R&D VACUUM ISSUES OF THE FUTURE GSI ACCELERATOR FACILITIES

H. Reich-Sprenger, H. Kollmus, A. Krämer, M. Bender, J. Kurdal, M.C. Bellachiamo and P. Spiller
GSI, Darmstadt, Germany

Abstract

The new GSI accelerator facilities (FAIR project) are planned to deliver heavy ion beams of increased energy and highest intensity [1]. Whereas the energy is planned to be increased roughly by a factor of 30, the ion beam intensities are planned to be enlarged by three orders of magnitude. To achieve highest beam intensities, medium charged heavy ions (e.g. U^{28+}) are accelerated. Since the ionization cross sections for these ions are comparably high, a UHV-accelerator system with a base pressure in the low 10^{-12} mbar regime is required, even under the influence of ion beam loss induced desorption processes.

An intensive program was started to upgrade the UHV system of the existing synchrotron SIS18 (bakeable) and to design and lay out the UHV systems of the future synchrotrons SIS100 and SIS300 (mainly cryogenic). One special technical difficulty common to SIS18 and SIS100 is the restriction on thin walled (<0.5mm), large aperture vacuum chambers, which have to withstand 300°C bakeouts or liquid helium temperatures inside the fast cycling magnets (minimum eddy – currents).

The strategy of this program includes basic research on the physics of the ion induced desorption effects as well as technical developments, design and prototyping on bakeable UHV components (vacuum chambers, diagnostics, bakeout-control, pumping speed), collimator for controlled ion beam loss, NEG coating and cryogenic vacuum components.

ION BEAM LOSS INDUCED DESORPTION

A vacuum pressure increase during a high intensity U^{28+} run in SIS-18 was observed for the first time in 2001 [2]. It was noticed that the lifetime of the ions was no longer independent of the injected ion current. During injection ions are lost at the chamber wall or other aperture limiting devices and desorb there gas molecules. This leads to a pressure increase and therefore to a higher charge exchange rate and again to ion losses, which cause further desorption. Similar observations where reported in Ref. [3]. Here the desorption coefficient is about 10^4 molecules/ion. Out of the data measured at SIS-18 it was possible to calculate the ion induced desorption yield to 11000-27000 [4]. To confirm this observation a dedicated experiment was done. Therefore the U^{28+} ion beam was steered onto the chamber wall and a pressure increase of 3.5 10^{-11} mbar was observed. This increase corresponds to a desorption yield of 5200 and is in good agreement with previous observations [5].

Based on this experience and on measurements from CERN [6] two dedicated test stands were setup with the aim of measuring ion induced desorption yields more systematically and of finding an understanding of the underlying physical processes.

Experimental Set-up

The set-up of the desorption experiment [7] consists of two differential pumping stages and the experiment chamber itself. It is connected via a long conductance limiting tube (compare Fig. 1). The total pressure is measured with an extractor ion gauge, the partial pressures with a residual gas analyzer. The targets are mounted on a sample holder at a linear feedthrough. Up to 20 different targets (size: 50x50mm), including an Al_2O_3 fluorescence screen, were measured during one experiment.

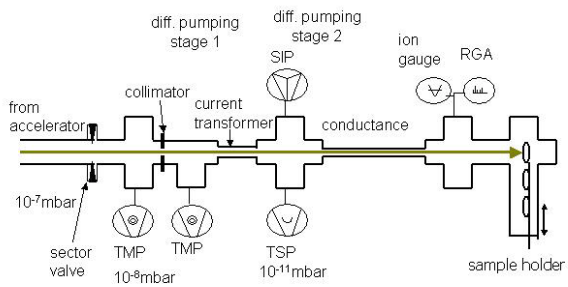

Figure 1: Experimental set-up at 1.4MeV/u with differential pumping stages.

The set-up was placed at a beam line at the HLI (high charge state injector) at GSI, where the only available beam energy is 1.4 MeV/u. Three different beam times were performed using three different ions on various targets. The intensities of the ion pulses varied between $1 \cdot 10^9$ and $1 \cdot 10^{11}$ ions. To measure the desorption yield in dependence of the intensity it was possible to change the pulse length between 300 µs to 5ms. All measurements were done under perpendicular incidence.

Out of the total pressure increase and with the help of the ideal gas law it is possible to calculate the ion induced desorption yield η_{eff}:

$$\eta_{eff} = \frac{\Delta p \times V}{N \times k_B \times T} \qquad (1)$$

with Δp the pressure increase, V the chamber volume, N the number of ions per pulse, k_B the Boltzmann constant and T the temperature.

