setup

The system used to measure the SEY is shown in Fig.1. The experimental methodology used to measure the secondary electron yield has been described in [4]
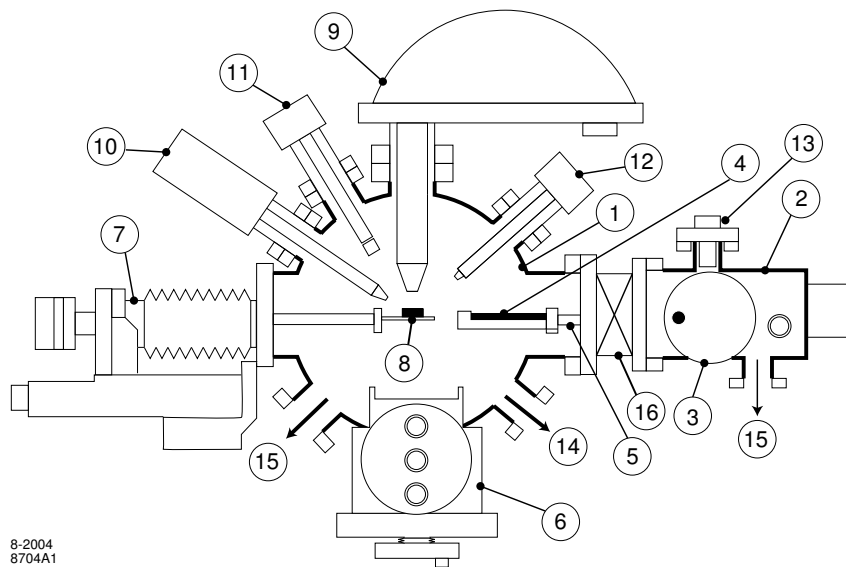
Figure 1: Experimental ultra high vacuum (UHV) system.

1 Analysis chamber - 2 Loadlock chamber - 3 Sample plate entry

4 Sample transfer plate - 5 Rack and pinion travel - 6 Sample plate stage

7 XYZθ Omniax^{TM} manipulator - 8 Sample on XYZθ - 9 Electrostatic energy analyzer

10 X-ray source - 11 SEY/SEM electron gun - 12 Microfocus ion gun

13 Sputter ion gun - 14 To pressure gauges and RGA - 15 To vacuum pumps - 16 Gate valve

The SEY (δ) definition is the number of electrons leaving the surface over the number of incident electrons (primary electrons), which becomes $\delta = 1 - I_T/I_P$. With I_P the primary electrons and I_T the total sample current being the difference between the primary and secondary electron current.

3   Conditioning

3.1   Thermal conditioning

A natural method for reducing the SEY of a material is thermal heating. Usually this is achieved during an in-situ bakeout. However, to be efficient the bake should be above 150°C. Nevertheless, any increase of surface temperature has an effect on the SEY [5, 6]. On some materials like Cu or Ag, certain oxides have an SEY below that of the atomically clean metal. Hence, growing an in-situ oxide by heating the surface, in presence of oxygen, is also a possibility [7]. Many examples can be found in the literature, and an excellent summary is available [8].

3.2   Particle conditioning

Another way of processing a surface to lower its SEY is to expose it to energetic particles : photons, electrons or ions. Usually the SEY of metals obtained after exposure to energetic particles is close to that of an atomically clean surface. This trend seems also not to be observed in the case of exposure to very energetic ions, MeV range per nucleons [9].

