EXPOSURE OF A Cu PLATED STAINLESS STEEL CHAMBER TO PHOTONS

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1. INTRODUCTION

The present design of the Large Hadron Collider (LHC) beam screen consists of a 1 mm thick, square section stainless steel tube at a temperature of between 10 K and 20 K with a 0.1 mm layer of Cu electrodeposited on the inside.

It is this electrodeposited Cu surface which will be subjected to bombardment by the 63.5 eV critical energy synchrotron radiation from the 7.7 TeV protons. The subsequent photon induced gas desorption causes a pressure increase which will decrease the required beam-residual gas lifetime and build up thick layers on the cold surfaces where only a few monolayers of cryopumped H2 already has a vapour pressure of 10^-6 Torr.

In this note we report on the measurements of the synchrotron radiation induced gas desorption at EPA beam energies of 565, 500, 345, 270 and 200 MeV, corresponding to photon critical energies of 280, 194, 63.5, 30.5, and 12.4 eV, respectively. Also a long exposure to photons of 63.5 eV critical energy was carried out to measure the clean-up rate as a function of photon dose.

In addition, the photoelectron currents produced in the test chamber could be measured by applying +1 kV to a 200 mm long wire suspended along the axis of the chamber.

2. TEST CHAMBER PREPARATION

The 4.2 m long, 131 mm diameter, stainless steel chamber was manufactured from 316 L+N stainless steel tube. Before electroplating the chamber with Cu, it was chemically cleaned first by immersion in perchloroethylene vapour at 121°C, then by immersion in an alkaline detergent at 65°C followed by rinsing in cold demineralized water and finally drying in a vacuum oven at 150°C. As an additional treatment, the bare test chamber was degassed in a vacuum oven at 950°C then baked at 300°C for 24 hours for a vacuum limit test.
The Cu electroplating was carried out by Flühmann AG\textsuperscript{1}) using pyrophosphate and a pulsed reversed current technique and consisted of a 0.1 µm Ni layer followed by 0.2 µm Au then 100 µm Cu.

Before installing in the synchrotron radiation beam line, the Cu plated test chamber was first pumped for about 10 days, without any baking, to compare its thermal outgassing rate with that of an identically prepared stainless steel chamber\textsuperscript{2}). No significant difference in thermal outgassing was found.

3. EXPERIMENTAL DETAILS

The Cu plated test chamber was mounted in the beam line at an angle of 11 mrad to the photon beam. The chamber was pumped without baking for a period of 70 days before the first measurement. Just before the measurement the total pressure was 5.4 \times 10^{-10} Torr and the residual gas spectrum is shown in Fig. 1. As is usual for an unbaked system, the residual gas spectrum contains mostly H$_2$O.

![Fig. 1. The residual gas spectrum after 70 days of pumping.](image)

The results are presented in the order that the measurements were taken. The final set was a cleaning run at 63.5 eV critical energy which is that of the LHC.

4. GAS DESORPTION RESULTS

4.1. 500 MeV

The test chamber was exposed to synchrotron radiation from a 500 MeV beam, which corresponds to a critical energy of 194 eV. The accumulated dose was of 3.3 \times 10^{18} ph/m. The results are shown in Fig. 2, where it can be seen that the initial yields are, in order of importance, H$_2$, CO$_2$ and H$_2$O with 6 \times 10^{-3}, 5 \times 10^{-3},$ and 4 \times 10^{-3} mol/ph, followed by CO with about 2 \times 10^{-3} mol/ph and CH$_4$ with 4 \times 10^{-4} mol/ph. No cleanup could be seen but the H$_2$O tended to increase slightly with dose.
Fig. 2. The photon induced desorption yields as a function of photon dose at 194 eV critical energy.

It is interesting to compare the photon induced desorption yields for unbaked bulk Cu\(^3\) and electodeposited Cu. This has been done at 194 eV critical energy and the results are shown in Fig. 3. It can be seen that for H\(_2\), CH\(_4\), CO and CO\(_2\) there is little difference (less than a factor of 1.6) between the two. The largest difference lies in the H\(_2\)O desorption yield which is about a factor 5 more for the electroplated Cu compared to the bulk Cu.
Fig. 3. The photon induced desorption yields for unbaked bulk Cu and electroplated Cu.

4.2. 200 MeV

The chamber was then exposed to synchrotron radiation of critical energy of 12.4 eV, corresponding to a beam energy of 200 MeV. The accumulated dose was of about $3 \times 10^{17}$ ph/m, and the highest yield was again that of $\text{H}_2$ at about $3 \times 10^{-4}$ mol/ph, $\text{CO}_2$ at about $2.5 \times 10^{-4}$ mol/ph, $\text{H}_2\text{O}$ at about $2 \times 10^{-4}$ mol/ph, CO at about $6 \times 10^{-5}$ mol/ph, and $\text{CH}_4$ at about $3 \times 10^{-5}$ mol/ph (Fig. 4). No cleaning was observed but, in contrast, the $\text{H}_2\text{O}$ desorption yield increased strongly with dose.
Fig. 4. The photon induced desorption yields as a function of photon dose at 12.4 eV critical energy.

