NSLS VACUUM SYSTEM OPERATING EXPERIENCE CONDITIONING AND DESORPTION YIELDS*

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ABSTRACT

All straight sections in both the VUV and the X-Ray rings have been filled with various insertion devices, most of them fully operational. Beam lifetime in the VUV ring is limited by the Touschek effect to ~ 100 minutes at 800 mA due to the small vertical beam size required by users. With no experiments running, X-Ray beam lifetime is >35 hours at 220 mA and is limited by beam gas scattering. During the past several years the U10 beam line was used to measure PSD yields from various metals to study their relative merits for light sources. These yields were also compared to those measured in X-Ray ring dipoles during initial commissioning when desorption was high. Despite the large differences in critical photon energies, agreement was quite good. Both rings are now fully conditioned and their pressures and lifetimes have reached equilibrium. Well established conditioning procedures are followed after every intervention into their vacuum systems.

INTRODUCTION

Photon stimulated desorption, PSD, is the most important factor influencing the design of a light source vacuum system. In conventional machines, desorbed gases are removed by an appropriately scaled pumping system close to the electron beam. In newer designs more complex chambers attempt to channel synchrotron radiation to an absorber away from the beam. The most commonly used metals in the construction of beam ducts are aluminum, stainless steel and copper and their PSD yields are discussed in the first part of this paper. The second part deals with conditioning of the X-ray ring and comparison of the data obtained on the U10B beam line with those obtained in the operating X-ray ring. In the third part the present status of the VUV and the X-ray ring is given along with some comments on time-dependent lifetime improvement and conditioning.

I. DESORPTION COEFFICIENTS -U10 BEAM LINE

Three meter long tubes made of aluminum, stainless steel and Cu-plated stainless were exposed to white photon beam having critical energy of 500 eV at the U10B beam line.¹ Desorption yields,

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η , were measured in molecules per photon at 10 milliradian incidence and plotted versus accumulated photons. In Fig.1 tubes having the following surface treatments are compared:

a) 6063 aluminum¹ with standard NSLS cleaning,² 2 day in situ 150°C bake-out, pressure after bake $\sim 1 \times 10^{-9}$ Torr.

b) 304 stainless steel,³ pre-baked at 200°C for 2 days, back filled with dry N₂, installed and pumped for about one week when P = 1.5×10^{-9} Torr was reached (no in-situ bake).

c) Cu-plated stainless,³ pre-baked at 250° C for 5 days, back filled with dry N₂, installed and pumped for about one week when P = 1.5×10^{-9} Torr was reached (no in-situ bake).

Fig. 2 depicts the lowest η s obtained by glow discharge in nitrogen for Al³ and in Al 10% O₂ for stainless, respectively. Referring to the above figures and various other experimental data gained on the U10B beam line we can make the following observation:

1) Aluminum exhibits initial yields between 20 and 100 times greater than stainless. The steeper slope in aluminum catches up with stainless within a dose of $\sim 10^{24}$ photons m⁻².

2) PSD yields of common gases found in vacuum systems, i.e., H₂, CO and CO₂, are similar in Cu and stainless for comparable surface treatments.

3) After a week of pumping to a pressure $\sim 1 \times 10^{-9}$ Torr, the water peak in an unbaked stainless tube is desorbed within $\sim 10^{23}$ photons m⁻². In a storage ring this is likely to take longer due to reflected photons, but an in-situ bake out may not be required.

4) A test run using only a pre-baked Al tube was started, but had to be terminated because a very high initial H₂O pressure rise would have required a lengthy low current operation.

In-situ bake is essential in both NSLS storage rings employing aluminum beam tubes after each exposure to the atmosphere. Otherwise, conditioning time would be prohibitively long.

5) The lowest η s are measured on surfaces which are subjected to glow discharge cleaning.

II. X-RAY RING DESORPTION AND CONDITIONING

The data presented in the previous section allows us to make some predications as to how much time is likely to be required to reach reasonable beam lifetime which is governed primarily by beam-gas interaction. Since Bremsstrahlung and Coulomb scattering are far more effective in degrading lifetime for CO and CO₂ than for H₂, H₂ is omitted in subsequent figures. To carry out the measurements calibrated BAG and RGA were mounted on the X1B1 dipole aluminum vacuum chamber containing a Cu crotch through which synchrotron radiation is extracted into beam lines, and a distributed ion pump (DIP). The entire machine including front ends was baked out above 100°C for one week* resulting in pressure of 1×10^{-10} Torr after cool-down. Hydrogen comprised 95% of residual gases. Very large gas bursts (10^{-6} Torr) were observed during the initial stages of commissioning. After one ampere-hour the desorbed gas content

depicted in Fig. 3 was 43% H₂, 25% CO-N₂, 16% CO and 16% CH₄. $\Delta P/I$ (pressure rise normalized to beam current in Torr/mA) is plotted rather than η , because neither the total pumping speed nor the incident photon flux are known sufficiently well. Assuming $S \geq 1001 \text{ s}^{-1} \text{ m}^{-1}$ in the dipole η_{co} at $1 \times 10^{23} \text{ photon/m} \leq 4 \times 10^{-5}$. A rough comparison is given in Table I.

