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PHOTO-DESORPTION FROM COPPER ALLOYS

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ABSTRACT

In support of the design of PEP-II, a high luminosity B factory proposed for the Stanford Linear Accelerator Center, we have measured the photo-desorption properties of several alloys to demonstrate suitability of the material and preparation procedure for ultra-high vacuum performance under high radiation loads. In our experiments we exposed cleaned bars of copper alloys to high photon doses on the VUV ring at NSLS for which the critical energy is 500 eV. Our strategy was to find a suitable material and preparation procedure for acceptable performance and then to search for cheaper materials or preparation procedures. To ascertain the effects of geometry on the commissioning time of an actual vacuum chamber we subsequently exposed a copper test chamber on the VUV ring. We also verified the beneficial effects of pre-conditioning a Cu test chamber. The energy dependence of photo-desorption from copper will be measured in an exposure of a copper test chamber on the X-ray ring at NSLS where the photon critical energy can be as high as 5 keγ.

INTRODUCTION

A well designed beam chamber of an appropriate material is the foundation of an adequate, mechanically stable vacuum environment that permits a long beam-gas lifetime and minimizes backgrounds in the detector of a collider. In flavor factories the photon flux on the chamber walls will be very large. Consequently, the chamber material will require both excellent photo-desorption properties and high thermal conductivity. Copper and stainless steel have the considerable advantage vis á vis aluminum of completely self-shielding the magnets in the arcs from radiation damage due to the hard component of the synchrotron radiation. The lead shielding that would be required to clad an aluminum chamber is thereby eliminated. As the walls of the vacuum chamber will be subjected to very high thermal loads, copper with its excellent thermal conductivity appears to be the preferred material for flavor factories despite the paucity of experience in building large copper beam chambers.

The gas load in the vacuum chamber arises from thermal out-gassing and from synchrotron-radiation-induced photo-desorption. In electron storage rings the dynamic gas load due to photo-desorption is much larger than the static thermal load and determines the operating pressure in the ring whereas the thermal desorption rate sets the base pressure in the absence of beam. The dynamic gas load, Q, is proportional to the number of photons per second striking the walls (or crotches) of the accelerator. In terms of the electron beam energy and current, the dynamic gas load is given by

$$Q\,(\text{gas}) = 2.4\text{x}10^{-2}\, E_{GeV}\ I_{mA}\, \eta_{eff}\, \frac{\text{Torr - l}}{\text{s}}. \qquad (1)$$

The photo-desorption efficiency, η_{eff}, is a property of the chamber that depends on several factors:

- the chamber material,
- the fabrication and preparation procedures,
- the degree of prior exposure to radiation,
- the angle of incidence of the radiation fan with respect to the surface,
- the photon energy.

In light of these complexities, rather than considering the photo-desorption coefficient to be a fundamental material property, the designer should regard η_{eff} as an effective engineering value that accounts for the differential illumination of the chamber walls by both direct (i.e., beam-produced) photons and diffusely scattered secondary photons. Using a single value of η_{eff} in Eq. (1) yields only a rough estimate of the actual dynamic gas load but one which is nonetheless useful in setting the scale of engineering task and in choosing the material of the chamber.

Measurements of η_{eff} [Gröbner et al., 1983], [Mathewson et al,1990], [Halama et al., 1990], [Bintinger and Limon, 1986], and [Ueda et al., 1990] for well exposed samples of Al, stainless steel, and oxygen-free, high conductivity (OFHC) copper indicate that one can obtain CO-equivalent values of η_{eff} in the range of $\approx 10^{-6} - 10^{-5}$ for Cu and stainless steel and of $\approx 10^{-5} - 10^{-4}$ for Al with reasonable beam cleaning times. At liquid He temperatures desorption coefficients for unbaked, Cu-plated stainless steel are much higher in the range of 10^{-2} - 10^{-3}. Although the beam-gas lifetimes in storage rings with lower critical photon energy than the B-factory suggest that aluminum chambers may eventually develop an effective $\eta_{eff} \approx 10^{-6}$, a more conservative design procedure is to adopt copper or stainless steel as the chamber material despite their higher cost per kilogram.

