

## Modeling Decontamination by Downstream Plasma Cleaning using Quartz Crystal Microbalance and UV-Visible Spectroscopic Data

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### BACKGROUND

Carbon contamination in scanning electron microscope (SEM) chambers can result in poorer image quality. Downstream plasma cleaning is an effective means for removing carbon contamination from SEM chambers. A plasma device, such as the Evactron De-Contaminator (D-C), is mounted on an unoccupied port on the SEM. When in use, the device creates oxygen radicals using a small leak of oxygen-containing gas and a low power (5-20 W) radio frequency (RF) plasma. The oxygen radicals flow through the SEM chamber, ashing hydrocarbons.

The goal of the research program at XEI Scientific is to understand the downstream cleaning process. In particular, we ask:

- 1) What chemistry is occurring in the plasma to create or remove oxygen radicals?
- 2) How many oxygen radicals are created, and what is their distribution in a vacuum chamber?
- 3) What chemistry occurs when the oxygen radicals ash hydrocarbons?

Previous work at XEI has focused on using gold-coated quartz crystal microbalances (QCMs) as a way to measure cleaning efficiency [1]. The QCM is contaminated with hydrocarbons and placed into the 30 cm diameter x 14 cm chamber shown in Figure 1. Using a set of six reactions, a model of QCM decontamination by the Evactron D-C was presented last year at this conference [2]. Some of the results of this work are shown in Figure 2. A separate method for determining oxygen radical concentration is needed to verify this work.

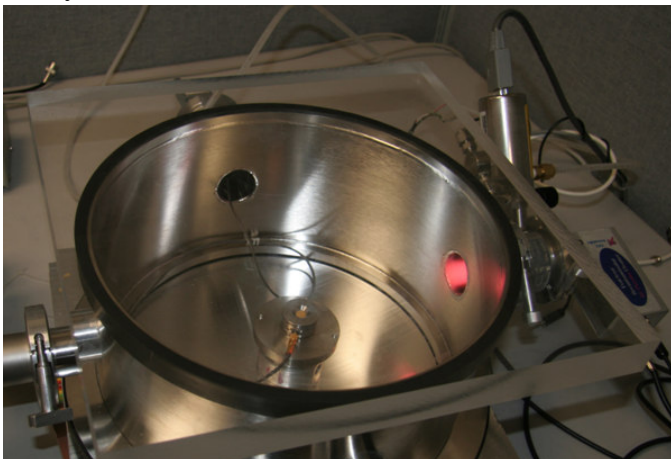


Figure 1: Photo of experimental setup for QCM work. The Evactron<sup>®</sup> D-C is attached to the port on the right side of the chamber. Note that the small plasma (colored pink) does not extend into the chamber. The pump port is on the left side of the chamber. The QCM is in the center of the chamber on a stand.

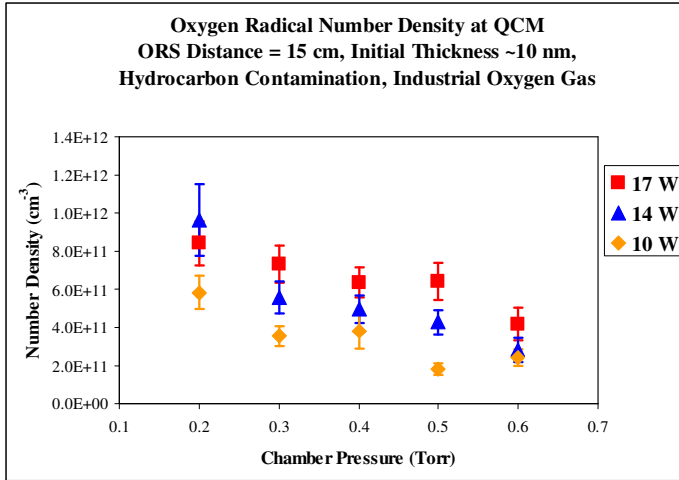


Figure 2: Initial determination of oxygen radical densities 15 cm away from an Evactron<sup>®</sup> D-C plasma using different forward RF powers and chamber pressures. Oxygen gas was used. For each data point, ~10 nm of pump oil was deposited onto the QCM. Deposition was done by heating pump oil in a vacuum chamber at ~0.2 Torr and allowing the evaporated pump oil to condense on the QCM. Note that the range of oxygen densities estimated is between  $2\text{-}10 \times 10^{11} \text{ cm}^{-3}$ .

