

UNDERSTANDING OF ION INDUCED DESORPTION USING THE ERDA TECHNIQUE *

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Abstract

In heavy ion synchrotrons like SIS18 at GSI high energetic ions can impact on the beam pipe and release gas molecules. This ion induced desorption deteriorates the accelerator vacuum and, as a consequence, the beam life time and luminosity. The desorption yield describes the number of released particles per incident ion. At the beginning of 2003 we have started phenomenological measurements on the desorption yield of various materials bombarded with different ion beams. In order to understand the physics behind ion induced desorption in more detail we have combined the desorption yield measurements with an *in-situ* material analysis using the ERDA technique. With this experimental setup we are able to show clear correlations between the material properties and the desorption behavior, e.g., we can show how the oxide layer on metallic samples influences the desorption even though the sputtered oxide is not the major content of the released gas.

INTRODUCTION

For the GSI future facility FAIR, SIS18 as injector for the SIS100 and the SuperFRS has to provide 10^{12} U^{28+} ions per second [1]. During this high current operation a dynamic vacuum in the lower 10^{-12} mbar regime is required. Presently beam correlated pressure rises are limiting the life time of the ion beam: ions interact with the beam pipe and atoms/molecules are released resulting in a pressure increase. In the following turns of the beam in the ring accelerator this “residual gas target” will trigger higher charge exchange rates leading to a self amplifying beam loss.

Since 2003 experiments were carried out at GSI measuring the desorption yield for various materials and surface treatments as well as for different projectile ions and energies using the pressure rise method [2]. For both, projectile ion and energy variation we found a dependance of the desorption yield on the electronic energy loss $\propto (dE/dx)^2$.

However, the phenomenological measurements suffer in information on the origin of the desorbed gas and the target properties. To investigate the ion induced desorption in a more controlled way we have combined a desorption yield experiment with an *in-situ* material monitoring using the Elastic Recoil Detection Analysis (ERDA). This technique allows us to distinguish between surface and bulk effects by the information on the target properties and possible modifications under ion irradiation.

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EXPERIMENTAL

ERDA Setup and Irradiation

The ERDA technique is a well established ion beam analysis tool in material research and details are described elsewhere [3]. Briefly, if swift heavy ions hit the samples surface at flat incident angles, target atoms are scattered elastically out of the sample. In our setup we measure the forward scattered recoil ions in a ΔE - E_{rest} analyzer where the ΔE measurement is realized by a drift path through a buffer gas (ionization chamber) and the E_{rest} detection is done with a solid state PIN diode. While the energy loss of a recoil ion in the buffer gas is a function of the atomic number Z , the residual energy E_{rest} is a function of the origin of the recoil ion inside the sample, since the beam ion as well as the recoil ion lose energy on their way through the sample. Therefore, we achieve an element specific depth profile of the irradiated probe.

To be close to the application in the accelerator and to have highest sensitivity during the pressure measurement, UHV conditions at a pressure of few 10^{-11} mbar are required. In addition to the ERDA detector the UHV chamber is equipped with an extractor gauge and residual gas analyzer to measure desorption yields in parallel.

For the experiments described here we used ^{136}Xe at an energy of 1.4 MeV/u delivered from the high charge state injector (HLI) of GSI. During the stainless steel run the charge state was 19^+ and for the copper run 21^+ .

Targets

To figure out the connection between desorption and the oxide layer on metals we decided to investigate the following targets.

Stainless steel: Stainless steel is the most used standard beam pipe material. It is known to have impurities like C, N and O but also Al and Si components. This components might contribute to the desorbed gas. The sample was standard cleaned and vacuum fired 316LN stainless steel.

Copper: Copper is also used for beam tubes or vacuum vessels. In contrast to stainless steel it is available with highest purity, e.g., OFHC copper, 99.95%. The surface is known to grow a copper oxide layer quickly. We have prepared two samples out of the same piece of copper: One was polished like accelerator cavities. After the polishing is was standard cleaned and dried for 4 h at 200°C . The second sample was lapped in the target laboratory of GSI. It has a higher surface roughness compared to the

polished one. After lapping it was cleaned with an acid and mounted in the vacuum chamber with minimum exposure to air. Later we will give a preliminary outlook on investigations on gold coated copper samples since gold is not susceptible for oxidation.

All samples were baked together with the vacuum chamber at 200° C for 5 days.

