Electron Stimulated Desorption in the PXIE Test Stand

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Abstract

The rate of the residual gas pressure increase as a response to the electron irradiation of a Molybdenum surface was recorded as a function of the total electron dose at the PXIE absorber test stand. Estimated desorption coefficient is reported.

1. Introduction

A device capable of absorbing a constant 17W/cm^2 power density is needed for the PXIE MEBT project. A structure made of molybdenum alloy TZM is being tested as an absorber using an electron beam in the test stand. Appropriate current and focusing are controlled to achieve the required power density. The focused electron beam causes rapid outgassing from the TZM surface, resulting in a measurable pressure increase due to electron stimulated desorption. In this paper, the experimental results of pressure effects by increasing beam current on the absorber are presented and discussed.

2. Electron stimulated desorption

Electron-stimulated desorption occurs as a result of an electron beam incident upon a surface in vacuum. At atmospheric pressure, molecules may adsorb to surfaces in weakly-bonded molecule layers. If an electron beam is incident upon the surface, it provides energy to break the bonds of the surface with molecules in the adsorbed layer(s), causing pressure to increase in the system.

Once a molecule is desorbed into the vacuum volume, it is removed via the vacuum's pumping mechanism. Hence, less molecules are available for desorption.

One can estimate the number of molecules desorbed per electron, $\frac{\Delta N_m}{\Delta N_e}$ from experimental data, in a simple model assuming that all desorbed molecules are pumped out (as opposed to sticking to another surface of the test chamber) and neglecting an effect of desorption induced by secondary electrons. Also neglected is an increase in thermal desorption due to elevated surface temperature. The pressure increase due to desorbed molecules can be modeled starting with the ideal gas equation

$$PV = N_m k_B T. \tag{1}$$

[A] teacher intern with TRAC program, Fermi mentor: Alexander Shemyakin where P is the partial pressure related to the desorbed molecules, V is the volume occupied by them, N_m is the number of the molecules, k_B is the Boltzman constant, and T is the gas temperature. All molecules that are desorbed are assumed to be pumped out at the speed S of the turbo pump

$$S = \frac{\Delta V}{\Delta t}\,. \tag{2}$$

From Eq. (1), (2) the rate of removing the molecules can be related to the pressure as

$$PS = \frac{\Delta N_m}{\Delta t} k_B T\,. \tag{3}$$

The rate of electrons coming to the surface is determined by the beam current as

$$I = \frac{e \cdot \Delta N_e}{\Delta t}. \tag{4}$$

where e is the electron charge. To characterize the efficiency of the gas removal from the surface, one can introduce a desorption coefficient $\frac{\Delta N_m}{\Delta N_e}$, presenting the number of molecules kicked out of the surface by a single electron. Combination of Eq. (3) and (4) gives the relation between the desorption coefficient and the slope of the pressure rise with the beam current as follows:

$$\frac{\Delta P}{\Delta I} = \frac{\Delta N_m}{\Delta N_e} \cdot \frac{k_B \cdot T}{S \cdot e} = \frac{\Delta N_m}{\Delta N_e} \cdot 6 \times 10^{-7} \left[\frac{Torr}{mA}\right] \tag{5}$$

where the numerical estimation was made with S= 300 l/s and T= 300K.

3. Test stand

The test stand is pictured in Figure 1[1]. An electron gun produces a beam which is focused by two solenoid lenses and whose position is controlled by x- and y- direction dipole correctors. In part, using the correctors, the electron beam can be directed off the absorber to the collector where incident current can be sensed and calibrated. The absorber position can be adjusted horizontally by compressing or extending a bellow.