In the laboratory we have quantified the reduction of the SEY as a function of electron or ion bombardment. By ion bombardment we mean an ion beam, not a plasma glow discharge. A plasma glow discharge is very effective in cleaning the surface in a few minutes, but plasma gas pressure required for a stable discharge is above a mTorr [5]. Moreover, performing an in-situ glow discharge of in an accelerator vacuum beam pipe is far from trivial.
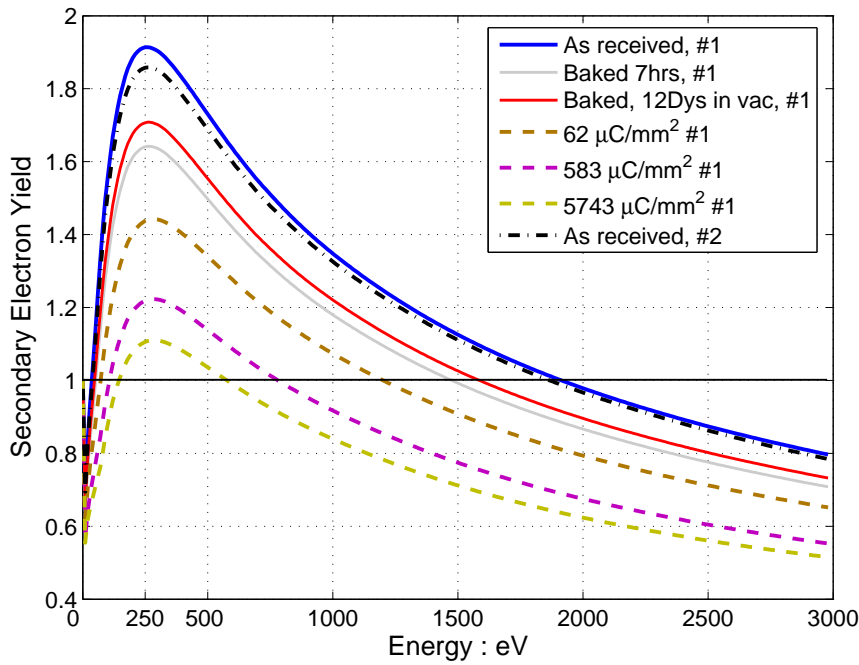
Figure 2: SEY of TiN/Al under different conditions. As-received (#1 and #2), baked at 150°C, vacuum recontamination after 12 days at 5.10^{-10} Torr and conditioning by 130 eV electrons. Measurement performed at 23° primary incidence.

4   Conditioning of Ti-Based Coatings

TiN and activated TiZrV getter coatings are good candidates for suppressing the ECE. TiN coating is known to have a SEY max (δ_{max}) below or close to 1 when freshly deposited [10, 11]. However, when the "as-deposited" film is exposed to air, its SEY maximum varies between 1.5 to 2.7 [12, 13]. Sputtering of air exposed TiN by Ar^+ ions or exposing it to a high dose of electrons will return δ_{max} to around 1 [11, 12, 14, 15].

In the ECE the energy gain of the secondary electrons is typically lower than 300 eV. In the case of the International Linear Collider (ILC) positron damping ring, the average energy was computed to be 130 eV [16]. The effect of 130 eV electron conditioning on the SEY and δ_{max} are shown in Fig.2 and 3, respectively.

