UHV-ERDA Investigations on Ion Induced Desorption ◇

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Introduction

In heavy ion accelerators the beam line vacuum is effected by lost ions impinging on the beam pipe. Due to ion induced desorption gas is released from the walls into the vacuum. This vacuum degeneration effects the ion beam life time and is a serious luminosity limitation for a heavy ion synchrotron like SIS18. Similar problems have been seen at CERN, BNL and FermiLab. Here we report on a new approach to understand the physics of the ion induced desorption using ion beam analysis. The technique is briefly introduced and first results with a silicon target are presented, showing a clear correlation between the desorption yield and the material constitution.

In 2003 an experimental program was started at GSI to measure desorption yields (desorbed particles per incident ion) in a dedicated test stand in continuation of similar experiments at CERN/LEAR [1]. Within these experiments, various materials and surface treatments have been investigated as well as a variety of beam parameters. A dependence was observed of the desorption yield on the electronic energy loss of the projectile ion inside of the material [2].

In parallel to these phenomenological investigations an UHV-ERDA set-up was taken into operation 2005 in order to understand the effects of ion induced desorption in more detail. ERDA allows an element specific depth profiling of the first 1000 nm of a sample with a resolution of about 20 nm. This depth profiling can be carried out *in-situ* parallel to desorption yield measurements using the same ion beam.

UHV-ERDA Technique

The need of a UHV environment during ion beam analysis is unusual. Here, it is necessary to be close to the application in the accelerator, where we have an average pressure in the lower 10^{-11} mbar range to minimize readsorption of residual gas on the sample and to be sensitive to low desorption yields, i.e. low pressure rises.

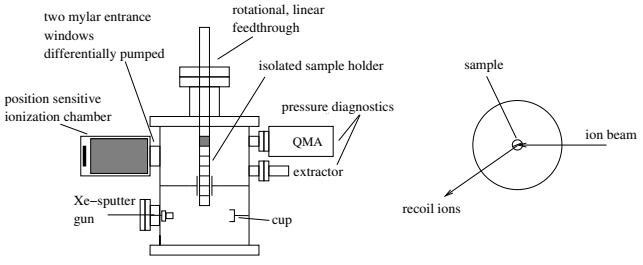

Fig. 1: Schematic of the UHV setup and the scattering geometry.

Therefore, the UHV-ERDA setup from the Munich accelerator laboratory [3] was transfered to GSI and modified to meet the new requirements. The essential parts of the UHV chamber, the irradiation geometry and the vacuum diagnostics are sketched in Fig. 1. In parallel to the ERDA measurements the desorption yield and the partial pressure distribution can be measured with an extractor gauge and a quadrupole mass analyzer (QMA). All data are stored event-by-event in listmode format allowing a later time resolved analysis.

All samples can be cleaned by a Xe-sputter gun in the lower part of the UHV chamber (Fig. 1). The Xe-sputter gun can operate up to 8 keV total energy with an average flux of $1{\cdot}10^{13}$ ions s^{-1}. This sputter gun can be used to remove surface contaminations like an oxide layer effectively and *in-situ*.

The UHV setup is installed on a new beam line at the HLI (high charge state injector) where the ion energy is fixed to 1.4 MeV/u. Fig. 2 shows a typical ERDA spectrum of stainless steel irradiated with 183 MeV Xe^{18+} ions: One can clearly see all stainless steel components such as Cr, Fe and Ni, also the light components C, N and O and as intermediate component Si.

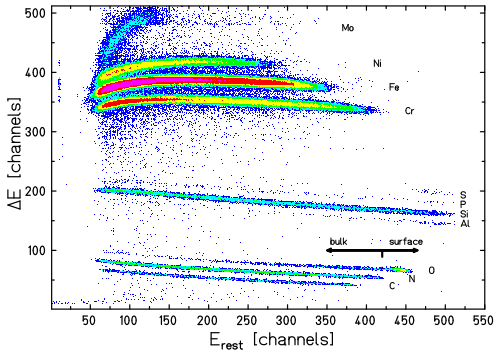

Fig. 2: A typical ΔE - E_{rest} spectrum measured with 1.4 MeV/u Xe^{18+} ions on stainless steel. Different elements are indicated.

Experimental Results from Silicon Samples

Silicium samples have already been investigated in the desorption yield test stand and have shown a quite low desorption yield of about 3 released particles per 1.4 MeV/u C^{2+} ion impact [4]. The desorbed gases are predominantly H_2, CO and CO_2. It is well known that H is dissolved in nearly all materials, even in extremely pure Silicon wafers. Unclear, however was the origin of CO and CO_2. To understand this in detail ERDA measurements have been carried out in parallel to total and partial pressure measurements.

Fig. 3 shows the total and partial pressure evolution for a Si wafer irradiated with 1.4 MeV/u Ca^{10+} projectiles with a time structure of 40 pulses per sec. and a pulse length of 5.5 ms. The number of ions per pulse is approximately $1{\cdot}10^8$. The beam spot is 20 mm^2. This corresponds to a flux of about $2{\cdot}10^{10}$ ions s^{-1} cm^{-2}. One can observe a total pressure increase of approx. $1{\cdot}10^{-9}$ mbar dominantly caused by H, CO and CO_2 desorption. In addition one can see, that this pressure increase is decaying as a function of the ion flux, sometimes called *beam scrubbing*. This cleaning or scrubbing can be observed for all gas components

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except H, which is dissolved in the Si bulk and therefore represents a nearly "infinite" reservoir.

