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Molecular desorption of baked stainless steel from irradiation with 9 GeV/nucleon Au^{79+}, 10 GeV/nucleon Cu^{29+}, and 23 GeV p^+ under perpendicular impact

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DISCLAIMER

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Abstract

We report on molecular desorption of baked stainless steel from irradiation with high energy ions under perpendicular impact. Ion induced molecular desorption has affected the performance of a number of ion accelerators, in which the beam loss typically occurs under small angles. However, experimental parameters can be easier controlled in measurements with perpendicular impact. Desorption coefficients for small angle impact can be estimated from these measurements. The measurements were carried out at Brookhaven's Relativistic Heavy Ion Collider.

INTRODUCTION

The desorption coefficient η is defined as the number of released molecules per incident ion. Measurements of the molecular desorption yields with ions in the GeV/nucleon energy range started only recently [1, 2]. Previous measurements extended to energies of a few MeV/nucleon only [3–9]. A summary of measurements was published in Ref. [10]. Reported desorption coefficients η for energies from 1 MeV/nucleon to 158 GeV/nucleon range from 10 to about 10^4.

Knowledge of these desorption yields is important for the design and operation of heavy ion machines in which large enough losses cannot be localized. These are typically machines that operate with ions that are not fully stripped. Operational problems were encountered at the SIS18 [11–13] and AGS Booster [13, 14], and were a concern for LEIR [15]. In RHIC molecular desorption from beam losses was suspected to contribute to the observed dynamic pressure rise [16], but it was later concluded that all operationally relevant pressure rises are caused by electron clouds. The ion beam losses in RHIC are not due to charge exchange processes, and are localized at either the collimators or another limiting physical aperture.

Here we report on molecular desorption measurements of stainless steel from irradiation with 9 GeV/nucleon Au^{79+}, 10 GeV/nucleon Cu^{29+}, and 23 GeV p^+ ions under perpendicular impact. The main beam and vacuum parameters are listed in Tab. 1. From Ref. [17], and given the measured RHIC beam pipe surface roughness, we expect an increase in η of about 2 orders of magnitude when going from a perpendicular to a grazing incident angle. The measurements were performed at the Relativistic Heavy Ion Collider (RHIC). RHIC consists of two 3.8 km long superconducting rings, named Blue and Yellow, with warm insertions.

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EXPERIMENTAL SETUP

A closed stainless steel vacuum valve was irradiated with the injected Au^{79+}, Cu^{29+}, and p^+ beams, and the pressure rise near the closed valve was observed on both sides of the closed valve. The experimental set-up is shown in Fig. 1. Tab. 2 lists the relative distance of the vacuum elements to the nominal interaction point (IP).

Measurements were taken in a warm interaction region of RHIC through which beam can pass in both directions. The interaction region extends to about 8.5 m to either side of the nominal beam interaction point IP. Close to the IP are on both sides a valve, an ion pump, and a cold cathode discharge gauge. Another ion pump and gauge is located 7.58 m from the IP on either side. On the left hand side a 5.85 m long NEG coated beam pipe was installed. The NEG coating was activated with a 2 hour bake at 250°C. From this we expect a pumping speed of about 5 $l \cdot s^{-1} \cdot cm^{-2}$ [18]. On the right-hand side, next to the pump P3 are 3 electron detectors, one of which contains micro-channel plates. Near the pump P4 are three beam shutters, which also increase the vacuum surface. Also mounted on P4 is a rest gas analyzer.

