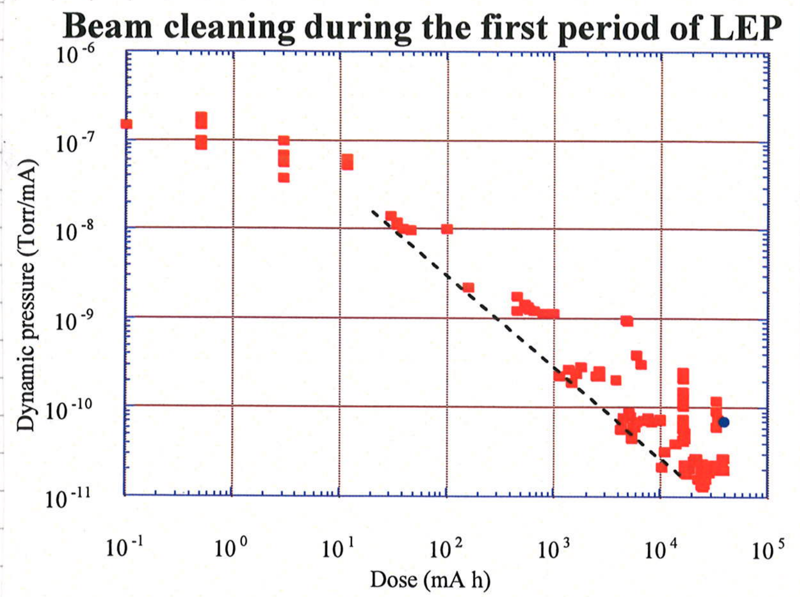
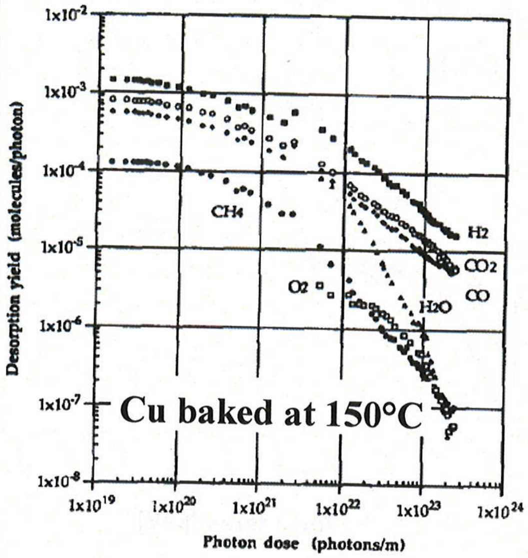

Beam cleaning during the first period of LEP

O. Gröbner. Vacuum 43 (1992) 27-30



O. Gröbner *et al.* J.Vac.Sci. 12(3), May/Jun 1994, 846-853

Particle accelerators for which induced desorption is a serious limitation can be run for some day, at a limited current, to reduce η. This operation is refered to as "BEAM CONDITIONING" or "BEAM SCRUBBING".

In section 3 we will consider another method to change the surface composition with a consequent radical reduction of η: non-evaporable getter thin film coating.

7.3 ION INDUCED DESORPTION

Ion induced desorption is in general studied in two diffent conditions.

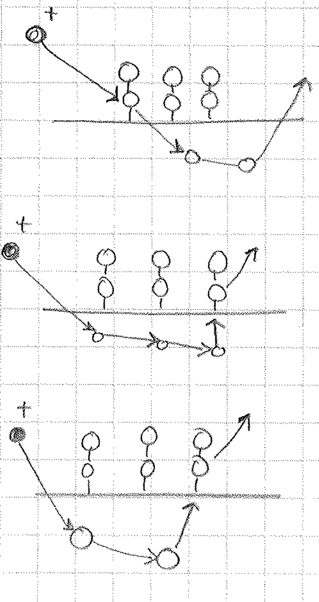
→ single ionized gas molecules found in vacuum system

→ highly ionized heavy atoms

- The first considers the fact that beam particles can collide with the residual gas molecules and ionize them. The gas molecule ions acquire kinetic energy interacting with the $\oplus$ beam electric potential. The energy of impact on the beam pipes' wall is in the range eV to KeV. The desorption yieds η_{ION} are measured in laboratory set-up.

