VARIATION OF THE ION INDUCED DESORPTION YIELDS WITH TEMPERATURE
AND THE NATURE OF INCIDENT IONS

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VARIATION OF THE ION INDUCED DESORPTION YIELDS WITH TEMPERATURE AND THE NATURE OF INCIDENT IONS

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Abstract

The ion induced gas desorption from a stainless steel surface has been measured using incident ions of different mass. This desorption yield was determined for baked and unbaked stainless steel samples at various temperatures (300 K, 77 K, 4.2 K). It is shown that the desorption yield of stainless steel surfaces depends on both the nature of the incident ion and the surface temperature.

1. Introduction

Ion induced gas desorption from the vacuum chamber walls has proved to be very critical in the operation of proton storage rings (CERN-ISR) where it may give rise to a pressure runaway process and consequent high beam loss rates, which are unacceptable during colliding beam physics experiments (1). Measurements of ion induced desorption yields, using \( \text{H}_2^+ \) ions, have allowed the comparison of various surface treatments designed to reduce desorption from the CERN-ISR vacuum chamber. Glow discharge cleaning was found to be the most suitable treatment (2). Nevertheless, the evolution of the gas composition during a pressure runaway was not completely understood. In particular, the influence of the residual gas composition and the importance of its variation on the desorption process remained obscure. For this reason, a study concerning the dependence of the desorption yield of adsorbed molecules (\( \text{H}_2, \text{CH}_4, \text{CO, CO}_2 \)) with the nature of the incident ion (\( \text{H}_2^+, \text{CH}_4^+, \text{CO}^+, \text{CO}_2^+ \)) as a function of surface preparation and temperature has been undertaken. In the absence of a proton beam, the residual gas in the ISR vacuum chamber, after a 300°C 24 hour bake, is mainly hydrogen and hence this must be the gas which initiates any pressure runaway mechanism. For this reason, the desorption yields measured with various incident ions are compared with that measured with \( \text{H}_2^+ \) ions and the concept of desorption efficiency (D.E.) of an ion with respect to \( \text{H}_2^+ \) is defined.

These desorption efficiencies have been determined for a stainless steel surface at various temperatures: 300 K, 77 K, 4.2 K in the case of an unbaked surface; 300 K and 77 K for a baked surface.

2. The Experimental Equipment

This equipment has been described in (3). It consists of a UHV vacuum system, bakeable to 300°C, containing an ion source (1 mA, 0-10 keV and giving a neutral outflow of \( 2\times10^{-10} \text{ torr} \) s for \( \text{H}_2 \) in normal operating conditions) and a cryostat supporting a stainless steel target which can be filled with a cryogenic liquid. The ion beam is momentum analyzed in a 30° bending magnet; the highest utilisable momentum corresponds to argon ions at 10 keV energy.

3. Definition of Desorption Efficiency and Measurement Procedure

The desorption yield (D.E.) \( n_{\text{j}i^+} \) is defined as the number of molecules \( j \) desorbed per ion \( i^+ \) striking a surface. To compare the efficiency of various ions \( i^+ \) for the desorption of the same molecule \( j \), it is adequate to consider
the ratio of the D.Y. of this molecule j by the different ions considered. These D.Y. may, in turn, be normalised to one ion as reference to give the D.E. Later H₂ is chosen as reference ion for reasons explained above and all D.E. will be defined relative to H₂⁺ ions. The D.E. of ion k⁺ for the desorption of molecule j is hence:

\[ \text{(DE)j}_k^+ = \eta^{j}_k^+/ \eta^{j}_H^+ \]

For the measurements a mixture of the gases corresponding to the investigated ions (H₂⁺, He⁺, N₂⁺, CO₂⁺) was fed into the ion source and the required ion selected by the magnetic sector analyzer. The desorption yields of different molecules (H₂, CH₄, CO, CO₂) were determined using the procedure described in (4). For sake of brevity, only the D.E. will be shown on the subsequent figures. All the measurements were made using 5 keV incident ions, except for an unbaked surface at 300 K in the case of which a comparison of the D.E. has been made for 1 keV and 5 keV.

4. Results

The results are summarized in figures 1 to 5 where the D.E. are plotted as a function of the incident ion mass for the different desorbed species, at various surface temperatures. In the case of baked surfaces, no measurements could be obtained at 4.2 K for masses 16, 28 and 44, since the ratio of their desorption yields to the large pumping speed provided by the cold surface was too small; hence the D.E. could not be determined in that case. Figures 6 and 7 show, using the same data, the D.E. now plotted as a function of the desorbed molecular mass with the incident ion as parameter for an unbaked (6) and baked (7) target at room temperature.

