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Gas Desorption from an OFHC Copper Vacuum Chamber by Synchrotron Radiation Photons

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Abstract

An OFHC copper chamber was exposed to 3.75 keV critical energy synchrotron radiation for a total dose of $2.7 \cdot 10^{23}$ photons/m. After this dose, photodesorption yields down to 10^{-5} mol/photon were reached for H_2 , CO and CO_2 and 10^{-7} mol/photon for CH_4 , H_2O and O_2 and a total of about one monolayer of gas was desorbed. From observation of the transient behaviour of the desorption at the beginning of an irradiation period after a prolonged interruption, the desorption yield was found to be proportional to the coverage and followed an exponential decay with increasing photon dose. This in contrast with the normal behaviour where the desorption yield decreases linearly with dose on a log-log scale. With the chamber heated to 70°C, the photodesorption yields for H_2O and O_2 increased but the others remained relatively independent of the temperature. At the end of the irradiation period a substantial wall pumping was observed in the chamber. For CO, CO_2 and O_2 it was about 1160, 280 and 80 ls^{-1} respectively.

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1. INTRODUCTION

In high energy, high intensity e^+e^- storage rings such as so-called Tau charm¹ and B meson^{2, 3} factories, strong gas desorption from the vacuum chamber wall due to synchrotron radiation is expected. This pressure increase limits the beam lifetime and can be an important source of background in the detectors. In medium energy synchrotron radiation sources, which operate at somewhat lower intensities, the requirements for beam lifetime are comparatively higher resulting in similar specifications for the pressure and hence the desorption rate. It is this extra synchrotron radiation induced gas load which must be coped with by the pumps to give a pressure such that the lifetime and background conditions are satisfied. Also in these machines the initial gas desorption is usually high thus an initial conditioning period is required where continued running is necessary to remove gas from the surface and reduce the pressure to acceptable levels. A suitable material for the vacuum chamber is copper, but few data are available which indicate how long the conditioning period would be and what levels of desorption can ultimately be obtained⁴.

For this reason an extended irradiation of an OFHC Cu chamber with synchrotron radiation of 3.75 keV critical energy from a dipole magnet was carried out on a dedicated beam line on the DCI storage ring at Orsay, France. A total beam dose of $2.7 \cdot 10^{23}$ photons/m (207 A hours) was accumulated over a period of 11 weeks, more than 2 orders of magnitude larger than in previous 24 hour runs.

Many transient effects were observed at the start of the individual exposures to the photons and after interrupting the beam. The investigation of these provided additional insight into the various mechanisms at work in photon stimulated desorption of gases from technical Cu surfaces which are attributed to a two step process where as a first step in the desorption process, molecules on or near the surface are activated or dissociated by the photons or by the photo electrons. In a second step, the molecular species which recombine and accumulate on the surface desorb thermally. This thermal desorption does not require the photon irradiation and continues for many hours after an irradiation period.

2. EXPERIMENTAL DETAILS

2.1 Vacuum system

The main features of the test facility at the DCI ring have already been described previously⁵ - nevertheless, for completeness, the schematic layout is shown in Fig. 1. Bending magnet synchrotron radiation is first collimated both vertically and horizontally to 4.7 mrad before striking the 3.6 m long, 131 mm diameter test chamber at an average grazing angle of incidence of 11 mrad. The vertical collimation attenuates the photon spectrum below 6 eV. The calibrated conductance provides a pumping speed of 72.5 ls^{-1} for N_2 . The material of the chamber studied in this experiment was OFHC copper.

Fig. 1: Schematic layout of the experimental test facility on an external photon beam line at DCI.

