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Photoelectron current from the substrate with cryosorbed gases

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1. Introduction

Most of the length of the LHC vacuum chamber will be at cryogenic temperature. High intensity photon flux will stimulate photoelectron emission from the wall of the LHC vacuum chamber. The photoelectrons participate in different processes in the vacuum chamber, some more important ones are the gas photodesorption and the beam induced multipacting. The aim of the present work was to study one important question: how much the layer of condensed gas will change the photoelectron emission.

This note describes the study fulfilled from March to May 1998 in the frame of the collaboration between CERN and the Budker Institute of Nuclear Physics (Novosibirsk, Russia) (see item 1.4) [1].

2. Set-up

The ‘open geometry’ set-up which was used to measure the photodesorption of cryosorbed gases [2] was modified to measure the photocurrent from the substrate with a condensed gas layer by the synchrotron radiation. The layout of the installation is shown in Figure 1.

The main difference: two isolated electrodes were installed in front of the substrate. The electrode C_1 which is close to the substrate is conic with a 35-mm hole. It is a collector of the photoelectrons. The bias between the collector and the substrate could be varied from –300 V to +300 V. The second electrode C_2 is a disc with a 25-mm hole at the centre. This electrode plays two roles: (a) no direct photons irradiate the first electrode; (b) the potential of about –50 V is a good electrostatic barrier for any photoelectrons from both sides of the second electrode.

The photocurrent from the substrate with cryosorbed gases was measured from the electrode C_1.