For a measurement a single stainless steel vacuum valve was closed. Beam was injected through the closed valve,

Table 1: Parameters relevant to the desorption measurment.

parameter	unit	Au^{79+}	Cu^{29+}	p^+
beam relativistic γ	...	10.52	12.07	25.94
kinetic beam energy	GeV/n	8.86	10.30	23.40
avg. bunch intensity	10^9	0.73	4.8	186
bunch spacing	s		4.0	5.1
bunches deposited	...	18-28	20-37	56
beam pipe diameter	m		0.1215	
pipe conductance, N_2	$m^4 \times s^{-1}$		0.22	
speed/pumps, N_2	$m^3 \times s^{-1}$		0.27	
speed of NEG, N_2	$m^3 \times s^{-1}$		25	
static pressure	10^{-11} Torr	5	2	100
year of measurements	...	2004	2005	2005

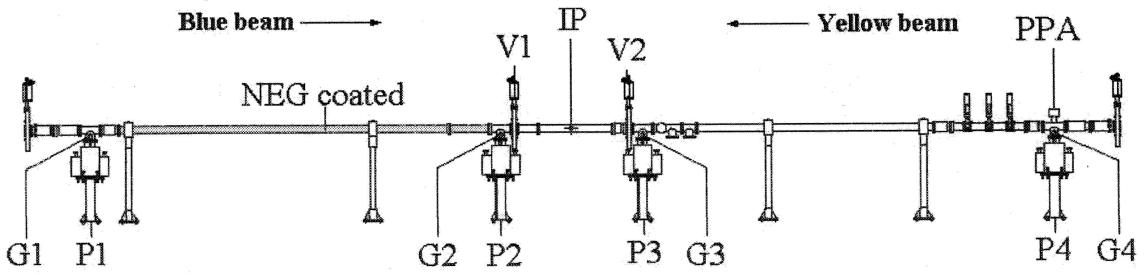

Figure 1: Layout of vacuum equipment. G denotes gauges, P pumps, V valves, PPA a partial pressure analyzer, and IP the nominal beam interaction point. On the left hand side is a 5.85 m section with activated NEG coating. Distances of elements relative to the IP are given in Tab. 2.

Table 2: Relative location of vacuum elements. All distances are with respect to the nominal interaction point. Negative values are to the left, positive values are to the right in Fig. 1.

element	distance to interaction point [m]
gauge G1	-7.58
pump P1	-7.58
gauge G2	-1.12
pump P2	-1.12
valve V1	-0.90
valve V2	+0.09
pump P3	+1.12
gauge G3	+1.12
pump P4	+7.58
gauge G4	+7.58

and dumped into a beam pipe wall after passing through a cold arc. The valves are 8 mm thick, and were baked for 24 hours at 200°C a few months prior to the measuement. The valves were not exposed to air during that time. The partial pressure analyzer PPA (see Fig. 1) can detect molecules with mass numbers 2 (like H_2), 15 (like CH_3), 18 (like H_2O), 28 (like CO), 32 (like O_2), and 41 (hydrocarbons like pump oil). H_2 is identified as the dominant source of the static pressure.

A total of 4 measurements were done: with valves V1 or V2 closed, and irradiated from both side for each of the two valves. Bunches were injected with either 4.0 s or 5.1 s apart (Tab. 1) until the pressure near the closed valve did not rise any more. Typically the pressure saturated after 20-30 bunches.

The pressure was observed with the gauges G1 through G4 (Fig. 1) on both the incoming and the outgoing side of the vacuum valve. Both G1 and G4 show consistently low readings, and only the gauges G2 and G3 were used to determine the desorption coefficient η. With enough bunches injected, and saturated pressure this is done using

$$\eta = \frac{\Delta p\, S}{\dot{N} k_b T} \qquad (1)$$

where Δp is the pressure rise, S the pumping speed, $\dot{N}$ the particle losss rate, k_b the Boltzmann constant, and T the absolute temperature. A more detailed description of the method is given in Refs. [19, 20].

The bunch intensity was measured with a current transformer in the transfer line to RHIC. After all measurements were completed, both Blue and Yellow beams were circulated in RHIC and the beam intensity transmission from the transfer line to the rings were determined.

MEASUREMENTS WITH GOLD BEAM

The pressure reading of the gauge G1 is consistently very low, near 1×10^{-11} Torr, and shows almost no change during the experiment. This may be because it is separated from the gas source by the 5.85 m long NEG coated pipe. The gauge G4 consistently shows, a relatively high reading, near 3×10^{-10}, also with little change during the experiment. Therefore, we will only use the gauges G2 and G3 in the analysis. The manufacturer specifies that in the pressure range between 10^{-11} Torr and 10^{-5} Torr the N_2 equivalent pressure reading shall be within a factor of 2 times the absolute N_2 pressure.