As Ueda et al. found that clean, machined, oxygen-free copper can attain CO-equivalent desorption coefficients $\leq 2 \times 10^{-6}$, the PEP-II B-factory and the UCLA phi factory adopted this value as their design basis. Such a low photo-desorption coefficient allows one to design the vacuum chamber of PEP-II with a conventional "elliptical" shape instead of being driven to adopt an ante-chamber design that would be more difficult and expensive to fabricate. Moreover, the required pumping in the arcs of the collider is only 125 L/s/m, a modest value already demonstrated with distributed ion pumps in PEP. The apparent cost disadvantage of copper or stainless vis á vis aluminum is more than offset by the relative simplicity of the chamber shape, by the reduction in the amount of pumping needed and by the shortening of the vacuum commissioning time. In contrast, for the phi factory proposed by UCLA, the small circumference forces the adoption of an ante-chamber. Nonetheless, the use of a more expensive material with $\eta_{eff} \leq 2 \times 10^{-6}$ (CO equivalent) is essential to keep the required distributed pumping < 1000 L/s.

The data of Ueda et al. on which the B factory and phi factory designs are based were taken with a photon beam of critical energy of 4.5 keV with the photons incident normal to the surface. These conditions are different from those that would obtain in either collider. For example, in the high energy ring of the PEP based B factory the critical energy will be 9 keV and photons will strike the surface at a shallow angle. The data of [Halama,1990], although taken at shallow angle, were obtained with a photon beam of 500 eV critical energy (appropriate for the phi factory or for SSC) and were not carried to large enough exposures as to actually observe desorption efficiencies as low as 2×10^{-6} (CO equivalent).

Although designing the pumping system to handle a gas load based on a photo-desorption rate of $\approx 2 \times 10^{-6}$ from a copper chamber seems to represent reasonable extrapolation of the experimental data base, it would not be prudent to commit to constructing so large and costly a vacuum system as required for a B factory without a series of validation experiments using the specific alloys, photon incidence angles, preparation and fabrication procedures as will actually be employed in the construction. In our studies we sought to establish experimentally 1) whether the apparent superiority of copper persists after more than 100 A-hr of photon scrubbing 2) the dependence of η_{eff} on the choice of alloying materials and the method of preparation and fabrication of the chamber. From a practical point of we have tried to answer the following questions: What is η_{eff} for a practical alloy, preparation and fabrication? What is least expensive acceptable alloy? What is η_{eff} for the actual chamber geometry as a function of dose?

EXPERIMENTAL PROCEDURE

Appropriate photon sources to make measurements on short sections of copper bars and test chambers are available at the National Synchrotron Light Source of Brookhaven National Laboratory. The first exposures of up to 500 Amp-hours would be performed on the U10 beamline of the VUV-ring, which has already be used for an extensive series of tests of photo-desorption properties of materials. As the beamline has a swivel point built-in, the exposures were conducted at an appropriate shallow angle. The existing U10 beamline and stainless steel test chamber are consistent with allowing a vacuum bake at 200° C and with conducting glow discharge cleaning of the samples. In our investigations, we have followed the experimental set-up and measurement procedures that have been described previously [Halama, 1990].

We began the experimental validation program with a series of measurements of the desorption properties of 1 m Cu bars mounted in a stainless steel test chamber. Later tests used a 2 m, electron–beam welded, copper chamber to evaluate the effects of preparation procedures and chamber geometry. As shown schematically in Fig. 1, the test chamber is connected to the beamline through a rectangular duct with a calibrated vacuum conductance and is pumped by a calibrated pump of speed S_i for the i^{th} molecular species. Samples were exposed with white light directly from the beam source without the interposition of monochrometers or filters in the beam line. The beam width and height, defined by horizontal and vertical collimators, are adjusted to restrict the area of exposure to the test sample. A residual gas analyzer identifies the relative abundance of the principal gas species desorbed (H_2, CH_4, CO, and CO_2). The primary quantity measured is the specific pressure rise for each molecular species ($\Delta P_i / I$) averaged over the test chamber as a function of photon dose, which data is of most direct relevance to the engineering design of the collider vacuum system. For photons generated over a horizontal angle, Θ, the average photo-desorption of the i^{th} species is

$$\eta_i = \frac{G\, S_i \frac{\Delta P_i}{I}}{\frac{\dot{N}}{I\,\Theta}} . \qquad (2)$$