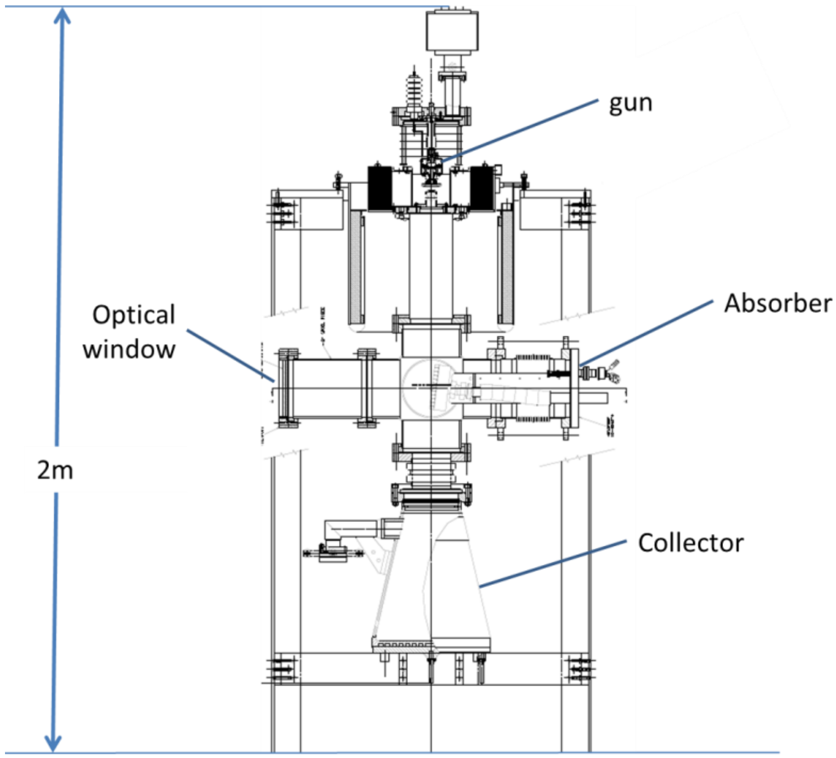

Figure 1: Drawing of test stand; turbo pump is perpendicular to the plane of the drawing on the opposite side shown (into page).

A turbo pump provides vacuum pumping to the test volume at a rate of approximately 300 l/s. An ion gauge located close to the pump provides an estimate of the pressure level in the test volume. A 30 l/s ion pump is located near the gun in a smaller cavity. The gun cavity is connected to the test volume by a 6 mm diameter aperture, so that contribution of the gun ion pump into the total pumping speed of the test volume is negligible.

A camera captures video through the optical quartz window, allowing size, position, and intensity of the beam to be visually monitored remotely using optical transition radiation (OTR). As an example, Figure 2 is a beam image showing a low-focused beam at 180mA. The absorber consists of 6 "fins", and "lobes" perpendicular to the incident surface intended to capture reflected electrons. The design height of each absorber fin is 10mm, which can be used for calibrating images and measuring the beam size.

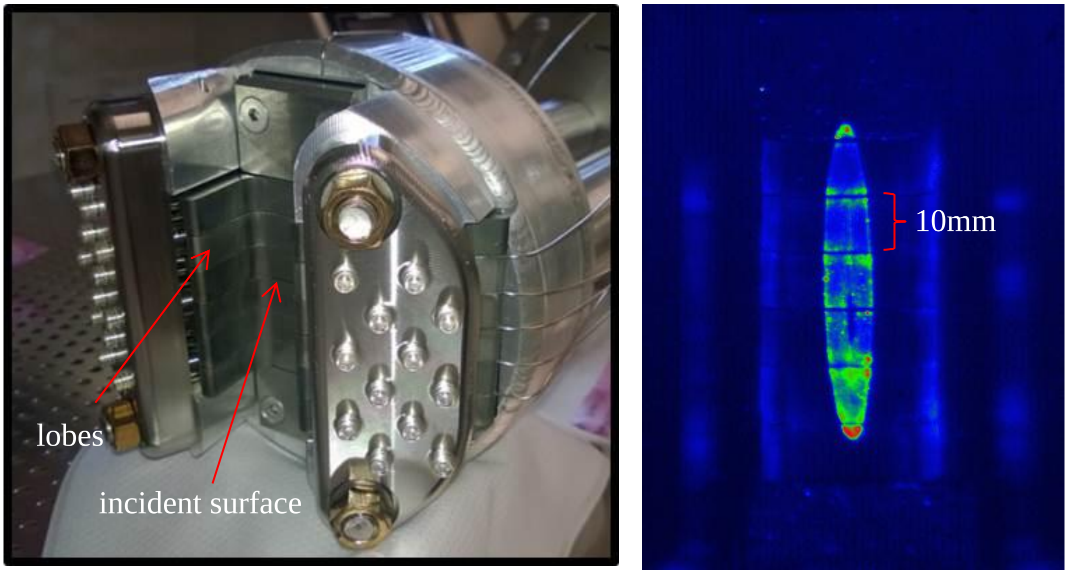

Figure 2: **a** - Photo of absorber surface and lobes prior to test stand installation. **b** - image captured by the camera showing the footprint of a 180mA beam spreading from just above fin 1 and extending into fin 6. False colors represent the image intensity.

4. Measurement procedure

Each day of testing, the first measurement taken was pressure with increasing current. The beam current in the initial tests was limited by pressure elevation in the gun cavity to 10^{-7} Torr. After conditioning, the tests were performed at the beam current up to 200 mA (Table 1). Parameters for the cathode filament, focusing lenses, and x- and y- corrector currents were standardized so that at 200mA, the beam was positioned approximately centered on the absorber surface with the major axis of the footprint of approximately 3 fins (30mm).