A calibrated Bayard Alpert gauge was located at each end of the chamber and a calibrated quadrupole gas analyzer was installed near the conductance to measure the partial pressures of the various desorbed gas species. The chamber was also equipped with a leak valve at its downstream end enabling different gases to be introduced to the chamber for gauge calibration purposes and to measure the surface pumping speed. After baking the stainless steel parts of the system at 300°C and the Cu chamber at 150°C for 24 hours, a base pressure in the low 10^{-10} Torr range was obtained. The chamber position with respect to the photon beam was checked by measuring the photon beam profile with the photoelectron current from vertically moving wires at each end of the chamber. A 20 cm long, 1 mm diameter stainless steel wire in the central part of the chamber which could be biased to +1 kV was used to measure the photoelectron current from the chamber wall. Gas analysis and data taking were performed by a specially developed microcomputer system.

2.2 Chamber preparation

The copper chamber was manufactured from 3 mm thick OFHC copper plate, rolled in four 90 cm long sections and electron beam welded to form a tube 131 mm in diameter and 3.6 m long. Conflat flanges were vacuum brazed to each end. Before welding, each 90 cm section was chemically cleaned by first degreasing in perchloroethylene vapour at 121°C, then deoxidising by immersion in an alkaline detergent, pickling in HCl, passivation in a chromic acid/H₂SO₄ bath, rinsing in demineralized water and finally drying with N₂ gas. To ensure that the complete chamber was subjected to all stages of all treatments, the four sections were placed in the vacuum brazing oven although it was only the two end sections which were actually brazed to flanges. Once the chamber had been finally welded together it was given a last chemical cleaning in the deoxidising alkaline detergent. The chamber was then vacuum tested at CERN by baking at 150°C for 24 h. When installed in the synchrotron radiation beam line, it was again baked at 150°C for 24 h after which the base pressure was $2.3 \cdot 10^{-10}$ Torr.

3. GLOBAL RESULTS

3.1 Desorption yield as a function of the photon dose

The gas species desorbed from the Cu surface in order of importance were H_2 , CO_2 , CO , H_2O , CH_4 and O_2 . In Fig. 2 is shown the dependence of the desorption yield, defined as the number of molecules desorbed per incident photon, on the photon dose for these various gas species. For clarity and to show the basic form of the curves, many data points have been omitted and, as a consequence, some finer structure is absent in the curves but will be presented in detail later.

Fig. 2: Variation of the molecular desorption yield at 3.75 keV critical energy for H_2 , CH_4 , H_2O , CO , O_2 and CO_2 with integrated photon dose for the Cu test chamber.

The initial desorption yields vary from 1.3×10^{-3} mol/photon for H_2 to 1.2×10^{-4} mol/photon for CH_4 . With continued photon exposure the yield of all molecules decreases strongly and final values in the 10^{-6} molecules/photon range could be obtained

except for H_2 . A very significant finding was that none of the molecular species showed a tendency to level off, even up to the highest dose of 2.7×10^{23} photons/m. Since the total pressure gauge and the residual gas analyser was not calibrated for O_2 and for H_2O the absolute values quoted for these two gases may be in error by up to a factor of 2.

During the operation of an actual machine it is the total N_2 equivalent gauge pressure which is usually recorded. The gauge pressure from P1 is shown in Fig. 3, normalised to the DCI beam current and plotted as a function of the photon dose. There it can be seen that, at photon doses above about 2×10^{21} photons/m and on a log-log scale, the normalised pressure decreases linearly with a slope of -0.84. In fact a similar scaling has already been observed in several operating machines ^{6,7}. Identical slopes would not be expected since the total pressure gauge gives a weighted sum of the individual gases and this weighting depends on the relative sensitivity of the gauge for each molecular species and the relative quantity of each gas present in the system. In turn, this is dependent on the actual pumping speed for a given gas in that particular machine.

Fig. 3: Variation of the total pressure rise normalised to beam current versus the integrated photon dose for the Cu test chamber.