It can be seen that after a surface has been cleaned by a bake (Fig.2) or by electron conditioning the SEY will increase even when the surface is left under a good vacuum (5.10^{-10} Torr), Fig.4. Any scrubbed or "clean" surface will adsorb molecules from the residual gas. The increase of the SEY is linked to the oxidation of the surface by the presence of oxygen atoms in these molecules. This was directly verified by observing the evolution of the XPS (x-ray photoelectron spectroscopy) carbon spectrum of TiZrV during exposure to residual gas [16].
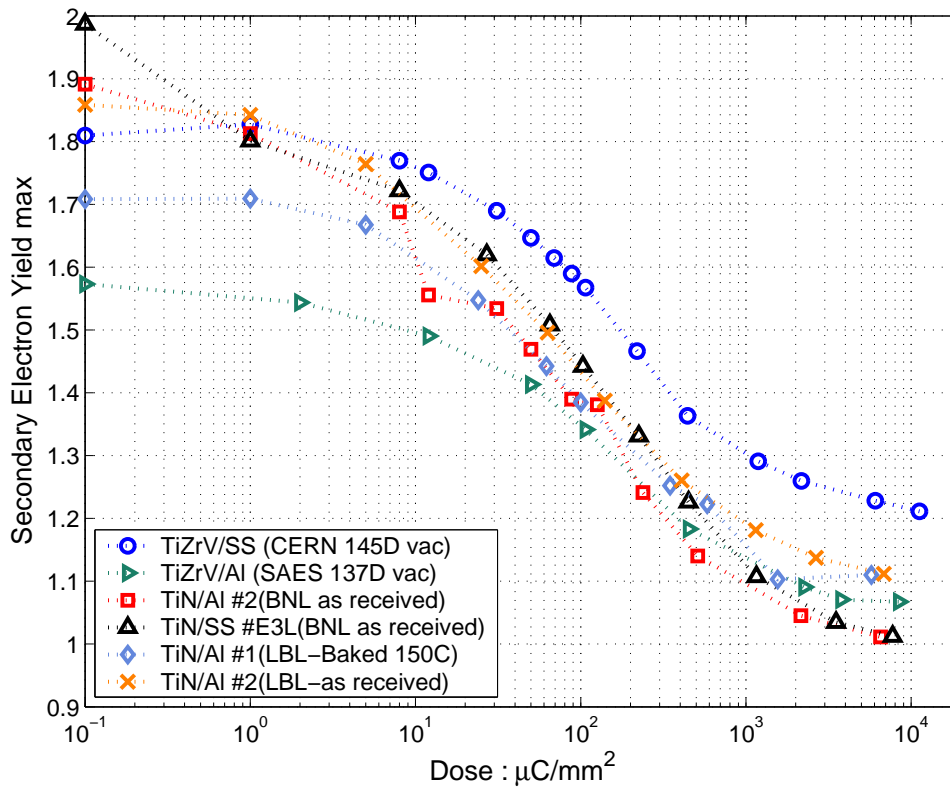
Figure 3: SEY of TiN and TiZrV getter under exposure by 130 eV electrons. Measurement performed at 23° primary incidence.
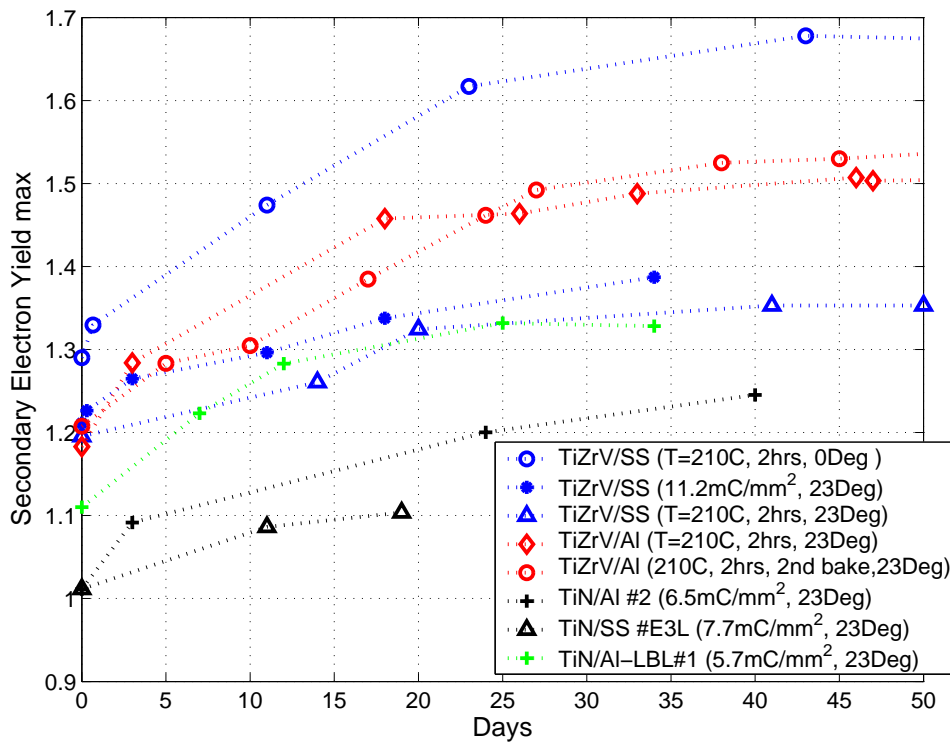

Figure 4: TiN and TiZrV NEG SEY increase when left in baked UHV atmosphere of 5.10^{-10} Torr.

During the passage of the circulating positron beam, ions will be created from the residual gas. Their energy, for the ILC damping rings, is less than 200 eV. Bombardment from these ions can also contribute to SEY reduction. To probe this effect, we have submitted three surfaces to ion bombardment. The results are summarized in Table.1. The experimental parameters are described in [17].

