Comparing the Effects of Different Gas Mixtures and Vacuum Chamber Geometries on the Evactron Cleaning Process

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INTRODUCTION:

The Evactron® De-Contaminator (D-C) uses downstream, or remote plasma cleaning to remove carbon containing contamination from electron microscope chambers by creating a flow of oxygen containing gas such as room air through a radio frequency (RF) generated plasma attached to the chamber. Oxygen radicals are created in the plasma and flow downstream, ashing carbon contamination. Using a quartz crystal microbalance (QCM), the effectiveness of the Evactron process has been quantified as a function of cleaning parameters such as chamber pressure during cleaning, RF power, and distance from the plasma source. The QCM measurements can now be extended in order to consider the effect of different gas mixtures and chamber geometries on cleaning.

EXPERIMENTAL NOTES:

Contamination is deposited on the QCM through the following methods. For hydrocarbon contamination (Hc), a small amount of mechanical pump oil (Duniway Stockroom, Part# MPO-190-1) is deposited into an 11 cm long vacuum tube with a leak valve is attached to one end of the tube and a vacuum chamber on the other end. Once the chamber is pumped down, the leak valve adjusted so that the pressure in the chamber is about 0.2 Torr. The tube is then heated, and the deposition of hydrocarbons onto the QCM, typically between 10 and 100 nm, can be monitored using a QCM monitor (McVac - MCM 160).

Alternatively, graphitic carbon is deposited onto a QCM using a spin coater (Chemat Technology, KW-4A). A few drops of a slurry of graphitic carbon (Ted Pella, Product #16053) in isopropyl alcohol are placed onto a quartz crystal disc removed from its holder and placed on the spin coater . The spin coater is run at 10k rpm for 1 minute, and then the disc is heated to remove excess alcohol. The disc is placed back into its holder and connected to the monitor inside the vacuum chamber. Additional pumping on the QCM is needed to remove any residual alcohol.

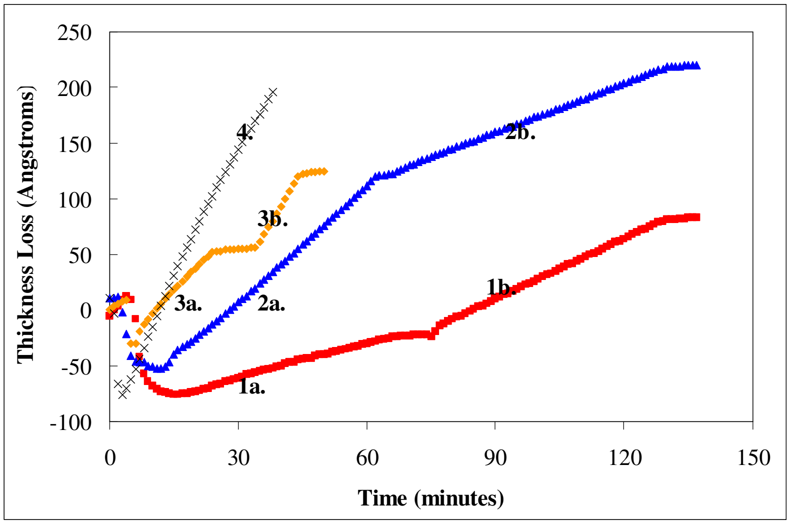
For all studies, the QCMs were placed in the middle of a cylindrical vacuum chamber with a diameter of 30 cm and 15 cm height. The QCM is placed in the center of the chamber about 15 cm from the port with the Evactron D-C. The vacuum port is opposite the port with the Evactron D-C.

The different gas mixtures are room air, dry 30% O_2 in N_2, and industrial oxygen. Water can be added to the dry O_2/N_2 gas mixture. A vacuum Erlenmeyer flask with a side tube is filled partially with water, and a fritted tube is submerged in the water. The dry gas passes through the frit and the side tube, continuing on to the Evactron gas manifold.

DIFFERENT GAS MIXTURES

For Contamination > 50 nm, we see that O_2/N_2 mixtures have difficulty removing contamination.

Figure 1: Contamination Removal using Different Gas Mixtures for contamination >50 nm



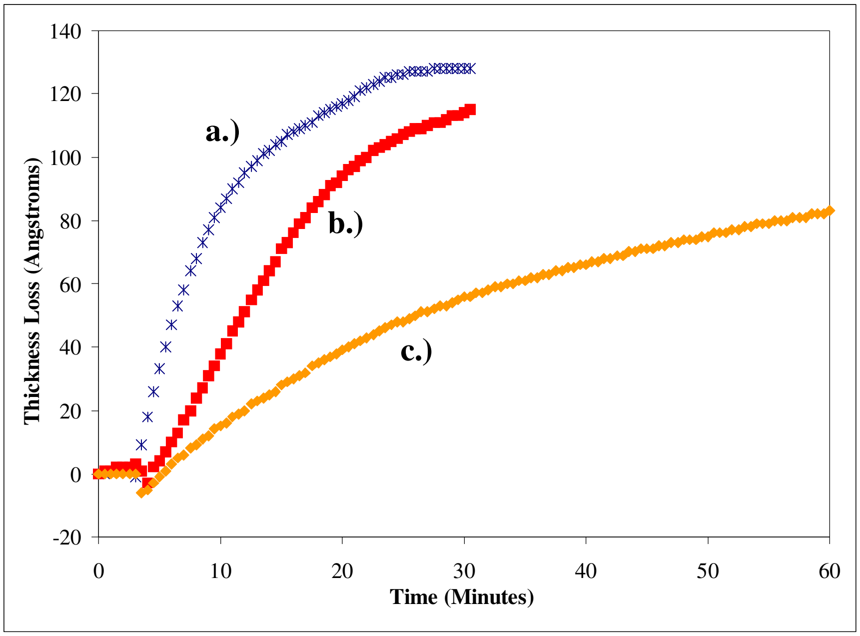
In Figure 1, the chamber pressure = 0.4 Torr, and the forward power = 14 W. The labeled sections are:

