Experimental Investigation of Dynamic Pressure in a Cryosorbing Beam Tube Exposed to Synchrotron Radiation

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Abstract
Results of photodesorption experiments on a 4.2-K beam tube irradiated with synchrotron radiation from the VEPP-2M storage ring are being reported. The experiments have been performed on SSC1 and SSC2 beamlines. Synchrotron radiation parameters of the SSC1 beamline are the same as the SSCl 20 TeV proton collider; critical energy = 284 eV, photon intensity 1*10^{16} photons/m/s. Photon intensity of the SSC2 beamline is eight times higher than intensity of the SSC1 beamline. We have used two experimental configurations to observe the density increase due to: (1) photodesorption of tightly bound molecules not previously desorbed and (2) photodesorption of weakly bound cryosorbed molecules. The two configurations used were a simple 4.2-K beam tube and a 4.2-K tube with a coaxial perforated liner. The photodesorption coefficient of tightly bound H$_2$ measured on the SSC1 beamline was observed to decrease monotonically with photon exposure, reaching 7*10^{-4} molecules per photon at the end of exposure (-1*10^{22} photons/m). The same experiment on the SSC2 beamline gave a similar result at photon dose 3.5*10^{22} photons/m. The photodesorption coefficient of cryosorbed H$_2$ increased with increasing H$_2$ surface density, reaching 7 molecules/photon at one monolayer surface density (sm$=3*10^{15}$ H$_2$/cm$^2$), where $\sigma_w$ is the sticking coefficient. The liner was shown to effectively shield cryosorbed molecules from synchrotron radiation.

2. EXPERIMENTAL SETUP

The experiments were performed on two synchrotron radiation beamlines SSC1 and SSC2 of the VEPP-2M electron-positron storage ring at Budker Institute of Nuclear Physics (BINP) in Russia. The schematic of these experiments is shown in Figure 1. The details and parameters of the beamlines were described previously [2]. The photon-critical energy and intensity of the SSC1 beamline are the same as the SSC (284 eV, ~1*10^{16} photons/m/s). Photon intensity of the SSC2 beamline is eight times higher than intensity of the SSC1 beamline. The simple beam tube and bore tube liner were 1-m-long sections of electrodeposited Cu on SS tube (ID = 32 mm, OD = 34.9 mm, Cu thickness = 70 pm). The liner was perforated with 600 2-mm-diameter holes spaced 1 cm axially and 60$^\circ$ azimuthally. The bore tube outside the liner was SS (ID = 41.9 mm, OD = 44.5 mm) welded to the liner with annular rings at the ends. The simple beam tube and the liner bore tube were in turn welded into a horizontal LHe cryostat (~20 l LHe) and formed the interface between LHe and vacuum. An intermediate 140-liter-volume tank was installed on the top of the horizontal cryostat. This setup allowed the experiments to be performed for indefinite periods of time without interruption at 4.2-K by adding LHe to the tank from a transport dewar. The static 4.2-K heat load was about 0.45 W. This low static heat load allowed measurement of the synchrotron radiation power hitting the beam tube by noting the increase in He boil off rate. The value obtained confirmed the calculated value. The temperature of the bore tube could be reduced to 2.5-3K by pumping on the LHe. The temperature was measured by a semiconductor gage installed on the outer wall of the bore tube. The temperature of the liner was not measured. We estimate the temperature rise at the center of the liner to be 5-10 K above the LHe temperature when exposed to a photon intensity of 125-250 mW/m.

Gas densities were measured with calibrated rf quadrupole residual gas analyzers (RGAs) at room temperature. An RGA was connected to the center of the beam tube and at each warm end. The center RGA viewed the beam tube through a 2.4-cm-diameter hole. Care was taken to avoid 4.2-K cryosorbing surfaces in the tube connecting the RGA to the beam tube. The connecting tube had a temperature of 77 K at the beam tube hole and made a transition through thin SS bellows to 294 K at the RGA. An annular vacuum gap of ~0.2 mm separated the 77-K viewing tube from the 4.2-K beam tube. Thin-wall SS bellows were used at the ends of the 4.2-K beam tube for transitions to 77 K and 294 K. The 294-K vacuum ends of the cryostat were pumped with combination ion and titanium sublimation pumps.