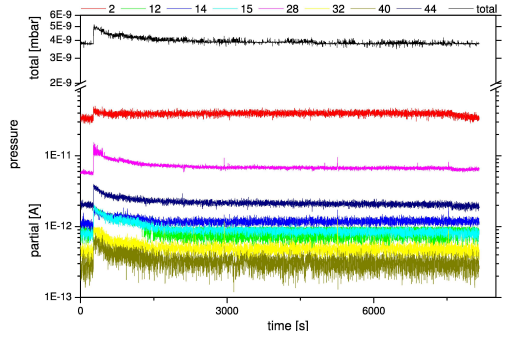

Fig. 3: Desorption yield measurements of a Si wafer irradiated with 1.4 MeV/u Ca^{10+} ions. The top line shows the total pressure evolution (N_2 equivalent), the lower lines (top/down) partial pressure of H, C, N, NH, CO and others.

Parallel to the pressure measurements an ERD analysis of the target was performed and the result is shown in Fig. 4: In contrast to the stainless steel probe, the Si sample is quite "clean". Only few C, N, O and F (from cleaning) contaminations are visible on the surface.

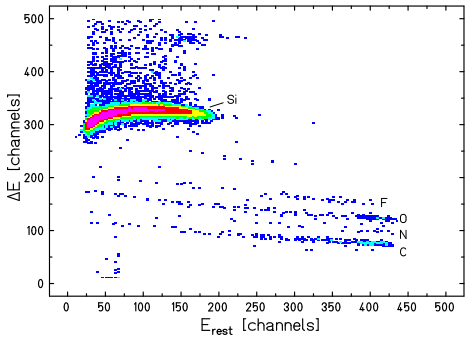

Fig. 4: ΔE - E_{rest} spectrum for Si. The projectile ion was Ca^{10+} with 1.4 MeV/u impact energy.

From ERDA the desorption of the C, N and O contamination as a function of the ion flux can be extracted and correlated with the pressure evolution shown in Fig. 3.

Discussion

Using the UHV-ERDA technique we have for the first time shown clear correlations between target properties and the corresponding ion induced desorption yield. The observed CO and CO_2 desorption from Si is caused by surface contamination. These contaminations are sputtered under ion beam bombardment leading to a cleaning of the target resulting in a decrease of the pressure rise down to the detection limit. Consequently, completely clean samples should show no desorption, except H and the sputtering of the target material itself.

Outlook

To verify the results further experiments have to be carried out with special focus on materials which can be easily used in accelerators. Stainless steel is not suitable, since the C, N and O contaminations are not only on the surface but in the whole bulk, representing an "infinite" reservoir for desorption.

A good candidate is Cu which can be produced in very high purity, comparable to Si. A disadvantage is the oxidation of Cu under atmosphere, which will again lead to a high desorption yield. In our ERDA setup this oxide layer can effectively be removed by the Xe-sputter gun, allowing a detailed study of the influence of the oxide layer on Cu. In additional experiments will be performed with "terminated" Cu surfaces, e.g., by pure Au coatings.

References

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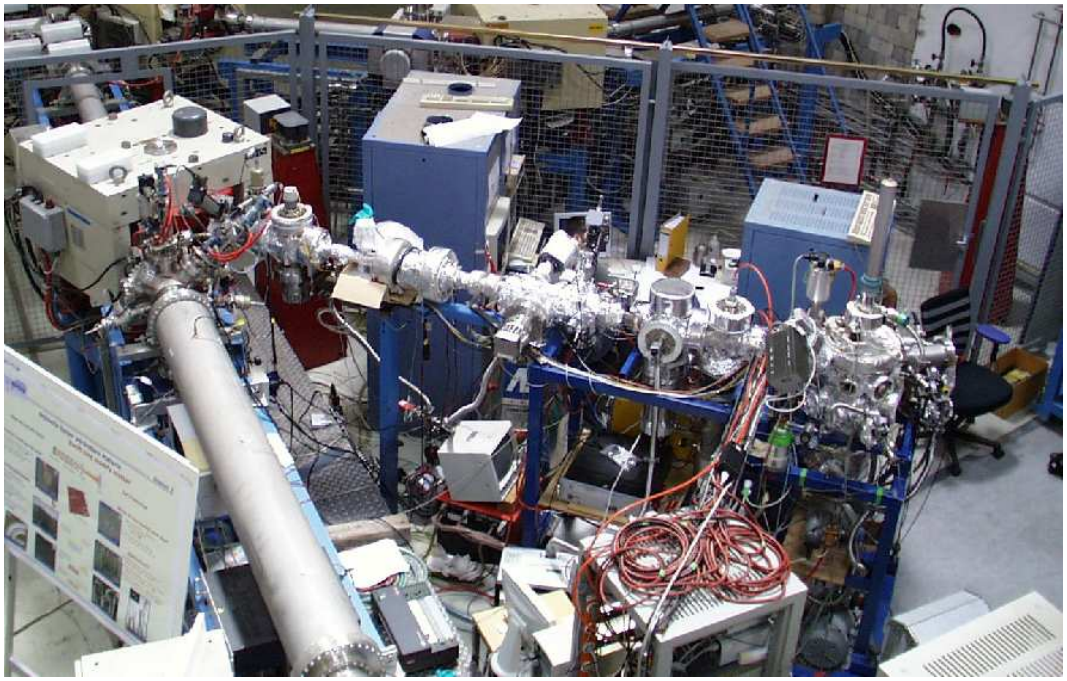

Fig. 5: The Munich UHV setup in the new HLI beam line at GSI.