On Figure 8 the ratios of the D.E. measured using 5 keV ions to that measured with 1 keV ions are given as a function of the desorbed molecule mass, for different incident ions bombarding on an unbaked surface.

5. Observations

In Figures 1 to 5 it appears that whatever the temperature of the sample or its state (baked or unbaked) there is a general tendency for the D.E. to increase with the mass of the incoming ion. On the contrary Figures 6 and 7 do not indicate a systematic variation of the D.E. of a given ion according to the mass of the desorbed species. In this case and especially for a baked surface, it is more likely that the chemical nature of the desorbed molecule and its binding energy to the substrate influences the D.E. A bakeout of the surface entails an increase in the D.E. of heavy ions for the desorption of mass 28 and a decrease of this D.E. for the desorption of mass 16. This is visible by comparing figures 1 and 4 for a room temperature target, figures 2 and 5 for a liquid nitrogen temperature target.

The temperature of the target seems to have little influence in general on the D.E. with the exception of that of the heavy ions for hydrogen desorption (cf. Figs. 1 and 3). It has been shown in ref. (3) that the D.E. changes with the hydrogen coverage on a liquid helium cooled target. For low coverages the D.E. of heavy ions are relatively low and comparable to those measured in the present case (4.2 K, unbaked target). Hence the lowering of the D.E. for heavy ions at 4.2 K is probably related to the formation of a thin H₂ condensed layer on the surface of the cold target by cryopumping of the residual hydrogen. This lowering might be expected according to the following considerations: the adsorption heat of physorbed hydrogen molecules is 8.3 \(10^{-3}\) eV/mol (7). The desorption yield of hydrogen by 5 keV energy H₂⁺ ions is 5 \(10^4\) (for coverages about \(10^{20}\) mol/m² i.e. about 3 monolayers) (3). The fraction F of the incident ion energy used to break the
binding of the hydrogen molecule to the surface is hence $8.3 \times 10^{-2}$. If the heavy ions would have kept their high D.E. under these conditions (about 10 for mass 44, figures 1 and 2), the fraction $F$ would become .83 for these ions, i.e. about 83% of the incident ion energy would be used for desorption. Such a high energy transmission is very unlikely and thus a decrease of the D.E. for heavy ions impinging on thin hydrogen condensed layers is expected.

The influence of the incident ion energy on the D.E. is shown on Figure 8 where the ratio of D.E. measured at 5 keV and 1 keV are represented. A slight increase with energy of the D.E. of heavy ions is visible; this effect is fairly constant for all desorbed molecules. On the contrary, a decrease is seen in the case of He$^+$ ions.

6. Discussion and Conclusion

From the preceding observations, it appears that heavy ions are more efficient desorbers, especially for heavy molecules like CO and CO$_2$. The temperature of the bombarded surface does not appear to influence the D.E. except in the case of a surface coverage modification introduced by cryopumping (case of hydrogen at helium temperature).

The influence of a bakeout on the D.E. of heavy ions shows that the binding energy of the adsorbed molecule influences the D.E. at least in the case of CO molecules. This can be inferred from that fact that the D.E. of heavy ions is enhanced when the mean binding energy of the remaining molecules is increased due to removal of the less tightly bound molecules by the bakeout. The complexity of the practical situation investigated here (polyatomic ions impinging on a mixture of adsorbed gases) does not allow direct comparison of the results obtained either with the theory developed by Winters and Sigmund (5) (desorption of N$_2$ adsorbed on clean W by noble gas ions) or with that of Taglauer et al (6) (desorption of O or CO adsorbed on nickel mono-crystals under He$^+$ bombardment).

Nevertheless, in the present case, the decrease of the helium ion D.E. with increasing ion energy is in agreement with the measurements quoted in (5) and (6).

Although the situation investigated here does not allow direct comparison with existing theory, it is close to the problems encountered in practical applications. The D.E. determined in this experiment can be used to foresee the changes in the residual gas composition of a system where the vacuum chamber walls are submitted to the bombardment of ions stemming from the residual gas.

7. Acknowledgements

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8. References

Fig. 1 D.E. versus ion mass, $T = 300$ K, unbaked target

Fig. 2 D.E. versus ion mass, $T = 77$ K, unbaked target

Fig. 3 D.E. versus ion mass, $T = 4.2$ K, unbaked target

Fig. 4 D.E. versus ion mass, $T = 300$ K, baked target

Fig. 5 D.E. versus ion mass, $T = 77$ K, baked target

Fig. 6 D.E. versus desorbed molecule mass, $T = 300$ K, unbaked target

Fig. 7 D.E. versus desorbed molecule mass, $T = 300$ K, baked target

Fig. 8 ratios of D.E. measured at 5 keV and 1 keV versus desorbed molecule mass, $T = 300$ K, unbaked target