3.2 Desorption yield as a function of the desorbed gas load

In view of the high gas desorption rate which is expected in the various designs of proposed particle factories, a large pumping speed will be required. A good candidate is obviously the non-evaporable getter (NEG) strip which can provide this high pumping speed for H_2 , CO , and CO_2 , but which suffers from the disadvantage that it must be reconditioned after pumping a given amount of gas, e.g. about 0.1 Torr l/m of $CO+CO_2$ in the case of the LEP ring⁸. Thus it is important to know how much NEG to install, which in turn is determined by the desorption yield and by the frequency with which the getter can be reconditioned during machine operation.

Integration of the desorption yields of Fig. 2 with respect to photon dose gives the total number of desorbed molecules/m, which may be converted to the gas load in Torr l/m. In Fig. 4 have been plotted the desorption yields for H₂, CH₄, CO and CO₂ as a function of the integrated quantity of desorbed gas. For acceptable lifetimes and backgrounds in these machines, it is estimated that desorption yields for CO and CO₂ of about $1 \cdot 10^{-6}$ mol/photon are required and, by extrapolation of the data in Fig. 4, this requirement would be achieved after about $5 \cdot 10^{-2}$ Torr l/m of CO and $7 \cdot 10^{-2}$ Torr l/m of CO₂ had been desorbed. For a LEP-type getter pump this would lead to not more than 2 reconditionings of the NEG strip. The behaviour of CH₄, which is not pumped by the NEG, differs from that of H₂, CO and CO₂ in that after $3 \cdot 10^{-3}$ Torr l/m have been removed, the desorption yield is already $<10^{-7}$ molecules/photon and continues to decrease rapidly with photon dose. This gas species will, therefore, not present a limitation to the vacuum system design.

Fig. 4: The molecular desorption yield for H₂, CH₄, CO and CO₂ versus the total quantity of the desorbed gas in Torr l/m of test chamber. The solid curves show an exponential fit to the data points.

The molecular desorption yield η in Fig. 4 has been fitted empirically by an exponential dependence on the integrated desorbed gas Q of the form

$$\eta = \eta_0 \exp\left[-\frac{Q}{Q_0}\right]$$

For the different gas species, a characteristic gas load Q_0 is obtained which is summarised in the following table.

Table 1

	H ₂	CH ₄	CO	CO ₂
molecules cm ⁻² / monolayer	1.8 10 ¹⁵	1.2 10 ¹⁵	1.0 10 ¹⁵	9.6 10 ¹⁴
η_0 (molecules / photon)	9.2 10 ⁻⁴	2.3 10 ⁻⁴	3.7 10 ⁻⁴	5.5 10 ⁻⁴
Q_0 (Torr l / m)	3.0 10 ⁻²	4.5 10 ⁻⁴	8.4 10 ⁻³	1.1 10 ⁻²
Q_0 (monolayers)	0.13	2.9 10 ⁻³	6.5 10 ⁻²	8.9 10 ⁻²

To convert from Torr l/m to monolayer coverage, it has been assumed that the gas desorbs from the entire internal surface of the test chamber. The result from this table suggests that the total amount of gas which desorbs from the Cu surface during the photon cleaning process is equivalent to approximately one monolayer. It is interesting to compare this result with similar measurements of an aluminium test chamber for LEP which give values nearly 10 times larger⁹.

3.3 Photoelectron current

The photon dose dependence of the photoelectron yield is shown in Fig. 5. During the initial period of photon exposure the photoelectron yield was found to decrease by a factor of 1.8, with very little decrease after a photon dose of 6×10^{21} photons/m.

Fig. 5: Photoelectron yield versus the photon dose

This behaviour may point to a change of the surface conditions which affects the secondary electron emission of the copper surface. Typical photoelectron currents measured in the Cu chamber were about 1 mA/m with a current of 300 mA stored in the DCI machine.

4. DETAILED RESULTS

The data presented in the preceding figures were acquired during a period extending over several months. During this time a number of further observations could be made which provide additional insight into the complexity of the desorption process and which illustrate the importance of molecular processes which may occur on a previously exposed surface even in the absence of direct photon irradiation.