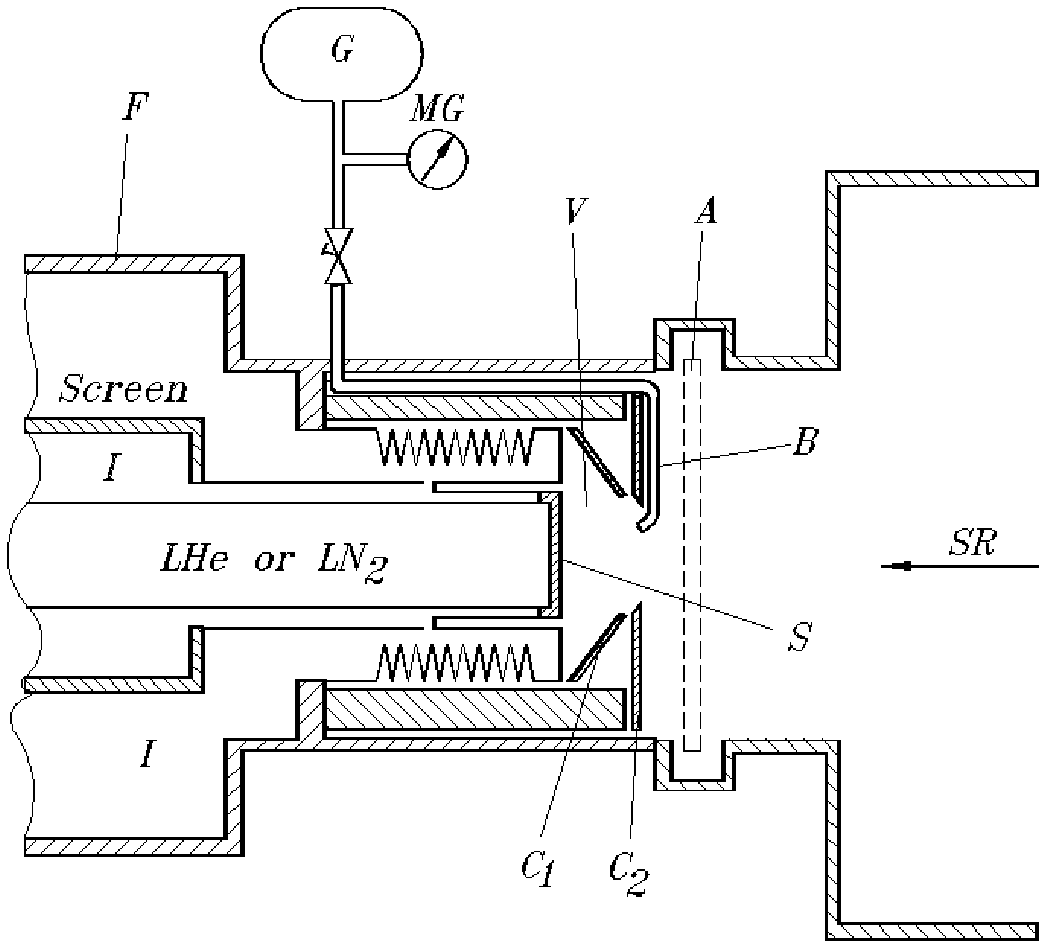

Figure 1. The experimental set-up on the synchrotron radiation beam line. *F* is the cryostat, *I* is the isolating vacuum, *V* is the experimental volume which can be separated from the beam line with the valve *A* shown in the closed position. The membrane gauge *MG* measures the gas pressure in the volume *G* which is injected via the pipe *B* and condensed onto the substrate *S* at cryogenic temperature. C_1 and C_2 are the insulated collector electrodes.

3. Experiment

In all experiments, the photoelectron yield was measured as the ratio of the measured output current I_{mes} (i.e. the electron flux from or to the substrate) to the incident photon flux $\dot{\Gamma}$:

$$k\,[e/\tilde{g}] = \frac{I_{mes}\,[A]}{e[Q]\cdot\dot{\Gamma}[\tilde{g}\,/\,\mathrm{sec}]}\,,$$

here e is the electron charge.

The photoelectron yield was studied as a function of condensed gas surface coverage for different bias potentials of the electrode.

The measurements were done for layers of condensed H_2, CH_4, CO, CO_2 and Ar and only one gas was studied in each experiment. The photocurrent was measured initially for a bare surface and afterwards the gas was injected onto the substrate, portion by portion. Each point in the presented graphics corresponds to the measurement after one gas injection. The measurements were done for different biases and the more interesting results at zero bias, 100 V and 300 V are presented in the graphics.

The photoelectron yield from the bare substrate is $1.7\cdot10^{-3}$ electron/photon at zero bias and $1.0\cdot10^{-2}$ electron/photon at 100 to 300 V bias.

3.1 Photoemission from condensed H_2

The H_2 was condensed on the substrate at about 3 K.

The photoelectron yield from the substrate does not change with surface coverage of the condensed gas up to about 10^{17} molecules/cm^2 and remains equal to the photoelectron yield from the bare substrate. The photoelectron yields at 100 V and 300 V are the same. The photoelectron yield at higher surface coverages decreases. A small difference appears between measurements at 100 V and 300 V.

For a surface coverage higher than 10^{18} molecules/cm^2 the photoelectron yield increases also with photon dose at any bias. This effect is not the result of a reduction of the surface coverage due to photodesorption. The variation of surface coverage was taken into account in the data which are presented in Figure 1.

3.2 Photoemission from condensed CO_2

The CO_2 was condensed on the substrate at about 68 K. The experiment was repeated twice: exp.1 and exp.2 in Figure 2.

The photoelectron yield does not change with respect to the bare substrate up to a surface coverage with condensed gas of up to 10^{16} molecules/cm^2. The photoelectron yields at 100 V and 300 V bias are the same.

The photoelectron yield increases by a factor of 1.5–2 for surface coverage between 10^{16}–$3{\cdot}10^{17}$ molecules/cm^2. The photoelectron yield at higher surface coverages decreases. A small difference is observed between measurements at 100 V and 300 V bias.

For surface coverages exceeding 10^{16} molecules/cm^2, the photoelectron yield decreases slightly with photon dose at any bias voltage.

3.3 Photoemission from condensed CH_4

The CH_4 was condensed on the substrate at 4.2 K.

The photoelectron yield does not change with surface coverage gas up to about 10^{17} molecules/cm^2 with respect to the bare substrate. The yield decreases for a higher surface coverage and for zero bias voltage as shown in Figure 3..