- In the second case, the heavy ions are produced on purpose in ion-sources and then accelerated for collisions. Typical ions are Pb^{53+}, U^{73+}, Ar^{10+}... The desoption studies are performed in the range 1 MeV/u to 100 GeV/u by set-up integrated in particle accelerators.

7.3.1 Gas molecule ions at low energy.



The desorption by ions (H_2^+, CH_4^+, CO^+, CO_2^+, Ar^+) can be depicted as the effect of a series of collisions among the impinging ion, the atoms of the metal and adsorbate.

(see J. Schou, CERN Accelerator School, Vacuum in Accelerators)

Typical values for the desorption yield for low ion doses are:

Ion energy ≈ 1 KeV
Baked copper or
stainless steel

$$\left.\begin{array}{l} \eta_{H_2} \overset{<}{\approx} \eta_{CO} \approx 1 \\ \eta_{CO_2} \approx \eta_{CO}/5 \\ \eta_{CH_4} \approx \eta_{H_2}/10 \end{array}\right\}$$

ion desorption yields are higher than electron and photon desorption yields

The desorption yield depends on;

see G. Hulla
CERN-THESIS-2009-026
05/03/2009

- ion mass
- ion energy
- nature of the desorbed gas
- material of the vacuum chamber

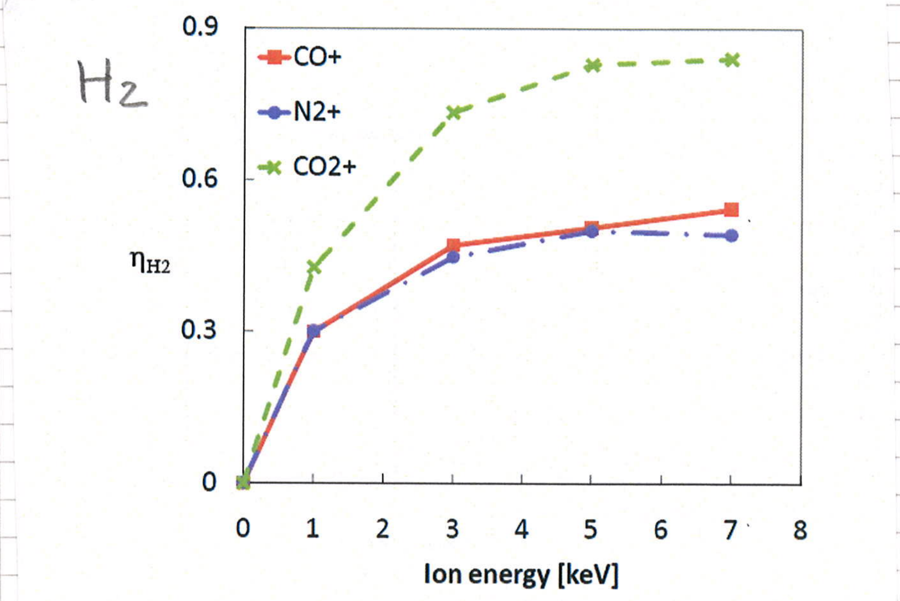


Figure 6.14: H_2 desorption yields of N_2^+-ions and oxygen containing ions incident on copper as function of the ion energy.