The electron beam energy in the VUV ring was 745 MeV throughout the exposures. Consequently the photon spectrum had a critical energy of ≈ 500 eV. We conducted all but one of the exposures were conducted with an angle of incidence of 110 mrad to maximize the photon dose per unit time. In these runs the horizontal and vertical acceptances were 10 mrad and 3.8 mrad respectively. Although the VUV ring can produce large integrated photon exposures in a relatively short time, the critical energy of the radiation is only 500 eV whereas in the high energy ring of PEP-II the critical energy of the photons will be ≈ 10 keV. We will, therefore, measure the dependence of the η_{eff} of copper on photon energy with subsequent exposures of a test chamber on the X28C beamline of the X-ray ring of NSLS, which can provide radiation with a critical energy of 5 keV.

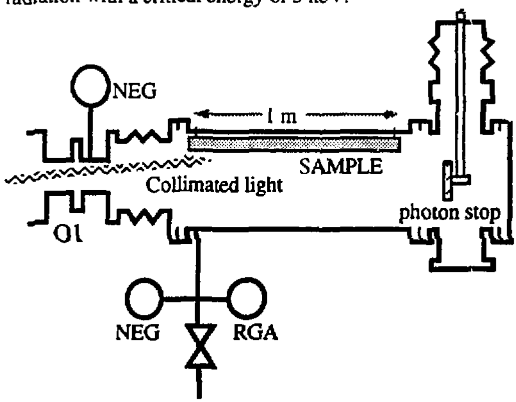

Figure 1 Schematic of test chamber with sample bar

We used sample bars for comparative studies while the test chamber provided a more realistic test for the estimating the vacuum commissioning time of storage ring of copper. The materials used in the study were class C10100 copper from multiple vendors, C10700 copper-silver alloy, and a dispersion strengthened copper, GLIDCOP™. The bars were tested with both the factories' mill finish and with a dry machined finish. The copper chamber was mill finish C10100 with dimensions identical to the stainless steel chamber in with the bar samples were tested. The copper chamber and all bars received an identical chemical cleaning treatment at LLNL before being shipped. All samples were vacuum baked in-situ at 200 °C prior to exposure to the X-rays.

Fig. 2 and 3 show the measured dose dependence of η_{eff} for machined C10100 and GLIDCOP respectively. After an exposure of 3×10^{23} photons/m, the C10100 bar was cleaned with an Ar glow discharge and vacuum baked to drive off any Ar that had been driven into the surface. This treatment yielded a final measured η_{eff} of 1×10^{-6} for CO. The C10100 bar with from other manufactures and with other finishes showed desorption coefficients at comparable dose not more that 1.5 times higher than that of the machined bar. The η_{eff} of the C10700 bar was twice that the the machined bar.

