PHOTODESORPTION AND ELECTRON YIELD MEASUREMENTS OF THIN FILM COATINGS FOR FUTURE ACCELERATORS

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Abstract

The performance of future accelerators could be limited by electron cloud phenomena and high photodesorption yields. For such a reason, the study of secondary electron and photodesorption yields of vacuum materials is essential. The eradication or mitigation of both secondary electron and molecule desorption could strongly reduce the beam scrubbing time and increase the availability of nominal beams for experiments.

Surface modifications with the desired characteristics can be achieved by thin-film coatings, in particular made of amorphous carbon and non-evaporable getters (NEG).

In the framework of a new collaboration, CERN's vacuum group has manufactured several vacuum chambers with a geometry similar to the beam pipe of future accelerators, and has applied different coatings on each of them. The samples were then irradiated at KEK's Photon Factory (PF) with synchrotron radiation of 4 keV critical energy during several days, allowing the measurement of the photodesorption yield as a function of the photon dose.

This paper presents the experiment and briefly summarizes the preliminary photodesorption and photoelectron yield data of different coatings. The results can be used for future machine design with similar conditions, such as the FCC-hh.

INTRODUCTION

When designing future accelerators, synchrotron radiation (SR) must be taken into account not only for its thermal effects, but also because the induced electron cloud and high photon stimulated desorption (PSD) reduce the beam's lifetime. One way to mitigate these phenomena is the application of different types of thin film coatings.

To measure their efficiency, a collaboration has been set up between CERN's vacuum group and KEK: the goal was to characterize the effectiveness of NEG and amorphous carbon coatings, and the effect of activation and vacuum firing. CERN has therefore manufactured six vacuum chambers, each conditioned and coated differently, then these chambers were installed in one of the PF's experimental hutches in Tsukuba, Japan and data was collected during a two-month test campaign.

SAMPLES

The 1200 mm long, 61 mm internal diameter vacuum chambers are manufactured of 316L type stainless steel, with three 35 mm ports opened by mechanical extrusion and subsequent welding. All ports use standard ConFlat flanges, one rotatable (machine side) and four fixed.

The three ports are connected to DN40 CF vacuum feedthroughs with a pin on the vacuum side - these pins hold bent stainless steel disc-shaped electrodes. A screw fixing system allows precise height and orientation adjustment to ensure that the discs follow the tube profile, while leaving a 1 mm gap allowing to use them as electrodes kept at high voltage.

The tube is closed from one side by a DN63 blank flange with a 4 mm injection tube drilled from its side: this allows gas injection during the experiment. The other side is open. All chamber components were cleaned following standard CERN chemical degreasing procedure, and fasteners and small parts, such as screws were cleaned with ultrasound in an ethanol solution. Following this basic treatment, each sample was conditioned and coated differently. Table 1 summarizes the treatment and coating types.

Table 1: Treatment Types and Experiment Durations for the Six Vacuum Chambers

Sample	Treatment and coating	Experiment duration (days)
1	Reference stainless steel sample basic treatment only	10
2	Stainless steel sample vacuum fired	7
3	TiZrV NEG coating not activated	6
4	TiZrV NEG coating, activated prior to the experiment	6
5	TiZrV NEG coating vacuum fired, activated	7
6	Amorphous carbon coating vacuum fired	11

Samples 2, 5 and 6 were vacuum fired at 950 °C for 2 hours to liberate the H_2 gas stored in the bulk. Once ready, all samples were transported to Japan filled with nitrogen for protection of the inner surface.

EXPERIMENTAL SETUP

We performed our experiment in PF's BL-21 hutch. The beam current, SR critical energy and the incidence angle are chosen to correspond with future machine designs, such as the FCC-hh (4028 eV critical energy, 490 mA beam, 30.7 W/m SR power [1]): the SR in our setup is originating from a 0.9634 T dipole magnet 13 m upstream, with critical