Table 1: δ_{max} reduction due to 250 eV ion conditioning. SEY measured at normal incidence

Thin Film	ion species	δ_{max}	Energy$_{max}$	Dose $\mu C/mm^2$
TiCN	H_2	1.29	280	1.11
TiN	N_2	1.09	260	3.39
TiZrV	N_2	1.15	300	2.29

Comparing the effect of conditioning to TiN, a gas-saturated TiZrV NEG was conditioned with a 130 eV electron beam, Fig.3, and to a 250 eV ion beam, Table.1. An N_2^+ ion dose of 0.96 $\mu C/mm^2$ reduces δ_{max} from 1.45 to 1.18, further exposure up to 2.29 $\mu C/mm^2$, causes only a δ_{max} decrease from 1.18 to 1.15 [17].

5 Technical Aluminium under electron exposure

Aluminium is one of the common metal used in fabricating the accelerator vacuum chambers. The SEY of atomically clean Al ranks among the best material with a δ_{max} around 1. Clean Al is extremely reactive to oxygen, however, upon air exposure, it will form a thick oxide with a δ_{max} well above 2 [4]. As discussed earlier, electron conditioning will bring the δ_{max} of the metal to its atomically clean value.

We repeated that measurement with oxidized aluminium. In the laboratory, we conditioned three different air-exposed technical aluminium surfaces and observed that the SEY decreases at first and then re-increases. Results shown in Fig.5 are similar for the two other samples [4].
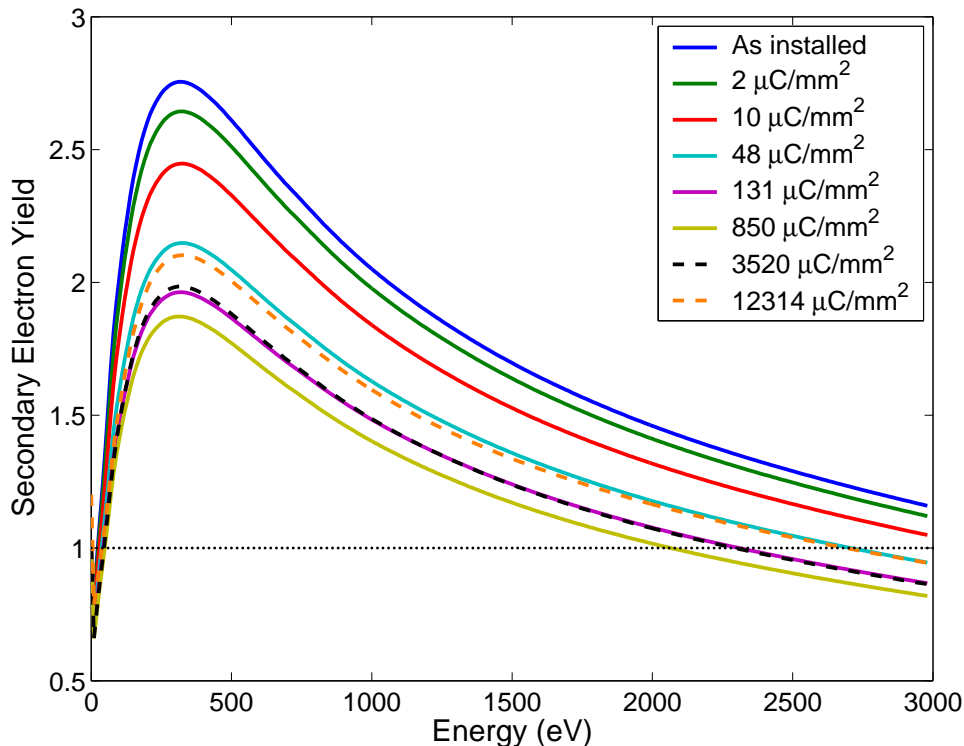

Figure 5: Al 1100 exposed to electron conditioning. The primary electron beam was impinging at 23° from normal incidence.

During conditioning the XPS spectra show the C1s peak shifting toward lower binding energy (BE)), signaling reduction of the oxide surface. With further conditioning, the trend stops and the peak broadens. Atomically clean Al shows one peak at 73 eV (metallic) and another, Al_2O_3, at 76 eV. Two of our samples show this double peak structure. Thus, during conditioning, the peaks evolve from oxide to clean Al and

then reverse again. The third sample was extremely oxidized but, again, the broad peak shifted to lower BE and then broadened further, consistent with the other samples [4].