4.1 Desorption from the opposite wall of the chamber

From previous observations¹⁰ it had been recognised that photon induced desorption in electron storage rings originates from the whole internal surface of the vacuum chamber and not only from the narrow band exposed to the direct flux of synchrotron radiation. In order to reconfirm the important rôle of scattered photons and photoelectrons a dedicated measurement was performed during this series of runs. For one of the irradiation periods, when a total of $2.7 \cdot 10^{23}$ photons/m had been accumulated, the chamber was repositioned with respect to the photon beam to irradiate the opposite wall. After an additional dose of $9.7 \cdot 10^{21}$ photons/m on this side of the test chamber the desorption yields were again measured. Figure 6 shows the comparison of the desorption yields for H₂, CH₄, CO and CO₂ at different values of the photon dose as measured at the normal side of the chamber (full lines) at the beginning, after $9.7 \cdot 10^{21}$ photons/m and after a dose of $2.7 \cdot 10^{23}$ photons/m with respect to the yields on the opposite side (dashed lines) after the same dose of $9.7 \cdot 10^{21}$ photons/m.

It can be seen that the opposite side of the chamber is lower by a factor of 5 after the same photon exposure. Assuming that the interior surface of the chamber starts off uniformly "dirty", this finding suggests that the opposite side of the test chamber must have experienced a significant cleaning effect from scattered photons and/or photoelectrons⁹.

4.2 Pressure variation at the start of irradiation

At the start of each irradiation period the different partial pressures show significantly different behaviours. Following an interruption of several hours, the typical evolution at the beginning of photon irradiation is shown in Fig. 7 for H₂, CH₄, H₂O, CO, O₂ and CO₂ extending over a period of 3 hours. Along the vertical scale in Fig. 7 are plotted the ion currents from the residual gas analyser which have first been normalised to the incident photon flux. Subsequently, to show more clearly the effect of the interruption of the photon exposure of several hours, these normalised ion currents have been divided by the corresponding values from the end of the preceding exposure.

Fig. 6: The molecular desorption yield for H₂, CH₄, CO and CO₂ at different values of photon dose for the directly exposed side of the Cu test chamber as compared to the desorption yield at the opposite side.

Thus, if nothing has changed in the interval between two exposures, this ratio should be 1. It is evident from inspection of Fig. 7 that for all observed gas species, a more or less extended transition period exists until the desorption process comes back to the steady state condition of the preceding run. Since the data shown were recorded at a total accumulated dose of approximately 10^{23} photons/m, any cleaning effect during this 3 hour period must be negligible, suggesting that for some of the gas species, it may take several hours to reach their steady state condition for desorption. The most striking observation is the strongly increased initial desorption of O₂ which can only be attributed to an increased amount of oxygen molecules which have accumulated on the surface during the irradiation-free period. The variation of the molecular desorption yield as a function of the photon dose, D , at the beginning of the irradiation period, the same data as shown in Fig. 7 as function of time, has been fitted with an exponential dependence of the form

$$\eta = 6 \cdot 10^{-7} \exp\left[-\frac{D}{D_1}\right] + 4.5 \cdot 10^{-7} \left(1 - \exp\left[-\frac{D}{D_2}\right]\right)$$

Fig. 7: The variation of the partial pressures at the beginning of an irradiation period which follows an interruption of several hours. The signals have been normalised to the steady state values at the end of the preceding irradiation period.

Fig. 8: Transient behaviour of the desorption yield for O₂ as a function of photon dose at the beginning of an irradiation period following an interruption of several hours (see also Fig. 7).

where $D_1 = 7.9 \cdot 10^{19}$ photons/m and where the second term contains a much larger 'build-up dose' $D_2 = 5.2 \cdot 10^{20}$ photons/m. The first term represents the exponential depletion of the accumulated O_2 molecules as it would be expected for a desorption yield which is directly proportional to the surface coverage of molecules. By integration of this term one arrives at a total surface coverage of $4.7 \cdot 10^{13}$ oxygen molecules/m. It takes typically $2 \cdot 10^{20}$ photons/m to desorb these molecules.