The gauge G2 shows a static pressure reading of 4×10^{-11} Torr, the gauge G3 of 6×10^{-11} Torr. This is consistent with the stated error for these gauges. After a valve is closed or opened the pressure reading the gauges G2 and G3 reaches up to 10^{-8} Torr. The pressure returns to the low reading within a few minutes, somewhat faster in G2 than in G3.

The pressure evolution and injected bunch intensities for the 4 measurements are shown in Fig. 2 for the closed valve V1, and in Fig. 3 for the closed valve V2. After a few bunches the gas load is balanced by the pumping speed and the pressure does not rise any more. Eq. (1) can then be used to determine η. Tab. 3 summarizes the calculated desorption coefficients. Note that half of the numbers in Tab. 3 are calculated from beam going into the valve, and the other half from beam going out of the valve. With Blue beam injected, the gauge G2 is used to determine η_{in}, and G3 to determine η_{out}. With Yellow beam injected, G2 is used to determine η_{out}, and G3 to determine η_{in}.

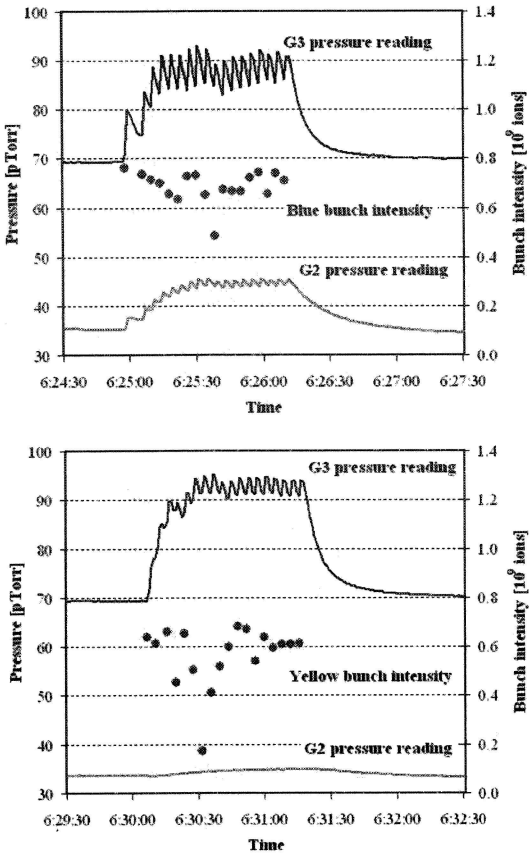

Figure 2: Measurements with gold beam and valve V1 closed. Injection of 18 Blue bunches (top), and 18 Yellow bunches injected (bottom).