6 NEG pumping and SEY

Activated getter surfaces [18, 19], like St707$^{\circledR}$, TiZr and TiZrV have a δ_{max} below 1.3 [20, 21]. They also provide linearly-distributed pumping capacity. The main interest in TiZrV coating over the other NEG alloys is that its activation temperature is lowest, 180°C [22]. During residual gas pumping the SEY of NEG increases (Fig.4), just as it does for initially-clean TiN. The SEY increase of NEG was followed with XPS measurement by monitoring the evolution of the carbon peak [16]. Significantly, during residual gas atmosphere saturation of NEG, the δ_{max} exceeds 1.3, the maximum value obtained when saturating NEG with individual common residual gases present in an accelerator environment [21]. This behaviour is seen for a freshly activated NEG as well as from a 11.2 mC/mm^2 electron conditioned surface, Fig.4. This suggests that fast saturation by a single species is different from slow saturation by multiple species, i.e., that time may play a role or co-adsorption of multiple species, may enhance the surface oxidation mechanism, as it can be seen in some surfaces [23]. The residual gas composition of a baked UHV is mainly composed of H_2 which readily diffuses into the NEG, CO, CO_2 , H_2O, and CH_4 which is negligibly-pumped by TiZrV [22]. The co-adsorption of the three oxidizing species enhances oxidation, similar to an air-oxidation, compared to oxides formed by dosing with a single specie. Thicker surface oxide has generally higher SEY. The process involved in building this thick oxide might be somewhat equivalent to cryogenic co-adsorption [24]. It is planned to test this hypothesis in our setup.

7 Conclusions

We have investigated a series of flat surface materials for suppressing the ECE. The most promising remedies are Ti-based coatings. TiN has historically been the choice for successfully reducing multipacting. Upon conditioning exposure to low energy ions or electrons, its atmosphere-oxidized surface δ_{max} returns to 1. TiCN was developed as an oxidation-resistant replacement for TiN; however, it behaves similarly to TiN. Another coating option is low temperature activated NEG, TiZrV. Following an activating-bake, its δ_{max} is 1.2. As a bonus, NEG coating provides distributed beam chamber wall pumping. While pumping toward film gas saturation, the δ_{max} increases. To return the SEY to low value and restore the pumping capacity, the film can be thermally re-activated multiple times. The SEY of the surface itself may also be restored by electron or ion bombardment, which will also recreate some surface pumping capacity.

Technical Al surfaces were investigated under electron exposure. We found that δ_{max} will not go consistently below 1.8. However, the behaviour at very large doses, above 3.10^4 $\mu C/mm^2$, was not measured. The SEY may increase further, stabilize or oscillate.

In an accelerator environment, synchrotron radiation, ions and electrons not only desorb molecules but also produce electrons which can lead to the formation of the EC. As we have seen, electron exposure is very efficient in reducing the SEY. However, as the EC conditions the surface, the number of secondary electrons diminishes, hence the EC can oscillate between being ON or OFF. Nevertheless, photons and ions directly created by the beam may ensure that an EC does not develop, but only direct measurements in beam chambers will confirm this [25, 26].

8 Acknowledgments

References

[1] O. Gröbner and R. Calder. Beam induced gas desorption in the cern intersecting storage rings. *IEEE Trans.Nucl.Sci.20 (No. 3)*, pages 760–764, 1973.

[2] O. Gröbner. Bunch induced multipactoring. In *10th Int. Conference on High Energy Accelerators, Protvino, pp. 277-282*, 1977.

[3] M. Pivi, R. Kirby, T. Raubenheimer, F. Le Pimpec. Suppressing electron cloud in future linear colliders. In *PAC, Knoxville, TN, USA*, 2005. SLAC-PUB-11201.

[4] F. Le Pimpec, F. King, R.E. Kirby, M. Pivi. Electron Conditioning of Technical Aluminium Surfaces: Effect on the Secondary Electron Yield. *Journal of Vacuum Science and Technology*, A (23):1610, 2005.

[5] R. Calder, G. Dominichini, N. Hilleret. Influence of various vacuum surface treatments on the secondary electron yield of Niobium. *Nuclear Instruments and Methods in Physics Research B*, B13:631, 1986.