The second term in the expression of η reflects the increase of the desorption yield with photon exposure and describes the creation of desorbable molecular species on the surface by the photons and the photoelectrons. The much longer characteristic dose for the build up of the desorption yield, D_2 , suggest that under the steady state conditions typical for this experiment, the molecular yield is limited by the rate with which the desorbable O_2 molecules can be produced, e.g. by the diffusion of the gas in the surface near layer.

Somewhat less pronounced, but clearly visible is a similar transient behaviour of H_2 and H_2O where it can be seen that following the interruption of irradiation, the desorption rate initially decreases before rising again to join the previous steady state values. This behaviour is again attributed to the presence of molecular states at the surface which desorb very readily when the photon beam is switched on. Subsequently these states are slowly reproduced by the photon irradiation.

This same process must also occur for other gas species as one observes a gradual build-up of the desorption yield over a period of several hours (corresponding to a photon dose of typically $2 \cdot 10^{21}$ photons/m) until a steady state condition is reached between the creation of desorbable molecular species on the surface by the irradiation and the depletion by the desorption process. In the same way as for O_2 , e.g. the increase of the molecular yield for CO is characterised by a build-up dose of $1.5 \cdot 10^{20}$ photons/m.

4.3 Pressure variation when interrupting the irradiation

The effect on the partial pressures of the desorbed gas species when interrupting the radiation is shown in Fig. 9 as a function of time. For clarity all pressures have all been normalized to 100%, the pressure just before closing the photon shutter. Two distinct types of behaviour are evident, a very fast decrease with a time constant of the order of seconds (difficult to record with the pressure gauge) and a very slow decrease with a time constant ranging from hours to days. The arrows show the end of the fast decrease and the start of the following slow decrease.

The initial very fast decrease can be attributed to the interruption of the photon flux and the absence of direct photon induced desorption. In the case of H_2O the direct effect of the photons is barely visible, reducing the desorption rate by only 5%. For the other gases the direct effect of the photons is larger ranging from 23% for CO to a maximum of 82% for H_2 .

The slow decrease, which can be observed for hours and even days appears to have its origin in an enhanced thermal desorption process. This enhanced thermal outgassing which causes the pressure in the test chamber to remain by several orders of magnitude above the initial static pressure before the first photon exposure, points to the fact that either the surface population of molecules has increased due to the photon irradiation and/or that their binding energy is lower.

Fig. 9: Partial pressures after closing the photon shutter normalised to the initial equilibrium pressures with photon irradiation. For clarity all pressures have been normalized to 100%, the pressure just before closing the photon shutter. The initial very fast decay is attributed to direct photon induced desorption. The following slow decrease is attributed to enhanced thermal outgassing.

The long term effect of the photon exposure on the outgassing rate can also be seen in Fig. 10. Since the partial pressure for CO₂ before the first photon irradiation was $2 \cdot 10^{-11}$ Torr, it can be seen that even after many hours of pumping the partial pressure is still more than one order of magnitude above this initial value, hence the system has not come back to its unperturbed state.

4.4 Chamber temperature variation

In order to verify whether, and to what extent, the observed variations of the desorption rate can be attributed to changes of chamber temperature when the photon beam is switched on and off, the temperature was recorded during several runs with thermocouples mounted on the test chamber. For a beam current of 315 mA in DCI the synchrotron radiation power incident on the Cu chamber was 64 W over a length of 3.12 m. Since the chamber was equipped with an insulating jacket for the bakeout, this power resulted in an approximately uniform temperature rise of 11°C. The temperature T (°C) of the chamber as a function of the time t (min) of irradiation, when the photon beam is switched on, can be fitted by the expression:

$$T = 22.2 + 10.92 \left(1 - \exp\left[-\frac{t}{55.3}\right] \right)$$

with a time constant of 55.3 minutes.