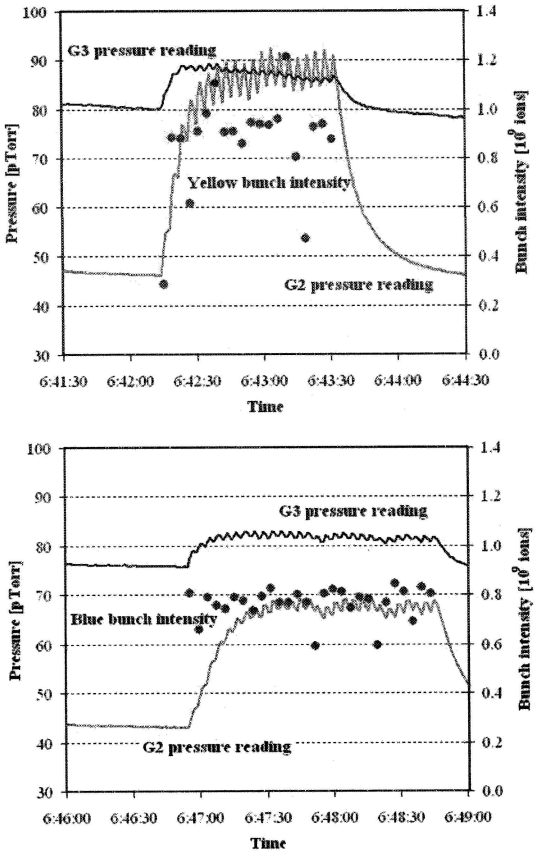

Figure 3: Measurement with gold beam valve V2 closed. Injection of 20 Yellow bunches (top), and 28 Blue bunches (bottom).

The calculated η values show a large variation, from 260 to 8000, with an average value of 2400. With the large variation, the error of η is at least of order factor 2. The source of the large variation is not known in detail. Contributions come from the uncertainty in the pressure reading, the uncertainty in the pumping speed (particularly the NEG section), and possible molecular desorption from the beam pipe walls after being hit by either beam particles, or fragments of beam particles when coming out of the closed valve.

The partial pressure analyzer showed little change in the H_2 pressure. With Blue beam injection a slight increase in the CO, O_2, H_2O, and CH_3 pressure (or molecules of the same mass), as well some heavier molecules could be observed. Only very small partial pressure changes were observed with Yellow beam injection.

MEASUREMENTS WITH COPPER BEAM

The measurements with copper beam were done in the same way as with gold beam a year earlier (Tab. 1). Measured pressure increases and injected bunch intensities are shown in Fig. 4 for valve V1 closed, and in Fig. 5 for valvue V2 closed. When Yellow beam was injected with V1 closed a gauge on the outgoing side of V1 (not shown in Figs. 4 and 5) showed a decrease in pressure of unknown origin.

The calculated desorption coefficients η are summarized in Tab. 4. They range from 10 to 400, with an average of 140. Here too, the error in η is at least of order factor 2. The uncertainties stem from the same reasons as in the gold beam measurement.

Table 3: Summary of measued desorption coefficents η_{Au} with gold beam.

measurement	η_{G2} (next to NEG)	η_{G3} (no NEG)
V1 + Blue	2300	1100
V1 + Yellow	300	1600
V2 + Yellow	8000	260
V2 + Blue	5400	300
average	4000	800

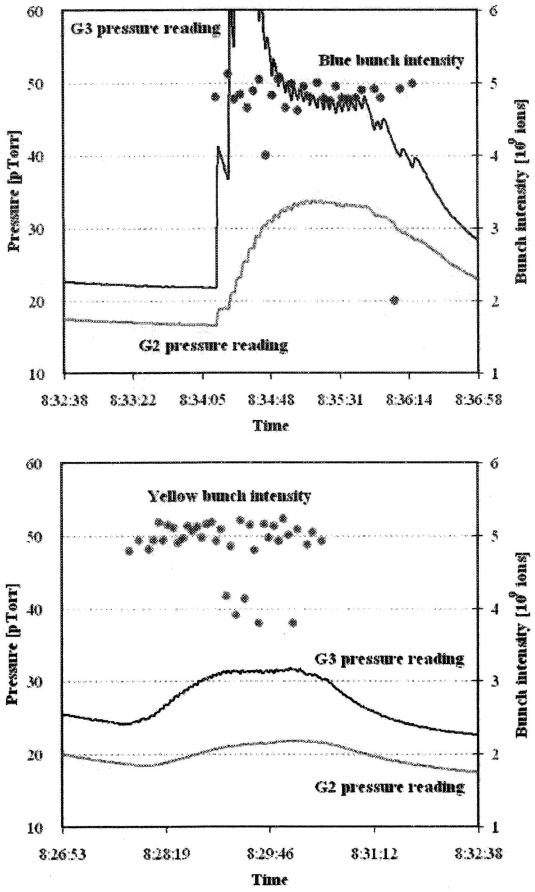

Figure 4: Measurements with copper beam and valve V1 closed. Injection of 28 Blue bunches (top), and 37 Yellow bunches injected (bottom).