### OBTAINING OXYGEN RADICAL CONCENTRATION USING Ag-COATED QCMs

The use of a silver-coated QCM to measure oxygen radical concentrations from a plasma source has been previously reported [3]. The cartoon in Figure 3 illustrates the mechanism.

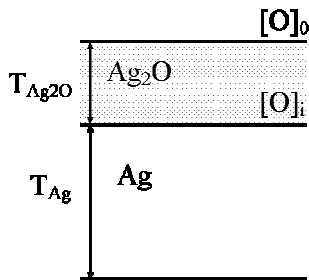


Figure 3: Cartoon describing Ag<sub>2</sub>O growth. See text.

The net growth on the QCM is due to the creation of a silver oxide (Ag<sub>2</sub>O) layer. As the oxide layer ( $T_{Ag_2O}$ ) increases, the amount of oxygen radicals at the silver (Ag) layer ( $[O]_i$ ) becomes less than the concentration of oxygen radicals in the gas phase ( $[O]_0$ ). The change in the silver and silver oxide thicknesses are

$$\frac{\Delta T_{Ag_2O}}{\Delta t} = \frac{J}{C_{Ag_2O}}; \frac{\Delta T_{Ag}}{\Delta t} = -\frac{J}{C_{Ag}}$$

where  $C_i$  are the concentrations of the two layers and  $J$  is flux of  $[O]_i$  at the Ag/Ag<sub>2</sub>O interface. In more detail,

$$J = \frac{D[O]_0 - LT_{Ag_2O}}{T_{Ag_2O} - D/k_s}$$

where  $D$  is the diffusion constant and  $k_s$  is the reaction rate of  $[O]_i$  and Ag. It was found that the dependence of  $J$  on  $T_{Ag_2O}$  differs from the standard Deal-Grove model [4] by a loss factor  $L$ , which may be due to recombination of oxygen radicals on the  $Ag_2O$  surfaces. A better fit for the data is obtained when  $L$  is a non-zero value, as seen in the graph in Figure 4. The graph Figure 5 shows data and model fits at different chamber pressures. Table I shows model results. Note that results for the oxygen radicals' concentrations using this method are an order of magnitude less than the results from the more indirect contamination thickness loss model.

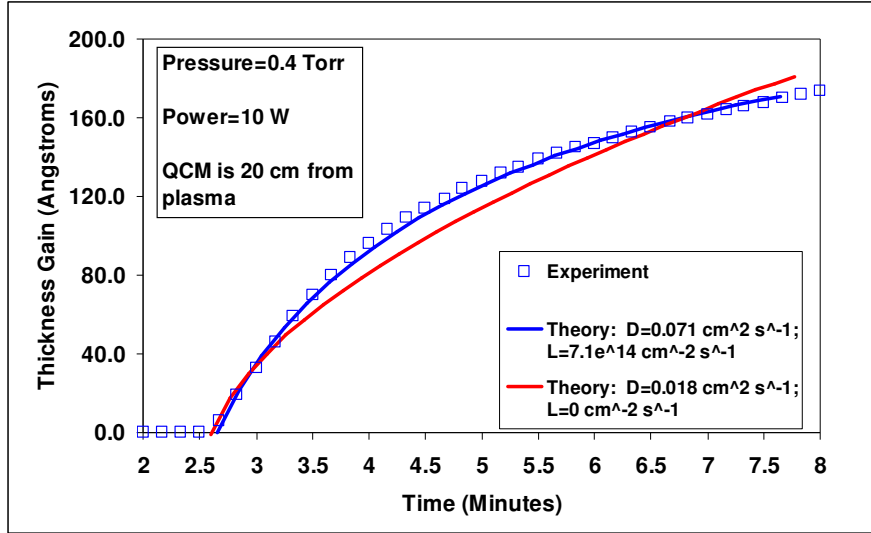


Figure 4: Comparison of two model fits to data for the Ag-coated QCM experiment. The blue squares are the experimental data points. The chamber pressure was set to 0.4 Torr and the forward RF power is 10 W. The QCM is  $\sim 20$  cm from the plasma, and  $O_2$  gas is used in the plasma. The blue line is the best fit for a non-zero  $L$  value (see text), and the red line is the best fit when  $L$  is fixed at  $0 \text{ cm}^{-2} \text{ s}^{-1}$ .