Similarly, for the cool-down after closing the photon shutter, the fit was

$$T = 22.2 + 10.92 \exp\left[-\frac{t}{24.2}\right]$$

with a shorter time constant of only 24.2 minutes.

Fig. 10: Partial pressure of CO₂ after closing the photon shutter versus time (hours). Before the photon irradiation the partial pressure was $2 \cdot 10^{-11}$ Torr.

Since the partial pressures in Figs. 9 and 10 show either considerably shorter or much longer time constants than the chamber temperature, it seems that the observed temperature effects can only partly account for the pressure variations and for the apparent changes of desorption rate as a function of time. In fact, as will be shown later, significant differences of the activation energy of the molecular species have been measured with and without photon exposure.

4.5 Temperature dependence of the desorption yield and of the outgassing rate

The effect of the chamber temperature on the photon induced desorption yield was studied further by raising the temperature by a larger amount than what is possible under the normal operating conditions with beam. This experiment was done after an accumulated dose of $2.7 \cdot 10^{23}$ photons/m had been achieved, hence any short term cleaning effect can be

neglected. Using the bakeout heating tapes wound around the chamber its temperature was increased from 22°C to 60°C. When the pressure in the absence of photon irradiation had reached a stable value of 5×10^{-10} Torr after 24 hours, the desorption yields were measured with a beam intensity of 220 mA, allowing 10 hours for the system to attain stationary conditions. During this period the chamber temperature had increased by a further 10°C to 70°C due to the synchrotron radiation power. Table 2 shows the ratio of the desorption yield at 70°C to the desorption yield at 33°C for H₂, CH₄, H₂O, CO, O₂ and CO₂.

Table 2

Gas	H ₂	CH ₄	H ₂ O	CO	O ₂	CO ₂
$\frac{\text{Yield}(70^\circ\text{C})}{\text{Yield}(33^\circ\text{C})}$	1.0	1.01	5.7	1.15	4.5	1.67

It can be seen that the increased temperature has no significant effect on the H₂ and CH₄ desorption yields. The CO and CO₂ desorption yields increase only slightly. A significant increase has only been found for H₂O and O₂ by factors of 5.7 and 4.5 respectively.

As part of this study, the partial pressures for each of the molecular species were recorded as a function of the temperature of the chamber during the cool down period without photon irradiation. The data were fitted to an exponential of the form $A \exp(-\frac{E}{kT})$, where E is the activation energy for desorption, k is Boltzmann's constant and T is the absolute temperature, from which the respective activation energies listed in Table 3 were calculated. The constant A contains the surface population of molecules.

To study in more detail the effect of irradiation on the activation energy of molecules adsorbed on the surface, this measurement was repeated after the test chamber had been demounted from the photon beam line and after it had been subjected to a second chemical cleaning and bakeout. It was assumed that this procedure would re-establish the conditions of an originally unexposed chamber. The activation energies in eV/molecule as measured under these conditions are quoted 'without exposure' in Table 3.

Table 3

Molecular species ----- Activation Energy (eV/molecule)	H ₂	CH ₄	H ₂ O	CO	O ₂	CO ₂
'without exposure'	0.15	0.12	0.42	0.13	0.46	0.27
'after exposure'	0.5	0.67	0.55	1.66	1.53	1.41

A comparison of the two sets of measurements shows, with the exception of H₂O, a strong increase of the activation energy for all gases. This observation suggests that, following the photon irradiation, the molecular species which are present on the surface of the test chamber and dominate the outgassing rate have higher activation energies, while the previously present lower binding energy states appear to have been depleted. The very slow

decrease with time of the dynamic pressure following an irradiation period as shown in Fig. 10 is in line with this observation. Furthermore, the strongly enhanced thermal outgassing rate at ambient temperature leads to the conclusion that the surface population of more strongly bound molecules has increased¹¹.