1a.) Hc removal, dry 30% O_2 in N_2.
1b.) Hc removal, 30% O_2 in N_2 with water added.
2a.) Hc removal, 30% O_2 in N_2 with water added.
2b.) Hc removal, dry 30% O_2 in N_2.
3a.) Graphitic C removal, dry 30% O_2 in N_2.
3b.) Graphitic C removal, 30% O_2 in N_2 with water added.
4.) Hydrocarbon removal, Industrial O_2.

Note that "Flat" parts of traces are where Evactron D-C is turned off.

However, for contamination <15 nm, we see that O_2/N_2 mixtures can remove contamination much more easily, as seen in Figure 2.

Figure 2: Contamination Removal using Different Gas Mixtures for contamination <15 nm



In Figure 2, the chamber pressure = 0.4 Torr, and the forward power = 14 W. The labeled sections are:

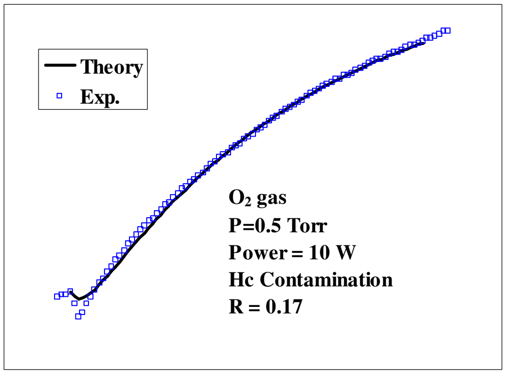
a.) Industrial O_2, Pressure=0.2 Torr, Forward Power=17W, 128 Å Hc Layer
b.) Dry 30% O_2/N_2, Pressure=0.2 Torr, Forward Power=17W, 114 Å Hc Layer
c.) Dry 30% O_2/N_2, Pressure=0.4 Torr, Forward Power=14W,
83 Å Graphitic C Layer.

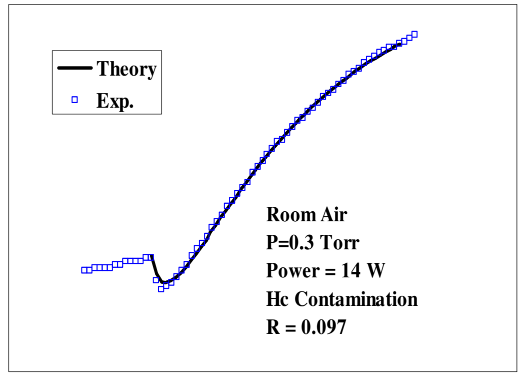
MODELING CONTAMINATION REMOVAL

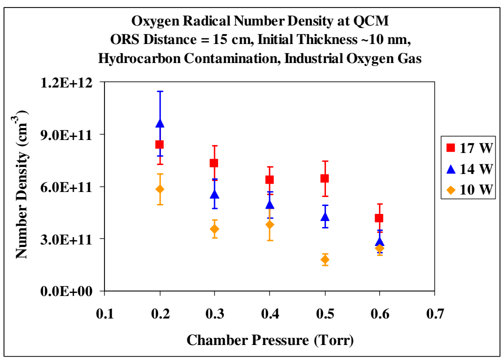
A simple model of surface contamination removal was devised. This model assumed that the entire contamination layer was subject to removal and that there are no transport processes within the layer. The removal of the layer is modeled using six chemical reactions. Only reactions with C atoms on the surface are considered.