RESULTS AND DISCUSSION

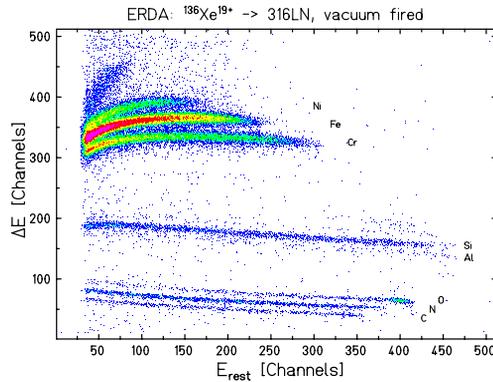


Figure 1: ERDA raw spectrum of the 316LN sample. Each ΔE branch represents an element while E_{rest} is a function of the depth in the target.

Stainless steel: Fig. 1 shows the raw ERDA spectrum of stainless steel. In this 2-dimensional representation the energy loss of the recoil ions is plotted versus their residual energy after passing the ionization chamber. One can clearly see the different elements of the stainless steel separated as branches. A high energy recoil ion belongs to the surface and a low energy recoil ion to the bulk of the sample. Here, one can clearly see the main components of stainless steel Fe, Cr and Ni as the three high Z branches (upper part of the spectrum). In addition one can see also contents like C, N and O as well as Al and Si.

For the oxide a concentration on the surface representing the oxide layer is visible. In parallel to the ERD analysis the desorption is measured by the pressure rise inside of the vacuum chamber. In Fig. 2 the sputtering of the oxide layer is compared to the pressure evolution during irradiation. The upper part shows the evolution of the oxygen concentration on the surface normalized to the Fe content. One can see a decrease of the oxide peak during the irradiation due to sputtering. The lower spectrum shows the pressure evolution: the initial pressure rise was measured to be $9 \cdot 10^{-10}$ mbar, corresponding to a desorption yield around 270. The pressure is decreasing comparable fast and after a dose of few 10^{13} Xe^{19+} ions the desorption was limited to a constant value of around 60. The measured residual gas composition was dominated by CO, followed by CO_2 and H_2 .

From the comparison it is obvious that the oxide layer on the stainless steel is not the source for desorption, since the slopes of both curves are different: after a certain dose

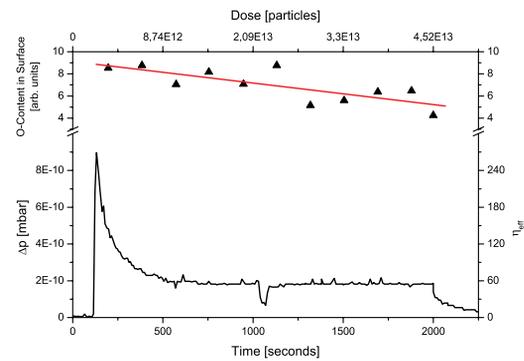


Figure 2: Dose dependent evolution of the oxide layer (top) and the desorption yield (bottom).

we archive a constant desorption on a comparable low level but the oxygen is only sputtered by a few percent.

Copper: In Fig. 3 the ERDA results for the two copper samples are shown in comparison. Both, the polished and the lapped copper show no contaminations in the bulk. While the lapped probe has a very small C, O and Al (from the treatment) contamination at the surface, the polished copper shows a huge oxide layer with the same amount of oxide as copper corresponding to a CuO layer. In the lower part of Fig. 3 the oxygen profile for the two samples is shown. In direct comparison and normalized to the copper content the oxide concentration on the polished probe was measured to be ≈ 30 times higher compared to the one on the lapped sample. During the irradiation a huge pressure rise was observed for the polished, oxidized copper corresponding to a desorption yield of 1500. The value for the lapped probe with minor oxide was 300. Even though the element profile did only change slightly within our sensitivity the desorption yield decreased to 80 for the polished resp. 15 for the lapped probe after a dose of around $3 \cdot 10^{12}$ Xe^{21+} -ions. The slightly higher desorption yield of the lapped copper in comparison to the stainless steel could be explained due to the higher surface roughness from the lapping procedure. This observation shows clearly the source of desorption: whereas both samples have the same bulk properties they show up a completely different surface. The lapped copper has a metallic surface with minor contaminations. The polished copper shows a highly oxidized, most probably insulating CuO surface. The time resolved analysis again shows that the oxide layer is not the source of the desorbed gas. Nevertheless it somehow seems to trigger a higher desorption of adsorbed gas.