4.6 Wall pumping effect after photon irradiation

Throughout the series of irradiations as well as during the calibration measurements of the RGA the pressure gradient along the test chamber as seen on the gauge P1 near the pumping orifice and on the gauge P3 at the downstream end of the test chamber (see Fig.1) was frequently recorded. Since the gas load due to photon desorption can be assumed to be evenly distributed along the test chamber, the ratio P3/P1 is calculated to be 1.36 based on the conductance of the pumping orifice and of the test chamber. Under the assumption of a uniform wall pumping speed, this pressure ratio has been estimated to vary between 1.36 and 1 when the wall pumping increases from zero to very large values. During the extended photon irradiation a ratio of 2.5 was measured in reasonable agreement with the expected value, and this ratio did not change with photon dose.

Measurements of wall pumping speed of the test chamber were performed three months after the end of the irradiation period. During this whole period the test chamber was kept under vacuum and the base pressure had reached its initial low value. For the measurement the test gas was injected at the downstream end of the test chamber through a side connection equipped with the gauge P3.

The parameters determining the pressure gradient along the test chamber and the ratio of the pressures from the downstream and upstream ends of the vacuum system are summarised as follows:

C_1	conductance of the pumping orifice, 72.5 l/s for nitrogen
P1, P2,P3	upstream and downstream pressure in the test chamber, P3 is the pressure at the gas injection port. Note that P2 can only be inferred from either P1 or P3 but is not measured directly.
C_0	conductance of the test chamber between gauges P1 and P2, (89 l/s for nitrogen)
C_t	conductance of the injection manifold between P3 and P2, (approx. 35 l/s for nitrogen)
S_0	uniform wall pumping speed (l/s)

The pressure ratio is calculated from the expression

$$\frac{P_3}{P_1} = \frac{1}{2} \left\{ \left[1 + \frac{C_1}{C_t} \right] [\exp(a) + \exp(-a)] + \left[\frac{aC_0}{C_t} + \frac{C_1}{aC_0} \right] [\exp(a) - \exp(-a)] \right\}$$

$$\text{where } a = \sqrt{\frac{S_0}{C_0}}$$

For $S_0 = 0$, that is for zero wall pumping, the ratio becomes simply

$$\frac{P_3}{P_1} = 1 + \frac{C_1}{C_0} + \frac{C_1}{C_t},$$

which gives approximately 3.9 for our experimental parameters. This ratio is independent of the gas species.

Under the conditions of gas injection at the downstream end of the test chamber during the initial calibration of the RGA with the baked and, up to then, unexposed chamber, the pressure ratio was found to be 2.8, in good agreement with the expected value of 3.9. However, following the repeated periods of irradiation, significantly larger ratios were observed as shown in Fig. 11, which could be explained only by assuming a strong wall pumping speed along the test chamber.

The pressure ratios were re-measured after the final irradiation period by injecting different gas species. For H_2 and CH_4 , the wall pumping effect was found to be absent, while for CO , CO_2 and O_2 pressure ratios as large as 145, 22 and 7 were measured for the three gases respectively.

Fig. 11: Ratio of inlet to outlet pressure in the test chamber during injection of CO and CO_2 as a function of time. Prior to photon irradiation a ratio of 2.8 was measured for both gases.

From these values we deduce wall pumping speeds of about 1160 ls^{-1} for CO , about 280 ls^{-1} for CO_2 and still 80 ls^{-1} for O_2 . These values were decreasing during prolonged gas injection as shown in Fig. 11 consistent with a gradual saturation of active sorption sites on the wall of the test chamber.

Following a gas injection, a bakeout at 100°C was sufficient to reestablish the pressure gradient and thus the wall pumping effect from before. This finding suggests that the creation of active sorption sites on the wall of the vacuum chamber during the photon irradiation is a relatively persistent and reversible effect.