### 4.3. 270 MeV

This beam energy corresponds to a critical energy of 30.5 eV. The accumulated dose was $9 \times 10^{17}$ ph/m. The yields were in the following order: H$_2$, CO$_2$, CO, H$_2$O and CH$_4$, with yields of about, $6 \times 10^{-4}$, $5 \times 10^{-4}$, $1.3 \times 10^{-4}$, $6 \times 10^{-5}$ and $3 \times 10^{-5}$ mol/ph, respectively (Fig. 5). Again the H$_2$O yield increased with dose, while the others gases remained relatively constant.
Fig. 5. The photon induced desorption yields as a function of photon dose at 30.5 eV critical energy.

4.4. 565 MeV

The test chamber was exposed to synchrotron radiation from a 565 MeV beam, which corresponds to a critical energy of 280 eV (i.e. corresponding to the critical energy of the SSC). A dose of about $4 \times 10^{18}$ ph/m was accumulated. The results are shown in Fig. 6, where it can be seen that the yield for H$_2$ was the highest at about $8 \times 10^{-3}$ mol/ph, followed by CO$_2$ with $5 \times 10^{-3}$ mol/ph, then CO and H$_2$O with about $2 \times 10^{-3}$ mol/ph and CH$_4$ in the $10^{-4}$ range. Once more the H$_2$O yield increased with dose.
Fig. 6. The photon induced desorption yields as a function of photon dose at 280 eV critical energy, which corresponds to SSC critical energy.

4.5. 345 MeV

The last set of measurements was carried out at an EPA energy of 345 MeV, which corresponds to a critical energy of 63.5 eV. This energy corresponds to the critical energy of the synchrotron radiation from 7.7 TeV protons in the LHC. We tried to accumulate as much dose as possible in order to see some cleaning effect. After two days (48 hours) of continuous running, we accumulated a dose of $1.25 \times 10^{21}$ photons/m, with a beam current of about 100 mA.

The photodesorption yields are shown in Fig. 7, where it can be seen that the initial values are the following: $1.1 \times 10^{-3}$ mol/ph for H$_2$ and CO$_2$, $3 \times 10^{-4}$ mol/ph for CO, $2.2 \times 10^{-4}$ mol/ph for H$_2$O and $7 \times 10^{-5}$ mol/ph for CH$_4$. 
All gases during the long exposure to photons exhibited the same behaviour, increasing their yields with dose until they reached a maximum and then decreasing with dose. Although H$_2$O showed the largest increase with dose before decreasing, the final yield measured after a dose of $1.25 \times 10^{21}$ photons/m was still above the initial by a factor of about 2.7. This is presented in Table 1, where the initial, maximum and final yields are presented, together with the ratios between the maximum and final values and the initial and final values.

After the maximum photon dose all desorption yields were decreasing and showing no signs of levelling off.
Fig. 8 The total quantity of gas desorbed from the electroplated Cu as a function of the photon dose.

In Fig. 8 is shown the total quantity of gas per metre of chamber (1 m of chamber has a surface area of 3142 cm$^2$) desorbed by the synchrotron radiation from the electrodeposited Cu. After a photon dose of $1.25 \times 10^{21}$ photons/m almost equal quantities of H$_2$, H$_2$O and CO$_2$, namely $1 \times 10^{18}$ molecules/m$=3.18 \times 10^{14}$...
molecules/cm$^2$, were desorbed. After the same dose 3 $10^{17}$ molecules/m of CO and 9 $10^{16}$ molecules/m of CH$_4$ were desorbed.

If we consider that 1 monolayer contains $10^{15}$ molecules/cm$^2$ then we have desorbed less than one monolayer of each gas.

4.6. Critical energy dependance

The dependance of the initial desorption yields on critical energy are shown in Fig. 9.

![Graph showing critical energy dependance](image_url)

**Fig. 9.** The initial photon induced desorption yields as a function of the photon critical energy for electrodeposited Copper.