CO

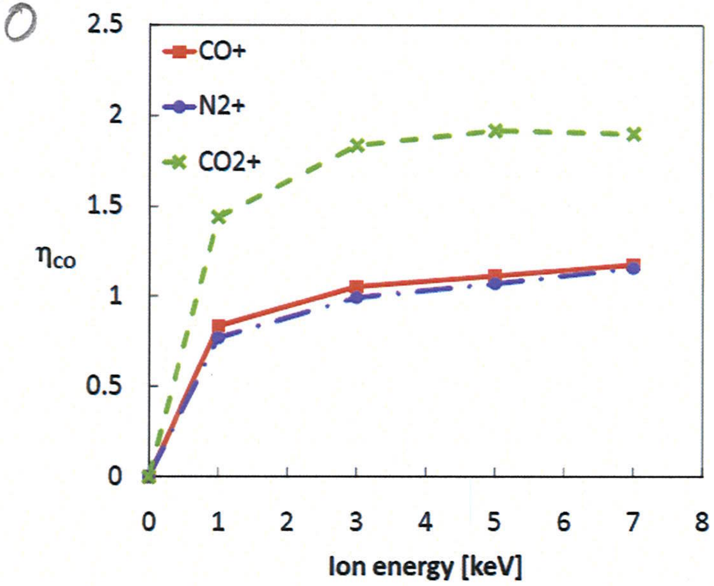


Figure 6.16: CO desorption yields of N_2^+-ions and oxygen containing ions incident on copper as function of the ion energy.

CO_2

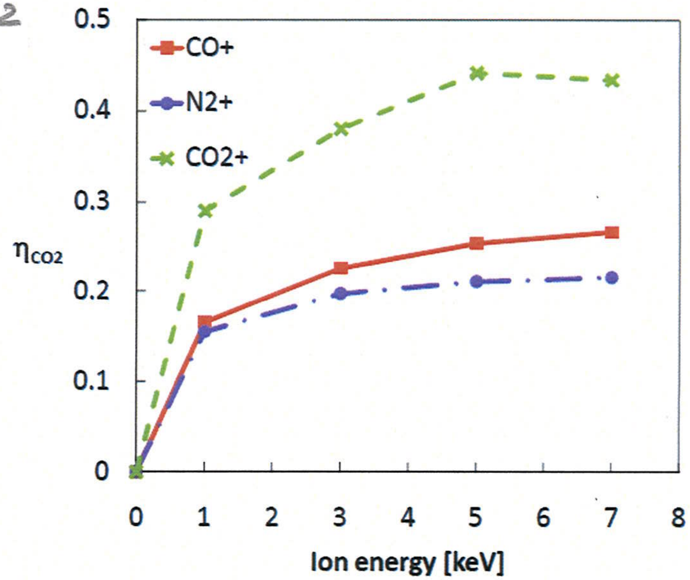


Figure 6.18: CO_2 desorption yields of N_2^+-ions and oxygen containing ions incident on copper as function of the ion energy.

The dose effect is visible for more than 10^{15} ions/cm^2. Saturation of the η values was measured for doses higher than 10^{16} ions/cm^2 ($\approx$ 10 times lower than the η at zero dose).

- The role of ion mass and energy and of the material of the substrate can be calculated in terms of energy loss. The key quantity is the stopping power

$$\frac{dE}{dx} = N \cdot S(E)$$

N = number density of atoms in the solid

S(E) = stopping cross section which depends on the energy E of the impinging ion.

S(E) can be divided in two contributions:

$$S(E) = S_n(E) + S_e(E) \begin{cases} S_n(E) = \text{nuclear stopping cross section} \\ S_e(E) = \text{electronic stopping cross section} \end{cases}$$

The "nuclear" part takes into account the energy transfered to nuclei as in sputtering processing. The primary ions undergoes several scattering and a complete change of trajectory. This energy transfer mechanism is dominant up to about 50 KeV ion energy.

The electronic part considers the energy transfered to electrons belonging to the solid, first to break the bonding with the nuclei and then to accelerate them. This process prevails on the nuclear one at high energy (E > 1 MeV).

The energy loss model, considering the nuclear part only, can fit the experimental data of ion induced adsorption at low energy.