At 100 V and 300 V bias the photoelectron yield from the substrate does not change with surface coverage with condensed gas up to about $2{\cdot}10^{15}$ molecules/cm^2 and remains approximately equal to the photoelectron yield from the bare substrate. The photoelectron yield at 100 V and 300 V bias are the same. It increases at higher coverage and remains about 2 times higher between 10^{16}–10^{17}.

At a coverage of about $3{\cdot}10^{17}$ molecules/cm^2, a significant difference between the data at 100 V and 300 V bias can be observed. The authors believe that this difference may be due to a discharge between the substrate and the collector. The indirect confirmation is that at about $2{\cdot}10^{19}$ molecules/cm^2 the measured current remains initially the same when the photon flux is switched off and then slowly decreases with time. At a slightly smaller or larger coverage, this effect also takes place, but the decaying occurs faster. Hence, the measured current is a composition of electron photocurrent plus discharge current, and the latter may be the dominant contribution. Under the condition that the discharge current depends on the potential gradient on the gas density and on the geometry of the substrate or the collector, one must conclude that the measured value at high coverage (exceeding 10^{19} molecules/cm^2) is irrelevant for the electron multipacting study for the LHC.

The same effect was detected at 100 V for surface coverages above $2 \cdot 10^{19}$ molecules/cm^2. The photoelectron current decreases at coverage of 10^{20} molecules/cm^2 for both 100 V and 300 V bias.

3.4 Photoemission from condensed CO

The CO was condensed on the substrate at 4.2 K.

The photoelectron yield from the substrate does not change with the surface coverage of condensed gas up to about 10^{17} molecules/cm^2 with respect to the bare substrate and decreases at a higher surface coverage and at zero bias voltage (see Figure 4).

At 100 V and 300 V bias, the photoelectron yield from the substrate is slightly less at 10^{16} molecules/cm^2 as compared to the bare substrate, but increases with surface coverage and at about 10^{17} molecules/cm^2 it is equal to the bare substrate. The photoelectron yields at 100 V and 300 V are the same. At a coverage higher than about 10^{17} molecules/cm^2, one observes a significant difference between data at 100 V and 300 V. The characteristics of the observed effect is very similar to CH_4. The authors believe that a gas discharge between the substrate and the collector occurs also in this experiment.

3.5 Photoemission from condensed Ar

The experimental set-up was not designed to study the gas dicharge processes. A fast experimental test with Ar condensed at 4.2 K was performed to compare the measured dependencies of this gas with the ones for CH_4 and CO. Argon was therefore chosen as a gas which could enhance this discharge effect. Indeed, with Ar. a much stronger effect was observed with essentially the same characteristics.

4. Summary

1) The photoelectron yield from the substrate does not change with surface coverage with condensed gas up to about 10^{16} molecules/cm^2 and remains equal to the photoelectron yield from the bare substrate.
2) The photoelectron yield is between 1.5–2 times higher for a surface coverage with condensed gas between 10^{16}–10^{18} molecules/cm^2 for condensed H_2, CH_4, CO and CO_2 as compared to the bare substrate.
3) For a surface coverage higher than 10^{18} molecules/cm^2 the photoelectron yield decreases with coverage for all gases at zero bias and for H_2 and CO_2 at the bias of 300 V. The photoelectron yield increases 2–3 times compared to the initial value of the bare substrate for a coverage of CH_4 and CO higher than 10^{18} molecules/cm^2 due to the gas discharge between the substrate and the collector. The general trend is that the yield decreases with higher coverage.

References

1. Addendum No. A3 to the Protocol dated 14 June 1996 to the 1993 Cooperation Agreement between CERN and the Government of the Russian Federation concerning the Russian participation in the Large Hadron Collider project (LHC). CERN-BINP, 1997.
2. V.V. Anashin, O.B. Malyshev, R. Calder, O. Gröbner. A study of the photodesorption process for cryosorbed layers H_2, CH_4, CO and CO_2 cryosorbed between 3 K and 68 K. Vacuum, Vol. 53 (1999) 269-272