[6] C. Benvenuti et al. Decreasing surface outgassing by thin film getter coatings. *Vacuum*, 50(1-2):57–63, 1998.

[7] N. Hilleret, C. Scheuerlein, M. Taborelli. The secondary electron yield of air exposed metal surfaces. *Applied Physics A*, 76:1085, 2003.

[8] http://ab-abp-rlc.web.cern.ch/ab%2Dabp%2Drlc%2Decloud/.

[9] A.L. Hanson et al. Electron emission from ion bombarded stainless steel surfaces coated and non-coated with TiN and its relevance to the design of high intensity storage rings. *Journal of Vacuum Science and Technology*, A19 (5):2116, 2001.

[10] E.L Garwin F.K. King R.E. Kirby and O. Aita. Surface Properties of Metal-Nitride and Metal-Carbide films deposited on Nb for radio-frequency superconductivity. *Journal of Applied Physics*, 61(3), 1987.

[11] R.E. Kirby, F.K. King. Secondary Emission Yield from PEP-II accelerator material. *Nuclear Instruments and Methods in Physics Research A*, A469, 2001.

[12] P. He et al. Secondary Electron Emission Measurements for TIN coatings on the Stainless Steel of SNS Accumulator Ring Vacuum Chamber. In *EPAC 2004*, 2004. SLAC-PUB-10570.

[13] B. Henrist. Mesure du taux d'electrons secondaires, echantillons de TiN sur acier AISI 304. Technical report, CERN-LHC-VAC 98-03, 1998.

[14] P. Prieto and R.E. Kirby. X-ray photoelectron spectroscopy study of the diference between reactively evaporated and direct sputter-deposited TiN films and their oxidation prperties. *Journal of Vacuum Science and Technology*, A13(6), 1995.

[15] S. Kato, M. Nishiwaki. Study on Electron Emission from Some Metals and Carbon Materials and the Surface Characterization. In *49th AVS*, 2002.

[16] F. Le Pimpec, F. King, R.E. Kirby, M. Pivi. Properties of TiN and TiZrV Thin Film as a Remedy Against Electron Cloud. *Nuclear Instruments and Methods in Physics Research A*, 551 (2-3):187–199, 2005.

[17] F. Le Pimpec, F. King, R.E. Kirby, M. Pivi. The effect of gas ion bombardment on the SEY of TiN, TiCN and TiZrV coatings for suppressing collective electron effects in storage rings. *Nuclear Instruments and Methods in Physics Research A*, 564:44–50, 2006.

[18] F. Meli, Z. Sheng, I. Vedel, L. Schlapbach. XPS analysis of the getter mechanism and getter activation process. *vacuum*, 41(7-9):1938, 1990.

[19] C. Benvenuti et al. A Novel Route to Extreme Vacua : the Non Evaporable Getter Thin Film Coatings. *Vacuum*, 53:219, 1999.

[20] I. Bojko Private comunication, CERN.

[21] B. Henrist, N. Hilleret, C. Scheuerlein, M. Taborelli. The secondary electron yield of TiZr and TiZrV non-evaporable getter thin film coatings. *Applied Surface Science*, 172:95–102, 2001.

[22] P. Chiggiato, P. Costa Pinto. TiZrV non-evaporable getter films: From development to large scale production for the Large Hadron Collider. *Thin Solid Films*, 515:382, 2006.

[23] N.M. Gupta, V.P. Londhe, V.S. Kamble. Gas-Uptake, Methanation, and Microcalorimetric Measurements on the Coadsorption of CO and H_2 over Polycrystalline Ru and a Ru/TiO_2 Catalyst. *Journal of catalysis*, 169:423–437, 1997.

[24] E. Wallen. Adsorption isotherms of H2 and mixtures of H2, CH4, CO, and CO2 on copper plated stainless steel at 4.2 K. *Journal of Vacuum Science and Technology*, A14(5):2916, 1996.

[25] Y. Suetsugu et al. Continuing study on the photoelectron and secondary electron yield of TiN coating and NEG (TIZrV) coating under intense photon irradiation at the KEKB positron ring. *Nuclear Instruments and Methods in Physics Research A*, 556:399, 2006.

[26] M. Pivi et al. ILC Electron Cloud R&D Tests in PEP-II: SEY station and rectangular groove chambers break. In *Ecloud, Daegu Korea*, 2007.