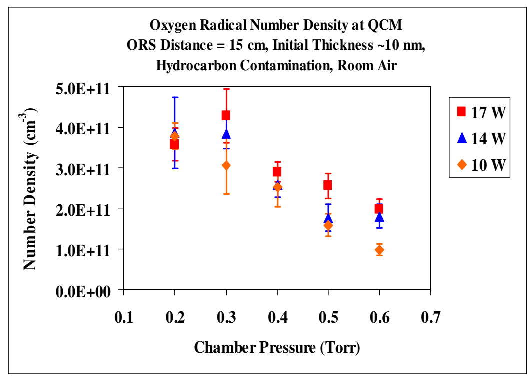
1.	C_s	+	**O**	→	CO_s			$Rate_1 = k_1[O][C_s]$
2.	CO_s	+	**O**	→	**Products**			$Rate_2 = k_2[O][CO_s]$
3.	CO_s	+	**O**	→	CO_{2s}			$Rate_3 = k_3[O][CO_s]$
4.	CO_{2s}	+	**O**	→	**Products**			$Rate_4 = k_4[O][CO_{2s}]$
5.	C_s	+	**NO**	→	CNO_s			$Rate_5 = k_5[NO][C_s]$
6.	CNO_s	+	**O**	→	C_s	+	**Products**	$Rate_6 = k_6[O][CNO_s]$

Rate constants k_1 through k_6 can be obtained by fitting thickness loss curves at different operating parameters. The concentration of oxygen radicals at the QCM surface can then be estimated. Below are examples of thickness loss fits. The results of the model are also shown with error bars based on the goodness of the fit.

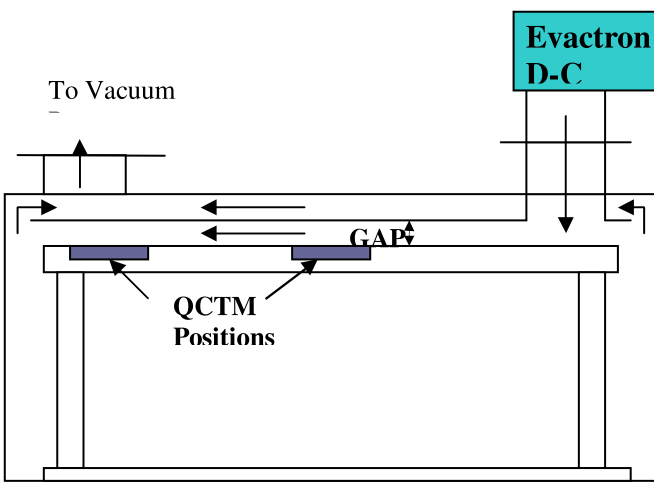






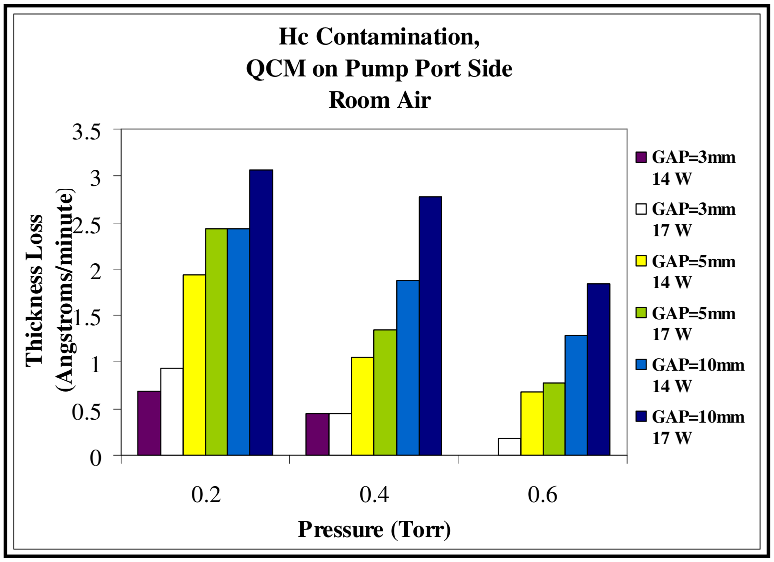


DIFFERENT CHAMBER GEOMETRY



Another series of experiments were done using a restricted chamber geometry represented in the figure above. The ports for the vacuum and Evactron D-C are on top of the chamber. A thin circular plate is placed between the vacuum port and the rest of the chamber, allowing flow to the vacuum to occur only on the edges of the chamber. The QCM is placed on a cylindrical plate (ϕ=251 mm) mounted close to the circular plate, and the gap between the circular plate and the QCM is measured. The results are shown in the figures below.

The loss rates are higher than expected, especially when compared to loss rates seen in more open chambers, suggesting that the geometry used is funneling the radicals into the areas near the QCM. Decreasing the gap between the circular plate and the QCM decreases the loss rate, since a smaller gap will be increase the probability that the radical will hit the wall surface and eliminate the radicals from the chamber.



CONCLUSIONS:

1) Industrial oxygen is a very effective gas to use in the Evactron process, especially for greater amounts of contamination. Also, when water is present, the cleaning process is more effective, suggesting that hydroxyl radicals produced in the plasma can easily break the C-H bond in Hc's and more easily initiate removal of the hydrocarbon layer.

2) Oxygen/Nitrogen mixtures are more effective at cleaning thinner layers (< 20 nm) of contamination than thicker layers The dry 30% O_2 in N_2 mixture is more effective at cleaning when graphitic carbon is the contaminant.

3) A simple kinetics model of contamination removal estimates that Oxygen radical concentrations 15 cm from source are between 1.-10. x 10^{11} molecules cm^{-3}.

4) Thickness loss rates for restricted flow chambers, such as the one seen in the top right figure, are not significantly decreased compared to more open chambers.

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