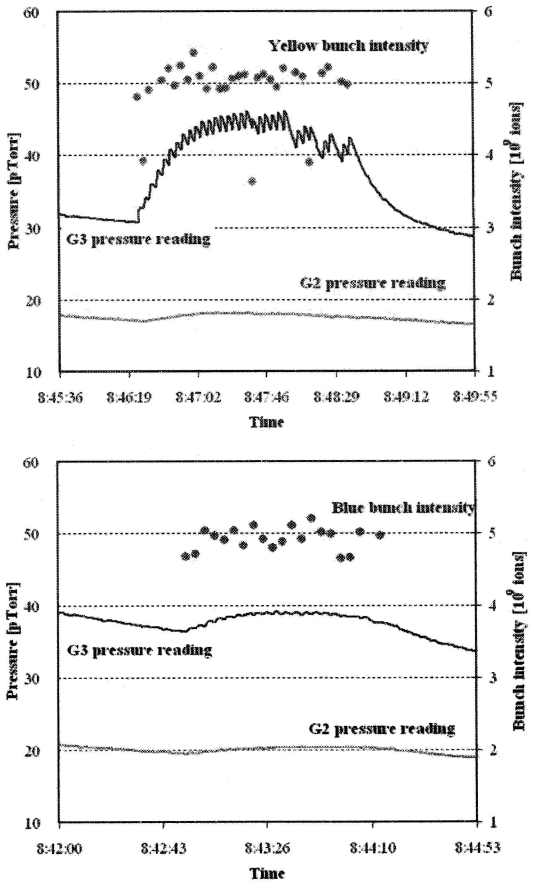

Figure 5: Measurements with copper beam and valve V2 closed. Injection of 30 Yellow bunches (top), and 20 Blue bunches injected (bottom).

MEASUREMENTS WITH PROTON BEAM

Deliberate beam losses, needed for the measurements of desoption coefficients, are only possible in locations with shielding. When RHIC is operated with polarized proton a polarized hydrogen jet is installed near the location where the measurements were done with Au and Cu beams, which leads to a higher background pressure of 5×10^{-9} Torr. No other loaction was available with both shielding and low background pressure. With the increased background pressure, and 56 bunches with a total intensity of 10^{13} protons a pressure increase of less than 10^{-11} Torr was observed with both the Blue and Yellow beam. With this only a very approximate estimate for η is possible, giving $\eta < 1$.

Table 4: Summary of measued desorption coefficents η_{Cu} with copp beam.

measurement	η_{G2} (next to NEG)	η_{G3} (no NEG)
V1 + Blue	40	120
V1 + Yellow	250	400
V2 + Yellow	10	40
V2 + Blue	–	170
average	100	180

SUMMARY AND DISCUSSION

We measured the ion-impact desorption coefficient of stainless steel, baked at 200°C for 24 h, with high energy ions under perpendicular impact. We found $\eta \approx 2400$ for $^{197}\mathrm{Au}^{79+}$ with a kinetic energy of 9 GeV/nucleon, $\eta \approx 140$ for $^{63}\mathrm{Au}^{29+}$ with a kinetic energy of 10 GeV/nucleon, and $\eta < 1$ for $^{1}\mathrm{p}^{+}$ with a kinetic energy of 23 GeV. These number are for N_2 or similar gas molecules. Errors are of order factor 2 for the gold and copper measurements, and larger for the proton measurement.

From Ref. [17] we would expect an increase in η by about 2 orders of magnitude for grazing incidents. Measurements presented in Ref. [10], however, show only small variations with the impact angle θ, certainly less than $1/\theta$. Ref. [10] also shows that the electronic energy loss scales as $(dE/dx)^n$ with $n = 1...2$. In our case the ion energy is

high enough for electronic losses to be dominant, and the energy loss should scale with Z^2 (Bethe-Bloch formulae). Comparing the desorption coefficients measured with gold and copper beam this is consistent with the scaling law in Ref. [10], althought the large error in the η measurements does not allow a conclusive statement.

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