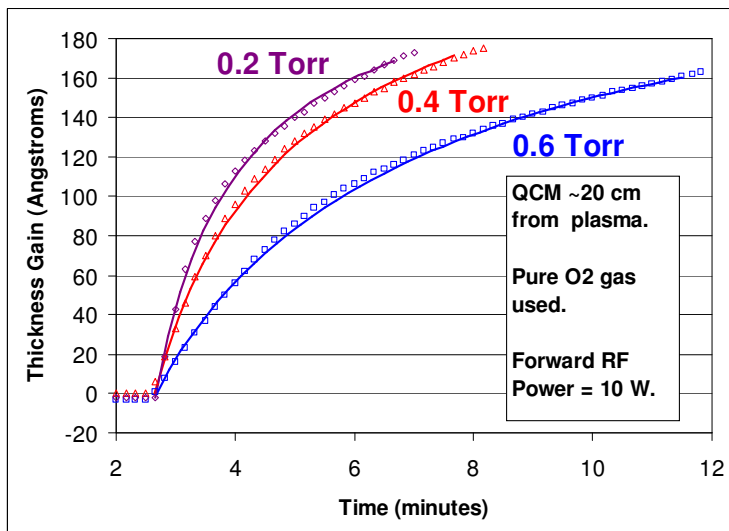


Figure 5: Experimental traces from the Ag coated QCM experiment. For all experiments, the forward RF power is 10 W, the QCM is  $\sim 20$  cm from the plasma, and  $O_2$  gas is used in the plasma. Blue squares are data points taken with chamber pressure at 0.6 Torr, red triangles are data points taken with chamber pressure at 0.4 Torr, and violet diamonds are data points taken with chamber pressure at 0.2 Torr. The lines of color corresponding to each set of data points are model fits to the data.

Table I: Results from the Ag Coated QCM Model

<b>Pressure (Torr)</b>	<b><math>[O]_0</math> (<math>10^{10}</math> <math>cm^{-3}</math>)</b>	<b><math>k_s</math> (<math>10^4</math> <math>cm\ s^{-1}</math>)</b>	<b><math>D</math> (<math>cm^2\ s^{-1}</math>)</b>	<b><math>L</math> (<math>10^{14}</math> <math>cm^{-2}\ s^{-1}</math>)</b>
0.2	9.07	1.57	0.071	10.
0.2	8.42	1.57	0.070	11.
0.4	5.83	1.57	0.070	7.1
0.4	5.83	1.57	0.071	7.1
0.6	2.72	1.57	0.074	4.0
0.6	3.01	1.57	0.078	4.2

### UV-VISIBLE SPECTROSCOPIC STUDIES OF PLASMA

By placing an adaptive vacuum fixture with a fiber optic coupler (see arrow in Figure 6) between the Evactron<sup>®</sup> plasma system and the vacuum chamber, we can probe the plasma using emission spectroscopy.

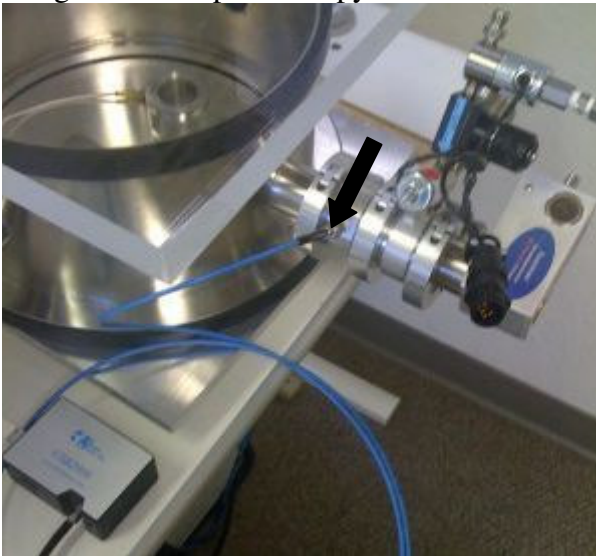


Figure 6: Experimental setup for the UV-visible optical emission. Vacuum fixture is between Evactron<sup>®</sup> plasma system and chamber. Black arrow points to fiber optic coupler.