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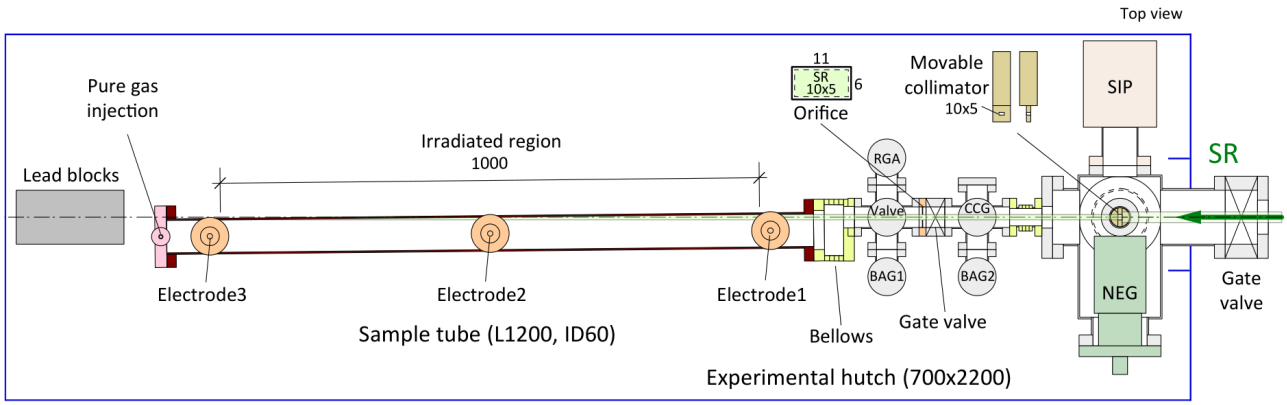

Figure 1: Experimental setup.

energy of 4 keV. The beam has 2.5 GeV energy and a nominal current of 450 mA, which was reduced to 400 mA for sample 5 in order to test a hybrid machine mode.

The SR light is shaped by a water-cooled copper collimator of 10 mm × 5 mm orifice, then passes a calibrated vacuum conductance of 7.05 l/s, until it finally hits the center of the sample at a 10 mrad incident angle over a length of 1 m. At full current, the SR flux arriving on the sample is $5.5 \cdot 10^{16}$ photons/sec and the power is 20.1 W. Depending on the coating type, the majority of these photons are absorbed either at the primary incidence location or on the end flange after one reflection. The system is pumped by a NEG pump of 1500 l/s, located upstream.

The vacuum sample is connected to the machine through a bellow to handle the 1 mrad rotation, and is aligned based on SR radiation patterns on photosensitive films fixed on the exterior. When absorbed, the SR photons desorb gas molecules from the surface, increasing the pressure in the chamber. This desorbing gas quantity can be calculated by the pressure difference on the two sides of the calibrated conductance, indicated by the Bayard-Alpert gauges BAG1 and BAG2 on Fig. 1. A residual gas analyzer, calibrated prior to the experiment for CH_4, CO, CO_2 and H_2 gases collects data about the composition of the desorbed gas. With the vacuum chamber grounded, the three electrodes are biased to 84 V, the highest available of the power supply, and the currents of collected electrons are measured by pico-ammeters.

Near the electrodes, three solenoids of 40 turns are wound around the vacuum tubes, capable of transmitting currents up to 20 Amps temporarily. This allows to create magnetic fields up to 30 Gauss inside the tube, to study a possible electron cloud mitigation method by external solenoids. The injection port of the end flange is connected to a CH_4 bottle through a variable leak valve.

EXPERIMENT

All samples were baked out at 120 °C for 20 hours, and on samples 4 and 5 the NEG coating was activated at 250 °C for 4 hours. Then, with the lead-plated experimental hutch closed, the ambient temperature stabilized at 31 °C, and the bias voltage was applied to the electrodes.

Opening a shutter, the samples were subjected to the SR for a duration between 6 and 11 days per sample (see Table 1), reaching an accumulated photon dose in the order of 10^{22} photons/m.

The pressures of the BAG gauges, the currents on the pico-ammeters, the wall temperatures near the electrodes, the beam current and the interpolated RGA data were logged every second.

The following data was gathered:

1. Total photon stimulated desorption yield, expressed in molecules per absorbed photon, as a function of the total absorbed dose. It is calculated from the measured pressure difference of BAG1 and BAG2, the photon flux derived from the measured beam current and the known conductance.
2. Partial (CH_4, CO, CO_2 and H_2) molecule yields from the RGA data, the beam current and the known conductance.
3. Photoelectron current as a function of the electrode bias voltage.
4. Photoelectron current as a function of the absorbed photon dose.
5. Photoelectron current as a function of the external magnetic field.
6. Wall pumping of methane: in previous experiments, though not published, a reduction of methane's partial pressure was observed when a saturated NEG-coated system was subjected to SR. We have investigated a hypothesis of SR induced wall pumping by activated NEG (through CH_4 breakdown to other hydrocarbons [2, 3]) by injecting methane into our experimental system, then measuring its partial pressure with SR on or off.

RESULTS

Figure 2 shows the total PSD molecule yield of the six samples as a function of the absorbed photon dose. One

of the immediate observations is that NEG coating, when activated, reduces the molecule yield by approximately two orders of magnitude. The vacuum fired NEG sample's high initial but low final yield suggests a contamination that might have happened during the transport or installation but which was eventually cleaned by the SR conditioning.