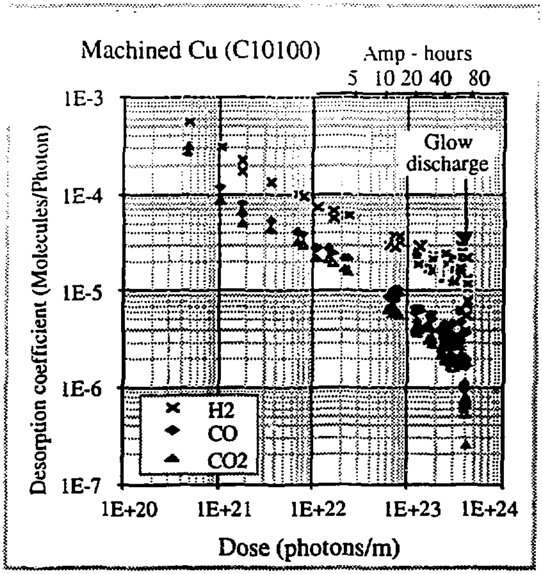

Figure 2. Dose dependence of desorption of best machined copper bar

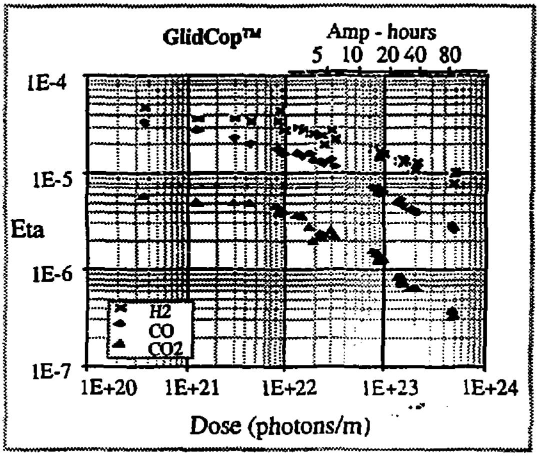

Figure 3. Dose dependence of desorption of GLIDCOP bar

To ascertain geometrical effects and to test the efficiacy of glow discharge cleaning as a pre-treatment, we tested the C10100 copper chambe in two ways. First we carried out a long exposure of 1×10^{24} photons/m. As illustratedin Fig. 4 the total photo-desorption of H_2, CO, CO_2 and CH_4 as expressed in CO equivalents was brought below the PEP-II design criterion of 2×10^{-6} molecules per photon. Translating the results of this run to PEP-II we expect that the chamber would be brought to the design level of η_{eff} in 20 - 30 A-hr.

At this point to simulate a pre-treatment procedure we subjected the chamber to an Ar glow discharge cleaning. We then vacuum baked the chamber at 200 °C to drive off the Ar, allowed the chamber to cool, and then back-filled the chamber with dry N_2. We subsequently opened the chamber to air and rotated it so that the photon beam would strike a new portion of the walls. After leaving the chamber open to air for slighly less than two days, we reassembled the beamline and conducted the usual vacuum bake. The lower curve of figure 4 shows the clear benefit of the pre-treatment.

CONCLUSIONS

We have shown that $\eta_{eff} \leq 2\times10^{-6}$ mol/photon is a practical design vaue for Cu vacuum chambers. Comissioning times to attain this value in B factories can be expected to be < 50 hr. Finally, pre-cleaning with an Ar glow discharge has been demonstrated to be an effective pre-treatment.

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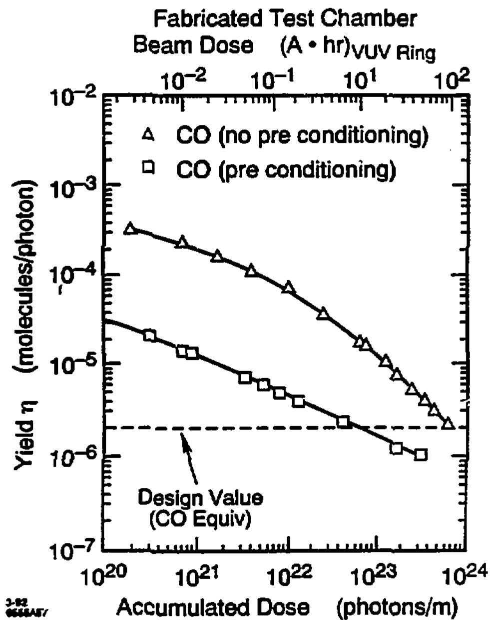

LLNL BNL Collaboration at NSLS
E_c = 0.5 keV at 110 mrad Angle of Incidence