TABLE I

	U10B	X Ray Ring
	3m Al tube	Al + Cu crotch
Bake	150°C, 24 hrs.	<120°C, 5 days
ϵ_c (eV)	500	1700
angle of incidence	10 mr	110 mr
η_{co} (mol/photon)		
at 10^{23} photons/m*	8×10^{-5}	$< 3 \times 10^{-5}$
at 10^{24} photons/m	2×10^{-5}	$< 1 \times 10^{-5}$

* additional 10^{23} photons/m at 136 eV

Despite many differences, the agreement is quite good.

The fact that the X-ray ring beam energy varies from .75 to 2.5 GeV during each operating cycle permits us to measure $\Delta P/I$ s as a function of photon energy from 126 eV to 5 keV. The data was taken several times during machine conditioning and is shown in Figs. 4 and 5 at 10 A-hrs. We also note that $\Delta P/I$ decreases by a factor of 10 and 40 for CO and CO₂, respectively, after 600 A-hrs at 2.5 GeV. Almost no change occurred between 400 and 600 A-hrs. Furthermore, the slope of the curves in Figs. 4 and 5 decreased with conditioning by a factor of approximately 2 between 10 and 600 A-hrs.

III NSLS STORAGE RINGS

The performance of synchrotron light sources is measured primarily in terms of beam lifetime, beam size, and the recovery of normal operation after a section of the machine has been brought to atmospheric pressure. All the above qualities depend to a large degree on the design of the vacuum system and its flexibility. The vacuum systems of the NSLS storage rings and their performance have been described previously.⁴⁻⁹ They are routinely operated twenty-four hours a day with scheduled studies and maintenance shifts. Following any intervention into the vacuum chamber, LN₂ boil-off is used for back-fill and standard procedures are followed.²

A. VUV RING

The VUV ring⁹ operates at 750 MeV ($\epsilon_c = 500 \text{ eV}$) and to date has accumulated over 8000 A-hours. The highest achieved beam

current of 1200 mA was limited by machine components such as heating of ceramics and available rf power. Routinely the ring is filled with 700-900 mA as shown in Fig.6. The pressure in the machine has reached equilibrium around 1500 A-hours, i.e., subsequent running of 6000 A-hours produced no significant improvement either in pressure or lifetime. This is due primarily to 16 beam lines which are connected directly to the machine and thus dominate its pressure changes. After the first 500 A-hours the lifetime has been limited by:

1) Touschek effect which depends primarily on electron density in the bunch and is significant in lower energy machines only, since $r_T \propto \gamma^3$.

2) ion trapping - where residual gas molecules ionized by circulating electrons tend to neutralize the beam and produce additional beam gas scattering.

As seen in Fig. 7, continuous improvement in pressure during the early stages permits operation with more bunches which further improves both the pressure and lifetime. As the walls of the vacuum chamber are scrubbed by synchrotron radiation, the commissioning time decreases and today represents only a few A-hours after a section has been vented to LN₂ boil-off.

The highest pressure, observed in bending magnets which comprise ~12 m of the circumference, varies linearly with beam current and reads ~11 nTorr at 1000 mA. In the rest of the ring (37 m), including the straight sections, the rf cavity, insertion devices, and injector, the pressure at 1000 mA is ~2.5 nTorr. This results in total average pressure of ~4.5 nTorr with the following partial pressures:

H ₂	(2)	-	3	nTorr
H ₂ O	(18)	<	0.2	nTorr
CO-N	(28)	-	2.4	nTorr
CO ₂	(44)	-	0.4	nTorr

which yields pressure dependent lifetime > 5 hours. However, inspection of Fig. 8 reveals a lifetime of 100 minutes only caused by Touschek effect. (Note the good agreement between one and six bunch operation) The reason that almost no change in lifetime is observed between 600 and 1000 mA is due to bunch shortening which keeps the electron density almost constant. One can obtain longer lifetime at the expense of beam size (emittance) by increasing the horizontal-vertical coupling, as seen in Fig. 7 Curve 5/90. Unfortunately, most experiments require small vertical beam size and therefore small coupling of ~ 1%. Trapped ion also increases the beam size by defocusing the beam. Lifetime could be improved only by lowering electron density, i.e., by filling all 9 available rf bunches. At present the VUV ring can work with up to 7 consecutive bunches due to onset of ion trapping. Reliable operating with 8 or 9 bunches is not possible since ion clearing system¹⁰ is ineffective, probably because β_{min} occurs in the center of the dipoles. The only way, then, to increase the lifetime is to

increase the bunch length by installing a harmonic cavity which was done last month. Testing is now in progress.