Results and Discussion

In the experiments the ion beam induced desorption yield for three different projectile ions (Pb^{27+}, Cr^{7+} and C^{2+}) and six different targets was measured. A summary of the results is shown in Fig. 2.

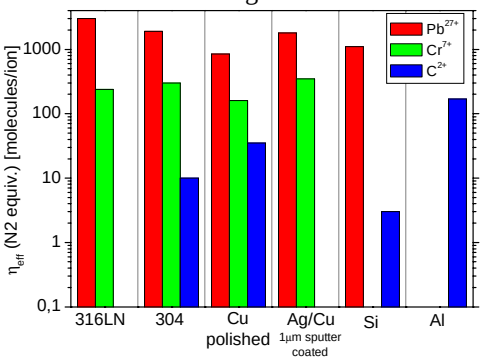

Figure 2: Summary of measured desorption yields.

The desorption yields vary between 3 and 3000 molecules per ion (in N_2 equivalent) and increase with mass and charge state of the projectile ion. The results of the Pb^{27+} beam time are consistent within a factor of 2–3 with desorption yields observed at CERN by E. Mahner et al. [6]. The measured partial pressure distribution under ion bombardment was dominated by H_2 and CO. The described experimental setup has been moved to the SIS18 experimental area and further experiments with coated targets, pumping surfaces and cryogenic vacuum chamber walls , as well as experiments at higher energies (from 10 MeV/u (SIS18 injection energy) to 100MeV/u (SIS100 injection energy)) will be performed in October of 2004. In order to get a deeper insight into the physics of the ion loss induced desorption, a second experimental setup for element specific in-situ target analysis using Elastic Recoil Detection Analysis (ERDA) [7],[8],[9] was built up to observe correlations between desorption yields and surface and bulk characteristics of the target. This setup was installed at the GSI HLI injector beamline (1.4 MeV/u fixed energy) and will give an experimental access to the element composition of the target material up to a surface depth of 1 µm under ion beam bombardment (see figure 3). Figure 3 shows as an example a measurement performed at the Munich tandem accelerator with an 1MeV/u Au^{30+} ion beam bombarding a Ti target [10]. The aim of the ERDA experiments is to find an answer to the question from where the desorbed gas species are released: from inside the bulk material or from the surface. First measurements are planned at the end of 2004.

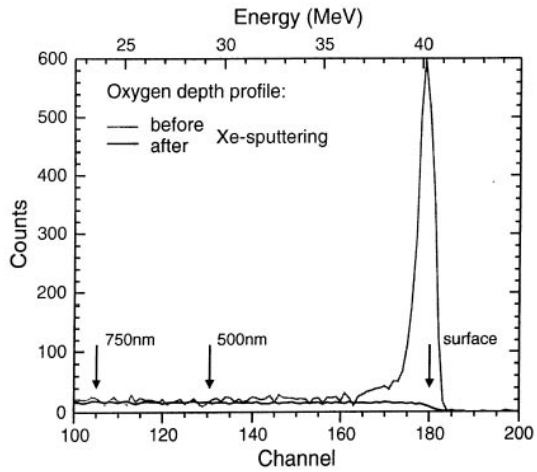

Figure 3: ERDA measurement with 1MeV/u Au^{30+} on Ti [10], Oxygen depth profile (concentration) before and after Xe sputtering treatment of the Ti target

SIS18 UHV UPGRADE

The aim of the SIS18 UHV Upgrade program is to improve the lifetime of high intensity medium charged heavy ion beams to values well above the synchrotron cycling time. The concept to reach this is based on optimized base pressure, increased pumping speed and controlled sources of desorption.

Optimized Base Pressure

One precondition to operate an UHV accelerator system in the low 10^{-12}mbar regime is a bakeout ability to a design value of 300°C of all vacuum components. Since several leakages of the thin walled SIS18 dipole chambers during high temperature bakeouts caused long term reparations, it was decided to procure a complete set of 24 dipole chambers of improved design. Together with a new designed bakeout equipment, these chambers were succesfully tested and will replace the existing dipole chambers during long time shutdown periods. A second precondition for an optimized base pressure is an optimized pumping speed of the existing system of ionpumps monitored by a powerful partial pressure and total pressure analysis. The existing system was upgraded in 2002 and 2003 to a number of 20 calibrated extractor gauges and 7 Residual Gas Analysers (RGAs), permanently controlled by a PC-based data aquisition.