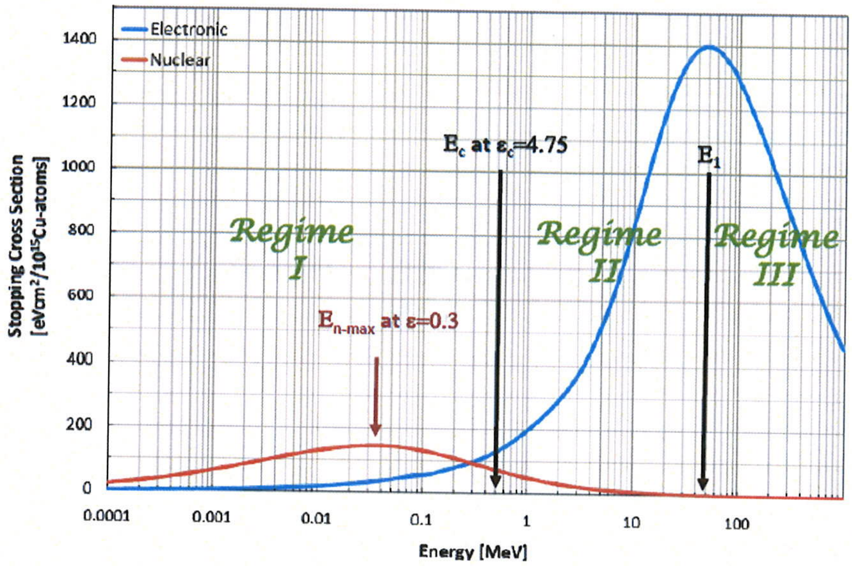


Figure 4.3: Electronic and nuclear stopping cross sections for Ar^+-ions incident on copper.

7.3.2 Heavy ion induced desorption

- In the last 15 years, several experiments have shown that high energy ($E > 1$ MeV/u) ions can induce the desorption of a huge quantity of gas. Desorption yields up to 10^5 molecules/ion were measured for In^{49+} at 158 GeV/u at the CERN SPS.

  A review of data can be found in E. Mahner, Phys. Rev. ST Accel. Beams 11, 104801 (2008).

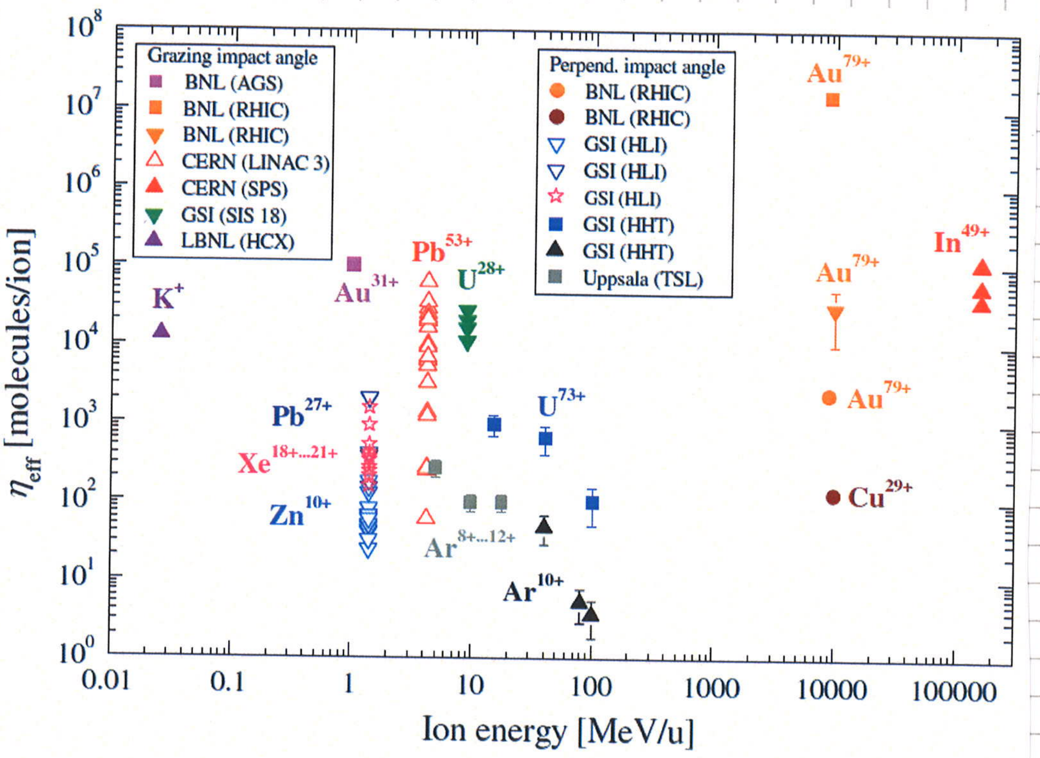
- Here again η_{ION} is reduced by increasing the dose of impinging ions.