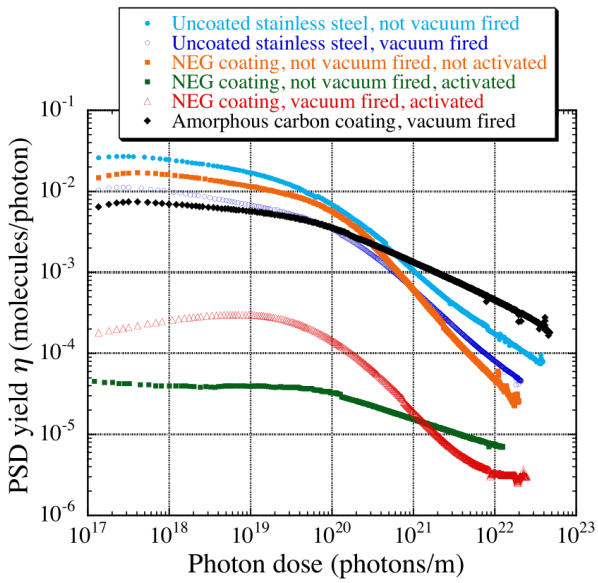

Figure 2: Molecule yields of different samples as a function of absorbed SR dose.

For every sample, at different stages of conditioning, we have performed a so-called bias test where we varied the electrode bias voltages between 0 and 84 volts. The electron current responses of the reference steel and the amorphous carbon samples are shown on Fig. 3, showing a saturation behavior at higher bias voltages, and also indicating that the electron yield is less than one-third for the carbon-coated surface.

Figure 4 shows that a magnetic field induced by an external solenoid is an effective way of reducing the electron cloud, as the desorbed electrons are steered by the Lorentz force on a small radius back to the wall. As in our case the electrodes and the SR incidence location had an angle of 90 degrees, we can see that the response is asymmetric: one magnetic field direction generated by positive solenoid currents steers electrons away from the electrode, while the other steers them towards.

Apart from the preview presented here, data for all samples and all the tests are available in a CERN technical document [4]. Subsequent analysis and interpretation of the data will follow.

Preliminary data shows that activated NEG coating has significantly lower PSD yield than the reference sample. Out of the six samples, the one coated with amorphous carbon had the smallest photoelectron yield, therefore it is a good candidate for electron cloud mitigation. The wall pumping effect of methane was not observed on any of the samples.

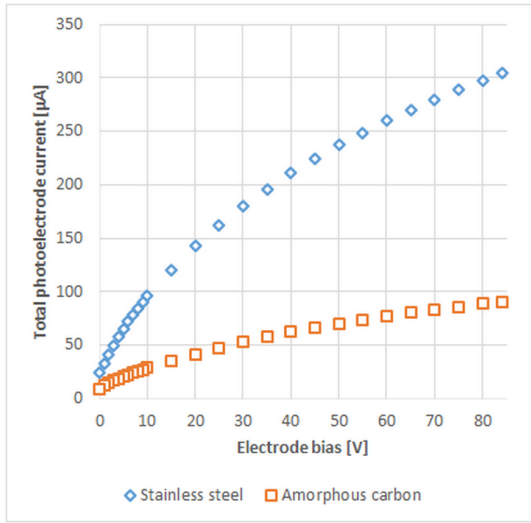

Figure 3: Photoelectron currents at different bias voltages for the stainless steel and amorphous carbon samples, at the beginning of the conditioning.

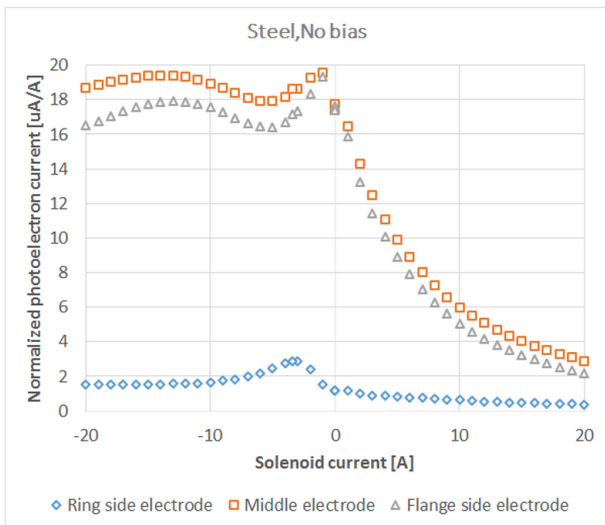

Figure 4: Photoelectron currents normalized by beam current on the three electrodes, as a function of the external solenoid current.

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