Increased Pumping Speed and Collimation

Beside the optimization of the existing ionpumps, additional pumping speed is planned to be introduced to the UHV system of the SIS18: cryo-pumps are able to increase the local pumping speed for almost all gas species, novel techniques such as thin film coated vacuum chambers could provide huge pumping speeds for chemical reactive gas species. In 2004 two cryo-pump systems were adapted to the SIS18 UHV system for

testing. One of these cryo-pumps was connected to a newly designed collimator with a cryo-pumped ante-chamber for desorbed gases (see figure 4). The preparation of thin film coatings (first vacuum arc NEG coatings see figure 5) and the characterization of these films was started in 2004. Figure 5 shows as an example SEM pictures of thin film coated samples of comparable surface roughness and structure, prepared with different coating techniques. The decision if these techniques could be used in large scale inside an upgraded SIS18 UHV system, strongly depends on the results of the experimental program (desorption).

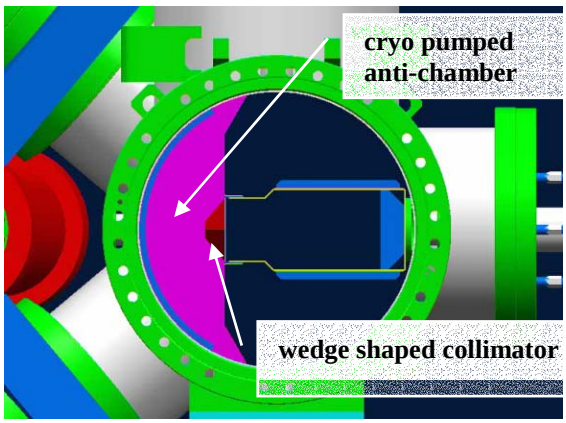

Figure 4: SIS18 collimator (mounted on a linear feedthrough from right side) with cryo-pumped anti chamber (left side), installed in 2003 [12]

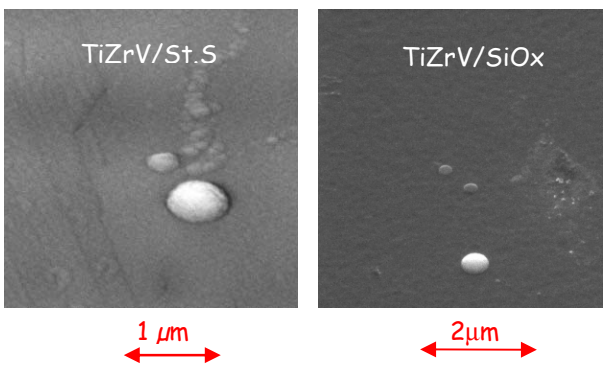

Figure 5: SEM pictures of NEG (TiZrV) coated samples. Left: sputter coated sample (stainless steel) [11], Right: first GSI vacuum arc coated sample (SiO)

SIS100 / SIS300 UHV SYSTEM DESIGN

Cryogenic Sections

The magnets of the new double synchrotron SIS100 / SIS300 will be superconducting. A technical study on possible vacuum chamber materials was performed in 2003 and in 2004 [13], and detailed design work and prototyping will follow in 2005. Under discussion for the SIS100 are thin walled dipole chambers of INCONEL® 625 or P506® or a vacuum chamber design using Al_2O_3 . For the SIS300 dipole magnet chambers comparable large wall thicknesses (up to 2.5mm) can be accepted, so that standard UHV compatible materials such as AISI 304 or AISI 316LN are being discussed .

Bakeable Sections

The design of the bakeable sections of the SIS100 and SIS300 will strongly depend on the results of the SIS18 UHV upgrade: all developed techniques will be implemented and tested in the first prototype bakeable section, which is planned to be built up in 2005.

REFERENCES

[1] W. Henning, "An International Accelerator Facility for Research with Ions and Antiprotrons" , EPAC 04 proc.
[2] A. Krämer et al., Proc. EPAC2002, Paris, 2547 (2002)
[3] J. Hansen et al., LHC/VAC Note 2001-007, PS/AE Note 2001-009 (2001)
[4] E. Mustafin et al., NIM A510, 199 (2003)
[5] U. Weinrich et al., GSI Internal Report (2002)
[6] E. Mahner et al., PRST-AB6, 013201 (2003)
[7] M. Bender, H. Kollmus and A. Krämer , GSI annual report 2003
[8] W. Assmann et al, NIM B118, 242-250, (1996)
[9] M. Bender, diploma thesis, GSI 2003
[10] H.D. Mieskes, NIM B 146, 1998
[11] C.Benvenuti et al., Vacuum 60 (2001) 57-60
[12] P. Spiller, GSI annual report 2003
[13] S. Wilfert and K. Keutel, "Die kryogenen Vakuumkammern der supraleitenden Magnete der Schwerionen Synchrotron-Ringe SIS100/300", GSI internal report (2004)