- It has been shown that the η_{ION} can be obtained by the electronic energy loss:

$$\eta_{ION} = k \left(\frac{dE}{dx} \right)_e^n$$

$$2 < n < 3$$

The transfer of energy to electron provokes a thermal spike that results in the desorption.



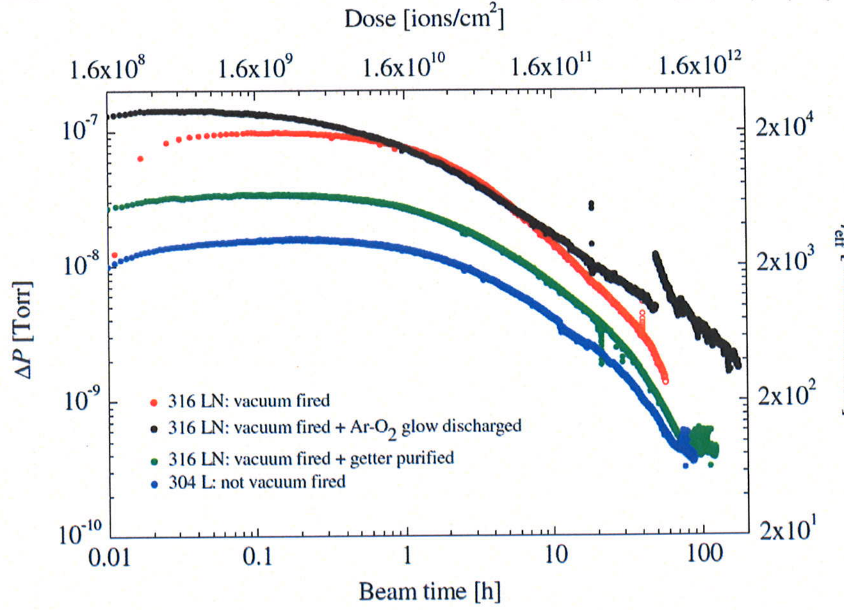
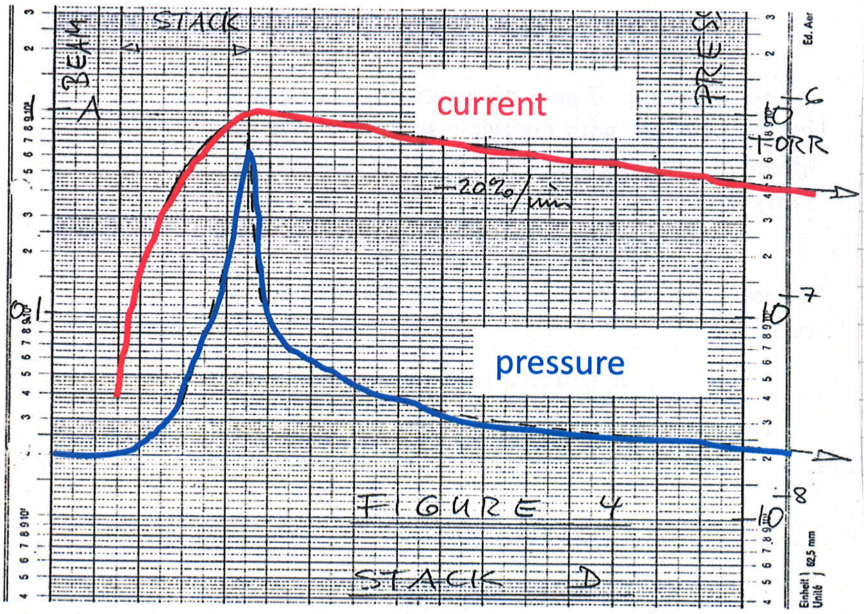