Description	Standard Test Value
Beam current	up to 200 mA max
Ion Gauge Pressure	varies, < 1E-6 Torr
Ion Pump Pressure	varies, <1 E-7 Torr

Table 1: Relevant test stand parameters

Figure 3 shows examples of pressure and current data collected on different shifts. A linear function of fit shows the slope of each plot, estimating the pressure increase with current, $\frac{\Delta P}{\Delta I}$. The number of electrons was estimated as the integral of current since the installation of the absorber.

The good linearity of the curves suggests that the electron stimulated desorption is the dominant mechanism of the pressure increase and the contribution of the thermal desorption is low.

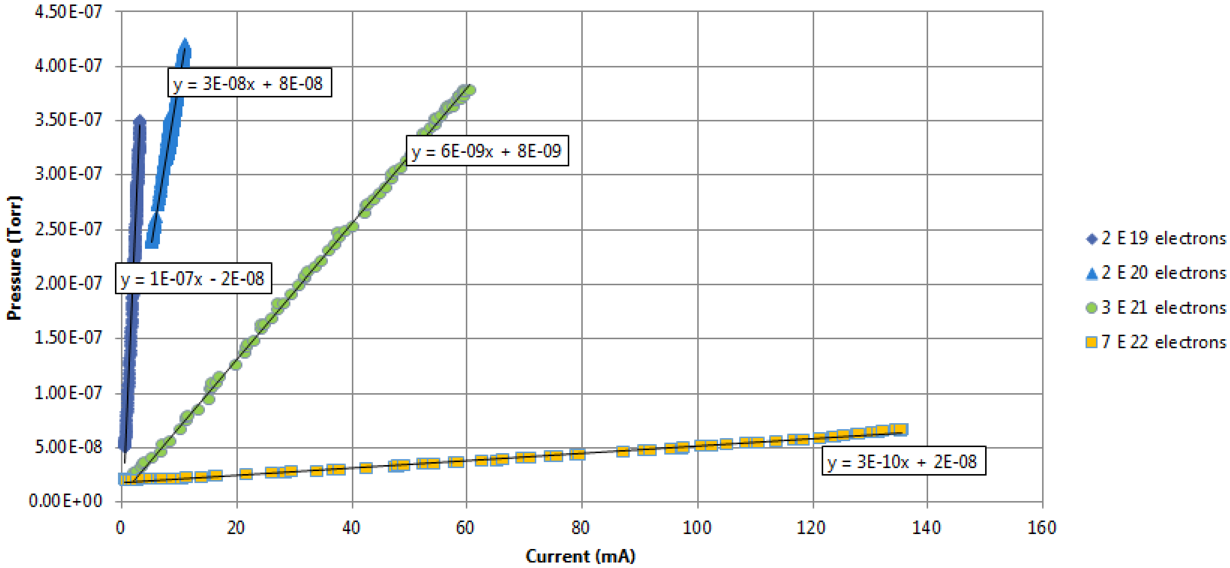

Figure 3: Plots of pressure with increasing current for several test shifts. Equations of linear fit are shown for each function.

5. Results and discussion

Figure 4 shows $\frac{\Delta P}{\Delta I}$ measured for different charges on the absorber surface.