B. X RAY RING

The X-ray ring operates at 2.5 GeV ($\epsilon_r = 5$ keV) with four insertion devices having ϵ_r up to 20 keV. The first phase of 627 Ampere-hours has been described previously in Ref. 4, 7,8 and 9. During the ensuing shut-down major modifications to accomodate insertion devices were carried out.⁹ We will cover only the commissioning and the operation following this more than one year long shut-down. Unlike the VUV, which has full energy injection, the X-ray ring is filled at 750 MeV ($\epsilon_r = 150$ eV) and the stacked beam is then accelerated to 2.5 GeV. This fact makes the conditioning significantly more time consuming. The first 28 A-hours are shown in Fig. 9, excluding running at lower energy during stacking and acceleration. After 16 A-hours lifetime at 100 mA exceeded 5 hours and the beam became usable for experiments. At 75 A-hours including minor interventions into the vacuum system, $I \times r$ product reached 2000. Since Touschek effect is negligible due to 2.5 GeV energy, lifetime is determined entirely by beam-gas scattering and is inversely proportional to pressure.

The ring (170 m in circumference) is divided into sections according to the gas load. The pressures read on calibrated BA gauges and averaged over respective sections are tabulated in Table II.

TABLE II

Amp- Hours	I mA	Straight Sections 1 = 114 m	Magnets 44 m	Cavities 12 m	Average Pressure
		Torr	Torr	Torr	Torr
620	0	7×10^{-11}	3×10^{-10}	6×10^{-9}	4×10^{-10}
620	202	3×10^{-10}	2×10^{-9}	8×10^{-9}	1.3×10^{-8}

Shut-down 2/87 - 3/88

1200	0	5×10^{-11}	$< 2 \times 10^{-10}$	4×10^{-10}	1×10^{-10}
1200	230	1.7×10^{-10}	1.1×10^{-9}	1.5×10^{-9}	5×10^{-10}

After 600 A-hours the residual gas content at high current operation is 61% H₂, 34% CO and 5% CO₂. In Table III we list calculated τ_c and measured τ_m lifetimes along with $\Delta P/Is$ averaged over the entire machine. Desorption in the dipoles is significantly higher.

TABLE III

Amp- Hours	I mA	$\Delta P/I$ Torr/mA	Pressure Torr	τ_w Hours	τ_c Hours
1*	50	5×10^{-10}		-0.5	
10 *	50	2.5×10^{-10}		-1	
620 *	200	6.4×10^{-12}	1.3×10^{-9}	8	16
+1200	230	2.2×10^{-12}	5×10^{-10}	37	43

*Before 1987 shut-down

The machine commissioning was started in April, 1989 and the A-hour clock was reset to zero. The lifetime at 200 mA in Fig. 10 shows a five fold increase which is due to the following:

- 1) increase in dynamic aperture.
- 2) decrease in gas desorption from the walls due to synchrotron radiation scrubbing (Table II).
- 3) increase in rf power.
- 4) improvement in RF cavity pressure and performance due to new Helcoflex seals and titanium nitriding.
- 5) installation of new plate DIPs¹¹ and NEG modules.
- 6) improvement in DIP pumping speed after long operation in good vacuum⁶.

The shaded strip (1990 in Fig. 10) gives the lifetimes with all insertion devices operating and 4 T field on the wiggler magnet. When the LEGS (Laser-Electron-Gamma-ray Spectroscopy) beam line is open the lifetime is halved. Further degradation in lifetime is observed when the wiggler field is raised to 4.7 T. The best lifetime (B in Fig. 10) is obtained with LEGS and insertion devices not operational and the wiggler field set to zero T. Fig. 11 shows typical "good" operation when one fill (250-110 mA) lasts more than twenty-four hours.

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Fig. 1 Comparison of desorption yields from baked aluminum, pre-baked stainless and pre-baked copper-plated stainless

Fig. 2 Comparison of desorption yields from glow discharged aluminum and stainless steel

Fig. 3 Normalized partial pressure rise, $\Delta P/I$, in X-Ray dipoles during first 7 A-hours of conditioning.

Fig. 4 Normalized partial pressure rise, $\Delta P/I$, in X-Ray dipoles vs beam energy (1A-hour $\approx 1 \times 10^{23}$ photons/m)

Fig. 5 $\Delta P/I$ in X-Ray ring dipoles vs critical photon energy

Fig. 6 VUV ring beam current and pressure variations during 25 hours of typical operation

Fig. 7 VUV pressure changes vs time due to venting of the vacuum chamber during the first 1200 A-hours

Fig. 8 VUV ring measured beam lifetime vs beam current for several bunch modes

Fig. 9 Current-lifetime product during the first 28 A-hours of conditioning

Fig. 10 X-Ray ring measured lifetime vs beam current during a four year span

Fig. 11 X-Ray ring beam and pressure behavior during 24 hours of typical operation.

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