3. DISCUSSION OF THE DATA

The $\text{H}_2$ dynamic density increase in the center of the tube is shown versus integrated photon flux in Figure 2. The curves A and B in this figure are obtained from non-liner experiments and the curves C and D from liner experiments. The A, B and C experiments have been performed on the SSC1 beamline, and the experiment D on the high intensity SSC2 beamline. The dynamic density of $\text{H}_2$ is shown assuming that the mean molecular speed corresponds to 4.2 K. This is a lower bound for the real molecular speed and thus the dynamic density in Figure 2 is an upper bound. The real molecular speed is unknown because the pressure in the experiments was measured by the RGA at room temperature. The measured quantity was $n\bar{v}$, where $n$ is the molecular gas density and $\bar{v}$ the effective mean molecular speed. The line E shows upper limit of $\text{H}_2$ density $3\times10^8 \text{ cm}^{-3}$ in the Collider beam tube to provide the desired vacuum limited luminosity lifetime of 150 hours. Recently we have begun to make progress directly measuring the molecular density inside the 4.2-K beam tube using charge exchange reactions of a proton beam. These measurements are described in a companion paper [3].

The dynamic density of $\text{H}_2$ in the beam tube without a liner (A, B Figure 2) increases rapidly with integrated photon flux and due to photodesorption of an increasing surface density of physisorbed molecules. This density can be expressed by following formula:

$$n = \frac{4\eta'\Gamma^*}{\sigma_w A_w \bar{v}^2},$$

where $\Gamma^*$ = photons/m/s; $\sigma_w$ is the sticking coefficient, $A_w$ the beam tube wall area per unit length; $\bar{v}$ the effective mean molecular speed; $n$ the dynamic molecular gas density, and $\eta'$ the desorption coefficient of the physisorbed molecules (recycling coefficient). The $\eta'$ coefficient for low surface coverage can be expected to depend linearly on the $\text{H}_2$ surface density and can reach a value of the order of unity at one monolayer $s_m = 3\times10^{15} \text{ H}_2/\text{cm}^2$ [4]. It is being seen from the plot that the $\text{H}_2$ density in the simple bore tube becomes higher than required density (E) after $2\times10^{20}$ photons/m. This is only about 6 hours of SSC operation.
and related increase in beam tube temperature require a more careful investigation of this point. The density decreases beginning of the experiment and decreases to times higher photon intensity in the second experiment. The same tube was used for both experiments with an intervening exposure to atmosphere. One can see that the four times higher photon intensity in the second experiment and related increase in beam tube temperature require a more careful investigation of this point. The density decreases from $4 \times 10^8$ l/cm$^3$ in the beginning of the experiment to $4 \times 10^7$ l/cm$^3$ at the end of experiment, with the perforated coaxial liner, physisorbed molecules accumulate behind the liner, where they are shielded from the photon flux, and the $H_2$ density is predominantly due to desorption of tightly bound molecules. To avoid influence of the thermal desorption of physisorbed molecules from the bore tube as one monolayer is approached the temperature of this tube was lowered to 2.5–3 K by pumping on the LHe.

The dynamic density in the liner configuration is determined by the following expression:

$$n = \frac{4\eta \Gamma}{p N_h A_h \nu}, \quad (2)$$

where $\eta$ is the desorption coefficient of tightly bound molecules, $N_h$ the number of holes per meter, $A_h$ the area of the holes, $p$ is the molecular transmission probability through a hole. The coefficient $\eta$ is equal to $4 \times 10^{-5}$ mol/photon at the beginning of the experiment and decreases to $4 \times 10^{-4}$ mol/photon at the end. The density becomes lower than required for luminosity lifetime at $1 \times 10^{21}$ photons/m. The photodesorption of other gases heavier than $H_2$, namely $CO$, $CO_2$, and $CH_4$, must also be considered for obtaining the required luminosity lifetime in a liner configuration. We have some information on CO and are modifying the apparatus to allow measurement of $CO_2$ and $CH_4$ as well.

Additional details of the cold photodesorption experiments are contained in references [5] and [6].

4. CONCLUSIONS

Based on the results of the experiments we make the following conclusions.

In the experiments reported here a simple 4.2-K beam tube does not provide the gas density required for SSCL Collider operation and the frequency of beam tube warm ups implied to keep the beam tube density within the allowable range would be inconveniently large. On the other hand the 4.2-K liner experiment achieved the required vacuum density after only a short conditioning period. The gas density in a liner configuration depends only on the desorption coefficient of the tightly bound gas and not on the desorption coefficient of gas physisorbed to the liner. The measured photodesorption coefficient changes from $4 \times 10^{-3}$ mol/photon at the beginning of experiment to $4 \times 10^{-4}$ at the end of experiment $1 \times 3.5 \times 10^{22}$ ph/m.

5. ACKNOWLEDGMENTS

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6. REFERENCES


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