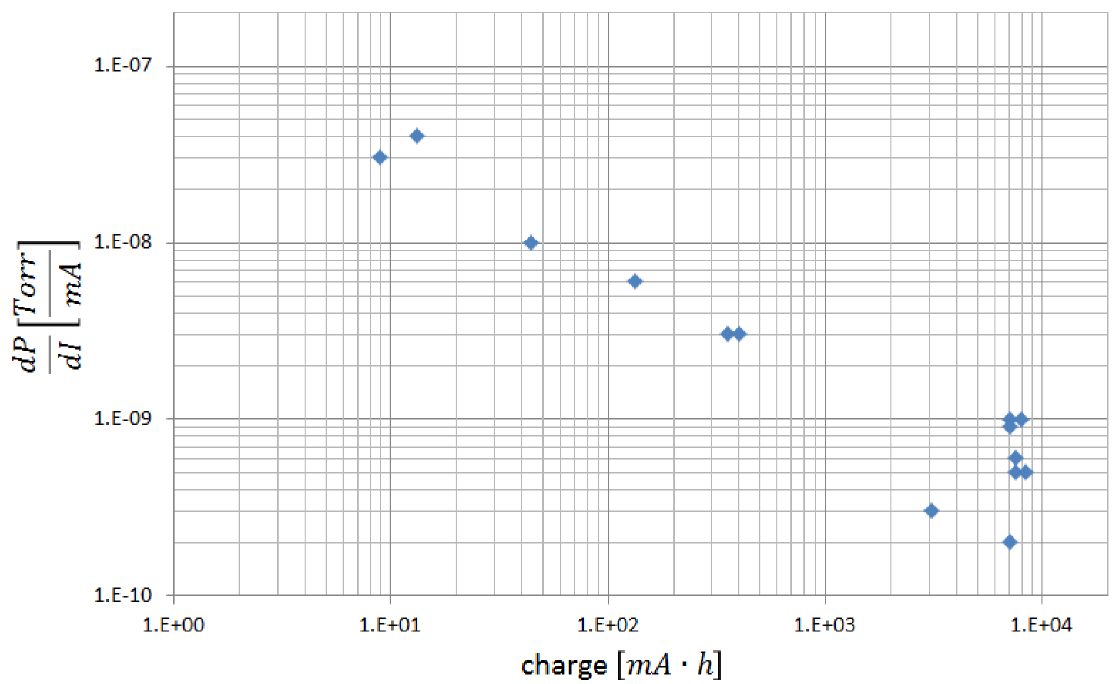

Figure 4: Plot showing pressure increase with current increase vs charge for test stand results.

The experimental desorption coefficient $\frac{\Delta N_m}{\Delta N_e}$ can be estimated using the inverse of Eq. (5) from the model in section 2

$$\frac{\Delta N_m}{\Delta N_e} = \frac{\Delta P}{\Delta I} \cdot 2 \times 10^6 \left[\frac{molecules}{electron}\right]. \quad (6).$$

Figure 5 shows the desorption coefficients as a function of the specific electron dose. The specific dose was estimated assuming that primary electrons irradiate the entire absorber surface, 27cm^2. It was found in Ref. [1] that approximately 55% of primary electrons' power is reflected as secondary electrons [1], however this paper does not consider effects of desorption by secondary electrons.

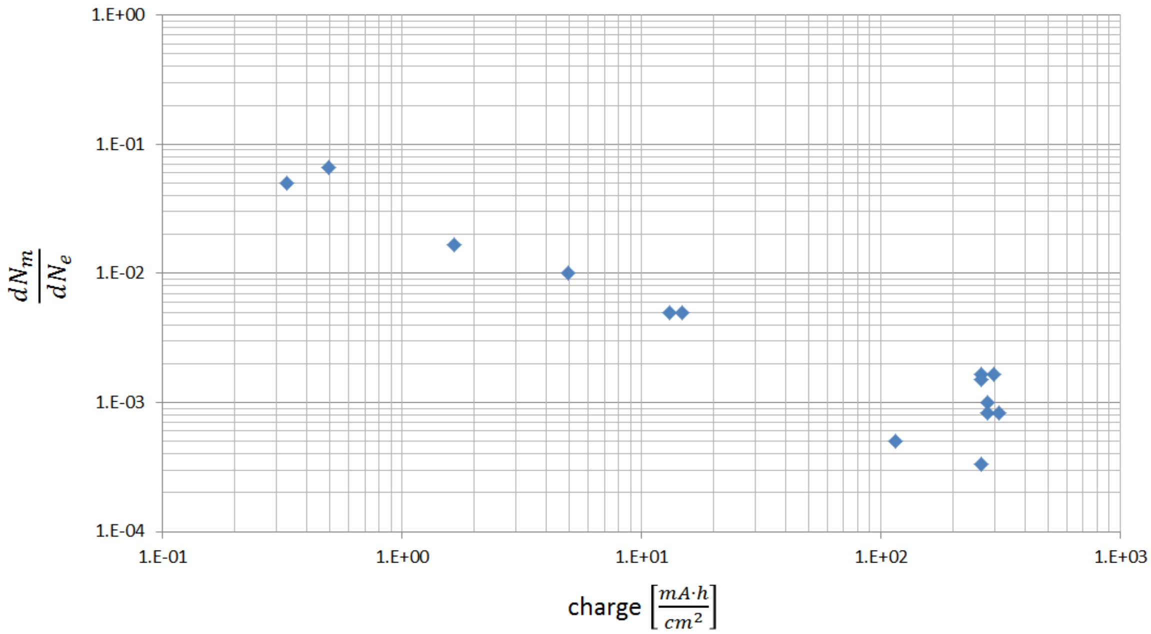

Figure 5: Plot showing desorption rate vs charge per surface area for test stand results.

The data shown in Figure 5 can be used to estimate the outgassing load in future applications.

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R. Thurman-Keup (Optical instrumentation)

H. Cheung (TRAC program advisor)

B. Penning (TRAC program advisor)

7. References

[1] A. Shemyakin, C. Baffes., *Design and Testing of a Prototype Beam Absorber for the PXIE MEBT*, Feb 2014, Project X Document 1259.