5. CONCLUSIONS

After exposing a 3.5 m long, 131 mm diameter OFHC copper chamber to 3.75 keV critical energy synchrotron radiation for a total dose of $2.7 \cdot 10^{23}$ photons/m, desorption yields down to 10^{-5} mol/photon were reached for H₂, CO and CO₂. For CH₄, H₂O and O₂ an even lower yield of 10^{-7} mol/photon was obtained. For all desorbed gas species the desorption yields show no signs of levelling off and lower yields can therefore be expected for larger photon doses. It should be noted that in an actual Tau-charm or B-meson factory a dose of $2.7 \cdot 10^{23}$ photons/m is modest and would correspond to an actual running time of only a few hours.

Although the photons only strike one side of the chamber, the whole inner surface is cleaned by the photoelectrons and the scattered photons. This fact must be taken into account when dimensioning the pumping capacity of a getter-pumped vacuum system and for estimating the required clean-up time of a vacuum system.

After a photon dose of $2.7 \cdot 10^{23}$ photons/m about one monolayer of gas is desorbed from the Cu surface. Such a gas load is well within the pumping capacity of a reasonable Non Evaporable Getter pumping system similar to what has been proposed for Tau-charm and B-meson factory vacuum systems. The total amount desorbed from the Cu surface is considerably less than what has been observed previously under similar condition from an Aluminium test chamber.

The observations of the transient behaviour of the pressure at the beginning and after an irradiation period may be interpreted as a manifestation of a two step process where as a first step in the desorption process, molecules on or near the surface are activated or dissociated by the photons or by the photo electrons.¹² The H atoms can diffuse from the bulk to the surface. Other species like O and C atoms have their origin in the Cu oxide layer and in the free C always present on such surfaces. In a second step, the molecular species H₂, CH₄, H₂O, CO, O₂ and CO₂, which recombine and accumulate on the surface desorb thermally. This thermal desorption does not require the photon irradiation and continues for many hours after an irradiation period.

This hypothesis of distinct processes for creation and desorption of surface molecules is in line with transient effects, particularly of O₂, H₂ and H₂O at the beginning of an irradiation period. For these molecular species the desorption yield after a prolonged interruption of the photon irradiation was found to be consistent with a desorption model where the molecular yield is directly proportional to the coverage, that is the yield follows an exponential decay with photon dose. In steady state conditions, however, obtained after a dose of some 10^{21} photons/m only, desorption and creation of molecules on the surface appear to balance each other.

Molecules on the surface appear to desorb either by thermally activated desorption or by the break-up of bonds due to incident photons or photoelectrons. The activation energy of these surface molecules, deduced from the temperature dependence of the outgassing rate, was found to be between 0.5 eV and 1.66 eV/molecule depending on the gas species. Prior to irradiation the activation energy for all gas species was found to be substantially lower, e.g. for CO by more than one order of magnitude. The desorption of molecules from high binding energy states following an irradiation period is reflected in a very slow decrease of the partial pressures with time.

With the exception of H₂O and O₂, where some temperature effect can be seen, the photon induced molecular desorption yields for the other gas species do not change over the temperature range from 33°C to 70°C.

A substantial 'wall pumping effect' by physisorption was observed at the end of the irradiation period. For CO it amounted to approximately 1160 ls⁻¹, for O₂ to 80 ls⁻¹ and for CO₂ to 280 ls⁻¹. Apart from O₂, the wall pumping effect did not disappear even after several months at a static pressure in the low 10⁻¹⁰ Torr range. However, when the chamber was exposed to a pressure several orders of magnitude above this base pressure the wall pumping speed was lost. Nevertheless, a mild bakeout (100°C) was sufficient to bring back the original wall pumping speed suggesting that it is a relatively persistent and reversible effect.

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