Since oxide free, clean copper turned out to be a low desorption material the question arises how to prevent the copper from oxidation. A possible solution could be a thin gold layer on top of the copper. We have tested two different gold coating techniques: coating by evaporation and galvanically coating. Fig. 4 shows the ERDA results for the two different gold coated copper samples. The bulk of

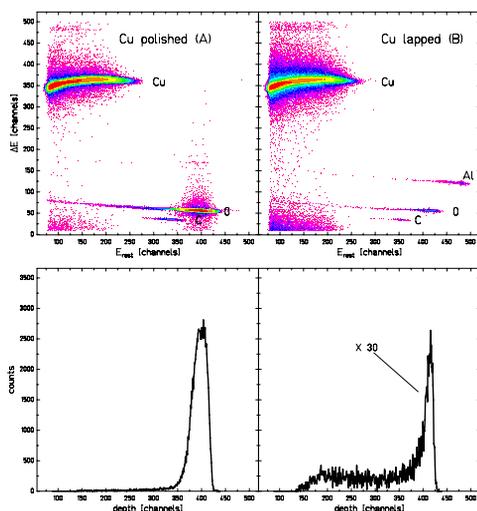


Figure 3: ERDA spectra of the copper samples. Left: polished with a huge oxide layer, right: lapped with few contaminations.

both samples is very clean. The sample with the evaporated gold shows very little C in the gold layer. The galvanically coated probe contains significant amounts of C, N and O as well as P inside of the gold layer. Nevertheless none of the coated samples shows a pronounced surface oxidation. We observed an initial pressure rise Δp between $3.8 \cdot 10^{-10}$ and $4.3 \cdot 10^{-10}$ mbar for both samples corresponding to a desorption yield η of 190 for thermally coated copper and 220 for the galvanically coated copper. A clear decay (beam scrubbing) was visible after irradiation with a dose of $2 \cdot 10^{13}$ Xe¹⁹⁺-Ions, but still a small Δp was left corresponding to yields between 15 and 30. Nevertheless the element profiles of the probes did not change significantly during irradiation.

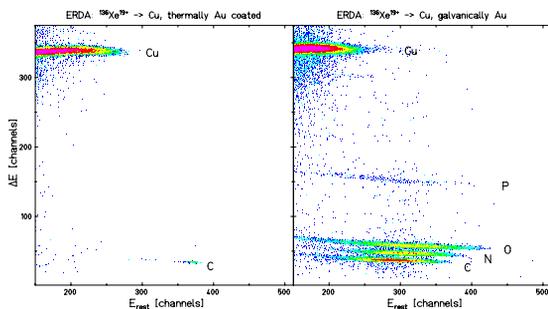


Figure 4: ERDA spectra of the two gold coated copper samples.

CONCLUSION AND OUTLOOK

For all investigated samples we measured an initial pressure rise followed by a decay, the so-called beam scrubbing. In all cases a small Δp ("base level" desorption) was remaining. The highest base level was observed for the ox-

idized copper sample. The change in the composition of all samples –like the sputtering of C, N and O– was always too small to explain the observed desorption yields.

The components of the desorbed gas were measured to be always CO, CO₂ and H₂. These gases also dominate the residual gas distribution in an UHV environment leading to the conclusion that the desorbed gas is delivered from surface adsorbates weakly bound to the sample. But the desorption of these adsorbates is highly correlated to the substrate properties. For example, an oxidized surface shows significantly higher desorption yields. This leads to the conclusion that the desorption of the adsorbates is linked to the sputtering of the substrate. Here, oxides are known to have high sputter yields [4]. The higher sputter yield can be explained by the Thermal Spike Model [5]. Since the copper oxide is an insulator the mobility of the electrons and therefore the thermal conductivity is strongly reduced compared to a metal. Within the Thermal Spike Model the sputter yield is linked to the thermal conductivity of the probe: A low thermal conductivity results in a high temperature of the ion track core and in consequence in high sputter yields compared to materials with a high thermal conductivity where the electrons are moderating the temperature distribution. In addition we also observe a slightly different base-level desorption for the different materials resp. treatments. This base-level desorption also seems to be linked to the sputtering: The cleaner the sample the lower the base-level desorption.

From the results obtained we can propose low desorbing materials which can be placed in the accelerator to collect lost beam ions. This materials must be high conducting and should not have any oxide layer. Also the coating itself as well as the bulk have to be as clean as possible to keep the remaining desorption yield small. For that reason the thermally gold coated copper is at present the best for the application. Furthermore, it is necessary to keep this collectors during bake out and cool down at a higher temperature compared to the environment to minimize the adsorbing of gas during cool down. In addition, beam loss should occur always under perpendicular incidence.

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