FIG. 7. (Color) Beam cleaning measurements for four different stainless steel (316LN, 304L) vacuum chambers continuously bombarded with 1.5×10^9 Pb^{53} ions (per shot) under $\theta = 89.2°$ grazing incidence. The shown desorption measurements were done with 4.2 MeV/u lead ions at LINAC 3; all four vacuum chambers were cut afterwards and samples of each chamber were studied with ERDA [70]. The obtained ERDA results are displayed in Fig. 3.

7.3.3 Pressure runaway provoked by ion induced desorption.

Ion induced desorption can trigger a rapid pressure rise in particle accelerators that results in a limitation of the beam current. This phenomenon was shown at the ISR in the '70 when increasing the proton beam current to about 1 A.



First documented pressure bump in the ISR

E. Fischer/O. Gröbner/E. Jones 18/11/1970

The instability can be easily understood:

- the residual gas is ionized by the positive particle beam
- the ions are accelerated by the beam potential toward the beam pipe walls
- the impinging ions induce gas desorption

The process can have a positive feedback.

The total flux of desorbed molecules per unit length of vacuum chamber is

$$Q = \eta_{ION} \cdot \sigma_i \cdot \frac{P \cdot I}{e} + Q_{th} \quad \left[\frac{Torr \cdot \ell}{s}\right]$$

where : σ_i is the cross section of ionization of the gas molecules

I is the beam current

Ionization probability for a proton $\dfrac{\sigma \cdot n \cdot A \cdot 1}{\underset{\nwarrow \text{ cross section area of beampipe}}{A}} = \sigma \cdot \overset{\swarrow \text{ gas density}}{n}$

Q_{th} is the thermal outgassing

The pressure in the beam pipe is

$$P = \frac{Q}{S_{eff}} = \frac{\eta_{ION}\, \sigma_i\, P\, I}{e \cdot S_{eff}} + \frac{Q_{th}}{S_{eff}} \longleftarrow \begin{array}{l} S_{eff} = \text{effective pump.} \\ \text{speed per unit length} \\ \left[\ell/(s \cdot m)\right] \end{array}$$

$$\Rightarrow \quad \underline{\underline{P = \frac{Q_{th}}{S_{eff} - \eta_{ION}\, \sigma_i\, \frac{I}{e}}}}$$

The pressure diverges for $S_{eff} - \eta_{ION}\, \sigma_i\, \frac{I}{e} = 0$, which defines a critical value for the current :

$$S_{eff} - \eta_{ION}\, \sigma_i\, \frac{I_c}{e} = 0 \Rightarrow \boxed{I_c = \frac{S_{eff} \cdot e}{\sigma_i \cdot \eta_{ION}}}$$

	$\sigma_i \left[10^{-18}\, cm^2\right]$	
H_2	0,22	0,37
He	0,23	0,38
CH_4	1,2	2,1
CO	1,0	1,8
Ar	1,1	2,0
CO_2	1,6	2,8
	⇑ 26 GeV	⇑ 7 TeV

Example :

$S_{eff} \simeq 10\ \ell/(s \cdot dm) \qquad 1\,\ell = 1\,dm^3$

$\sigma_{CO} = 1 \times 10^{-18}\, cm^2 = 10^{-16}\, dm^2 \qquad \eta_{ION} = 1$

$$I_c = \frac{10 \times 1{,}6 \times 10^{-19}}{10^{-16} \times 1} = 1{,}6 \times 10^{-2}\, A$$