Over the critical energy range 280 eV to 12.4 eV H$_2$, CH$_4$, CO and CO$_2$ decrease by a factor of about 30 whereas the H$_2$O decreases by about a factor of about 50.
The critical energy dependence of the desorption yields have been fitted to the following function:

$$\eta = A \varepsilon^b$$

where $\varepsilon$ is the critical energy, $\eta$ is the photodesorption yield and $A$ and $b$ are constants obtained by the fit. All yields were fitted separately and the results are shown in the following equations:

- $\eta(\text{H}_2) = 1.42 \times 10^{-5} \varepsilon^{1.13}$, with $R = 0.987$
- $\eta(\text{CH}_4) = 9.76 \times 10^{-7} \varepsilon^{1.12}$, with $R = 0.980$
- $\eta(\text{H}_2\text{O}) = 1.42 \times 10^{-6} \varepsilon^{1.33}$, with $R = 0.847$
- $\eta(\text{CO}) = 2.88 \times 10^{-6} \varepsilon^{1.19}$, with $R = 0.995$
- $\eta(\text{CO}_2) = 1.48 \times 10^{-5} \varepsilon^{1.08}$, with $R = 0.997$

where $R$ is the correlation coefficient.
The results are represented in Fig. 10, where it is seen, except for \( \text{H}_2\text{O} \), that the fit is reasonably good. But there are big differences in \( \text{H}_2\text{O} \) from initial values to the final ones.

This dependance of the yield on the critical energy can be more clearly seen in Fig. 11 where the total \( \text{N}_2 \) equivalent desorption yield is represented. To calculate this \( \text{N}_2 \) equivalent yield, we use the total pressure increase to calculate the desorption yield and consider that the only gas desorbed is \( \text{N}_2 \) (or CO), using the appropriate pumping speed to calculate the desorption yield. Since the \( \text{H}_2\text{O} \) desorption yield tended to increase with exposure to photons, this is reflected in the behaviour of the total pressure. In Fig. 10, for each critical energy, we have plotted the initial and the final total \( \text{N}_2 \) equivalent desorption yields with the arrows indicating the increase with exposure time.

On the double logarithmic scale there is a linear decrease of the total \( \text{N}_2 \) equivalent desorption yield with critical energy.

**Fig. 11** The total \( \text{N}_2 \) equivalent photon induced desorption yields as a function of the photon critical energy.
4.7. Photoelectron currents.

The measured photoelectron currents as a function of critical energy are shown in Fig. 12. The solid line is a best fit to the experimental points using an expression of second order in the critical energy. The equation is:

$$I_{pe} = -1.79 \times 10^{-2} + 2.19 \times 10^{-3} \varepsilon + 2.87 \times 10^{-6} \varepsilon^2$$

where $I_{pe}$ is the measured photoelectron current and $\varepsilon$ is the critical energy. The photoelectron current extrapolates to zero at a critical energy of 8.2 eV.

![Fig. 12](image)

**Fig. 12** The measured photoelectron currents as a function of the photon critical energy.

In Fig. 13 are shown the total $N_2$ equivalent photon induced desorption yields as a function of the measured photoelectron currents at the five different critical energies. In contrast to baked stainless steel\(^4\), there is at first sight no obvious linear dependence of the desorption yield on the measured photoelectron currents. However, if we consider only the initial desorption yields - the lowest points - where the $H_2O$ has not started to increase, there is a reasonable linear dependence.
5. CONCLUSIONS

Initial photodesorption yields for an unbaked electrodeposited copper surface have been obtained in the critical energy range available at the EPA machine from 12.4 eV to 280 eV. For 194 eV, the results are similar to those obtained for unbaked bulk copper, except that H$_2$O is a factor of 5 higher in the electrodeposited copper.

The behaviour of H$_2$O is singular in all the range of energies, because its yield is increasing strongly with dose, while the other gases remain essentially constant.

The dependance with critical energy was fitted quite accurately with a function of the type: $\eta = A \cdot e^b$, except for H$_2$O, where the fit was not very good, because of big differences between the initial values and the final ones. The values of $b$ ranged from 1.08 for CO$_2$ to 1.33 for H$_2$O.

A cleaning run up to a dose of $1.25 \times 10^{21}$ photons/m was performed at the LHC critical energy of 63.5 eV and corresponds to 2.2 hours of LHC operation at top energy and maximum beam current. However the cleaning effect was not very large,
with reduction factors going from 1.2 for H$_2$ to 2.2 for CO$_2$. The desorption yield for H$_2$O, however, increased with photon dose and ended up 2.7 times above its initial value.

The total quantity of gas desorbed after a dose of $1.25 \times 10^{21}$ photons/m was less than a monolayer for each gas.

At 345 MeV and a beam current of 100 mA there are 110 mW entering the test chamber amounting to 32.5 mW m$^{-1}$ incident on the Cu plated surface. It is presumably this power which causes some heating of the Cu surface and partly contributes to the increase in the H$_2$O desorption yield.

The measured photoelectron currents were fitted to a second order polynomial and the photoelectron current extrapolated to zero at a critical energy of 8.2 eV.

Finally, considering just the initial desorption yields, where water was not starting to increase, there is a linear dependence between the total N$_2$ equivalent photon induced desorption yields and the measured photoelectron currents.

6. ACKNOWLEDGEMENTS

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7. REFERENCES