The assignments in the spectra in Figure 7 are made using constants found in a standard reference [5]. Three types of hollow cathodes tested and are shown in Figure 8. The one on the left is standard. The center one has no holes through the cylindrical walls, and the right one has only four rows of holes. The strength of the  $N_2^+$  emission increases as the chamber pressure drops further below 0.2 Torr. As the pressure drops, fewer neutral collisions occur, which leads to more  $N_2^+$  formation. Nitrogen ion formation leads to production of NO and loss of oxygen radicals. A good flow of neutrals limits  $N_2^+$  creation, as demonstrated when gas flow is limited through the hollow cathode used to energize the plasma, as seen in the Figure 9.

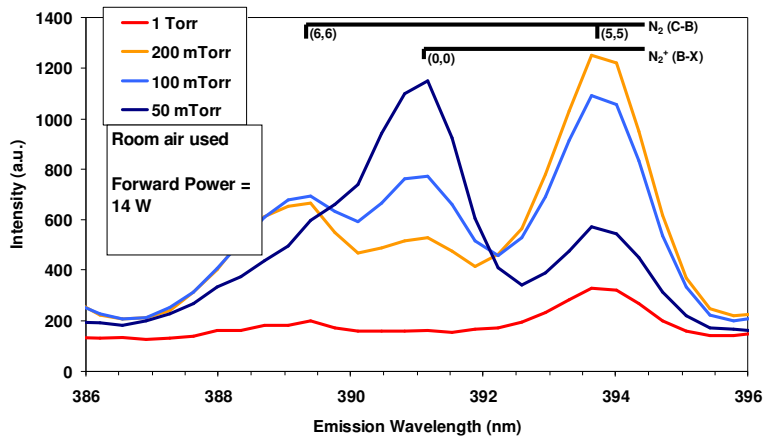


Figure 7: Detail of UV-visible optical emission spectra taken between 386-396 nm of a room air Evactron<sup>®</sup> plasma (14 W forward RF power) at various chamber pressures. The center feature at ~391 nm is due to  $N_2^+$  emission, and the other two features are due to  $N_2$  (C-B) emission.



Figure 8: Three types of RF electrodes used in study. Left electrode is standard electrode for Evactron<sup>®</sup> De-Contaminator. Center electrode has no holes through cylinder walls. Right electrode has only four rows of holes through cylinder walls.

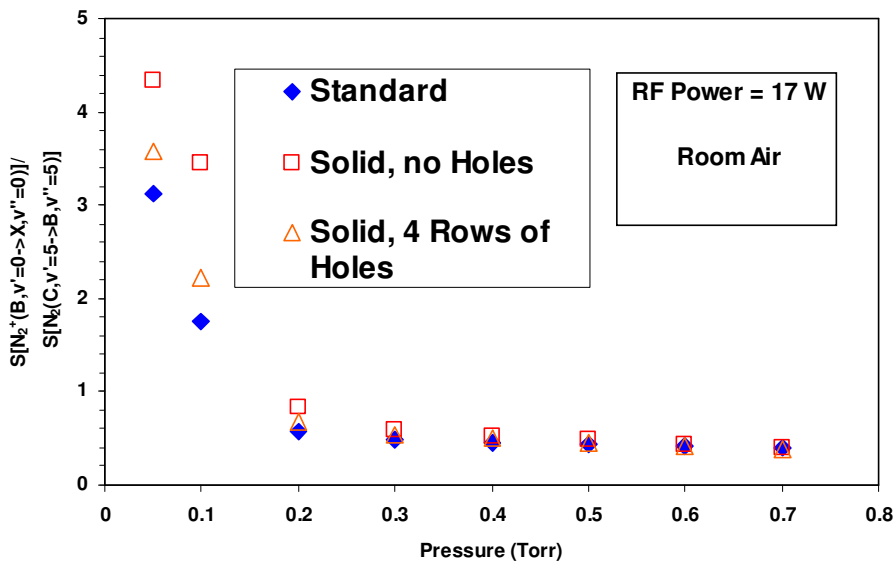


Figure 9: Ratio of  $N_2^+$  emission over a nearby  $N_2$  emission as a function of different RF electrodes and pressures. See previous figure for picture and description of electrodes. All experiments were performed using room air with forward RF power at 17 W.

## REFERENCES

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- [5] G.R. Herzberg, *Spectra of Diatomic Molecules* (Van Nostrand, Toronto, ON, 1950)