

Carbon Contamination Removal in Larger Chambers with Low-Power Downstream Plasma Cleaning

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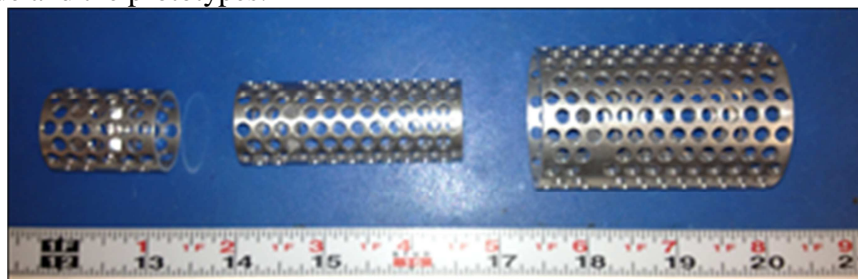
(Presented as a poster at the 2012 SPIE Advanced Lithography Conference, Feb. 14, 2012)

Abstract:

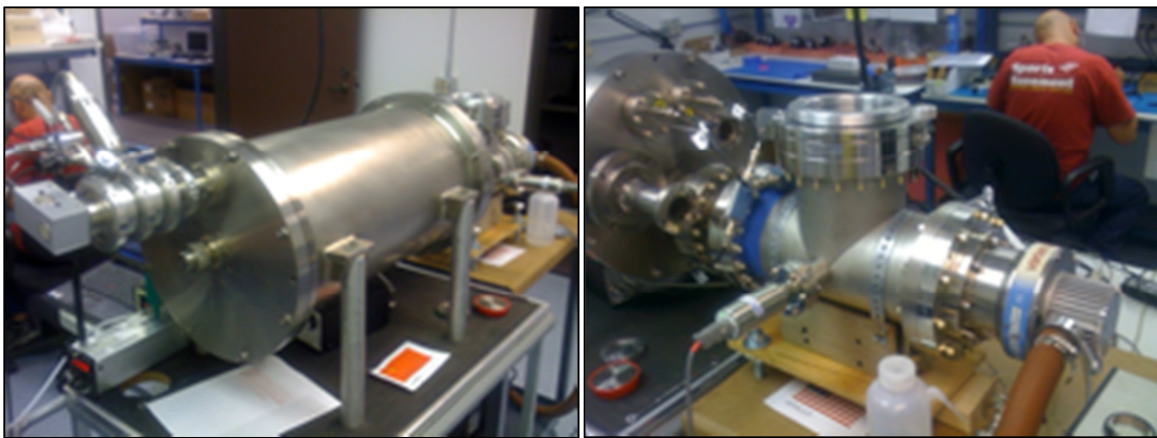
Many lithographic tools require carbon-free vacuum environments. A commercially available low-power (<20W) downstream plasma system which produces oxygen radicals in the 0.2-0.6 Torr pressure range has been shown to be effective in removing carbon contamination from standard SEM and FIB tools. However, in larger systems such as wafer or mask inspection tools the extent of cleaning in this pressure range is limited. A new downstream plasma system optimized for larger chambers has been developed which operates at higher power and lower pressure. Cleaning rates of over 1 nm/minute have been measure from over 0.5 m away from the plasma source.

There is a need for greater resolution in metrology as semiconductor manufacturing moves further into nanoscale features. One problem affecting the resolution of critical dimension scanning electron microscopes (CD-SEMs) is contamination on the sample and inside the microscope itself. The electron beam in a CD-SEM can crack any carbon compound adsorbed on the sample surface which its beam is examining. After cracking, these carbon compounds will reform as less mobile and higher molecular weight molecules; they will remain on the sample or optic surface. As the carbon layer grows, it will adversely affect the secondary electron signal and lead to changes in critical dimension measurements. For CD-SEMs, this build-up of carbon will detrimentally affect the measurements made by the tool. Similar to CD-SEMs, an extreme ultraviolet (EUV) beam can also crack adsorbed carbon compounds on an EUV optic or mask. For EUV optics or masks, the carbon will attenuate EUV light and decrease the reflectivity of the optic or mask. A decrease of only a few percent reflectivity, which can occur with only 10-20 nm carbon layer, will render an EUV tool unusable for high volume manufacturing.

XEI Scientific has designed new prototypes of the Evactron D-C, increasing in the size of the hollow cathode. This increase allows for operation of the unit at higher power and lower pressure. The picture below shows a comparison between the standard hollow cathode (on the left) and two prototypes. The first prototype, called the “Long”, increases the length of the hollow cathode 2x. The second prototype, called the “Jumbo”, increases doubles both the length and the diameter of the hollow cathode. All three prototypes are made from aluminum, and the size of the numerous small holes around the hollow cathode is unchanged between the standard hollow cathode and the prototypes.



Pictures of the system are seen below. The chamber consists of two sections. The first section is a cylinder 35.5 cm diameter and 63.5 cm length. On one end of this section is a KF40 port for the Evactron D-C. The “Jumbo” version of the Evactron D-C is seen in this picture. The Evactron D-C also includes an impedance match (silver box), a pressure sensor and a leak valve assembly. The other end contains ports for quartz crystal monitors (QCMs) which are used for cleaning rate measurements. Once in place the QCMs are 40 and 55 cm from the KF40 port used for the Evactron D-C. Also on the end with the QCM ports is a 4.5” diameter, 15 cm long connecting port to the second section of the system. This second section is a “tee” which is 33 cm in length and has 14 cm diameter subsections. It has a second pressure sensor and a 250 L/s turbomolecular pump (TMP) attached to it. Also, a QCM can also be placed in this section such that the QCM is 1 m away from the Evactron D-C port.



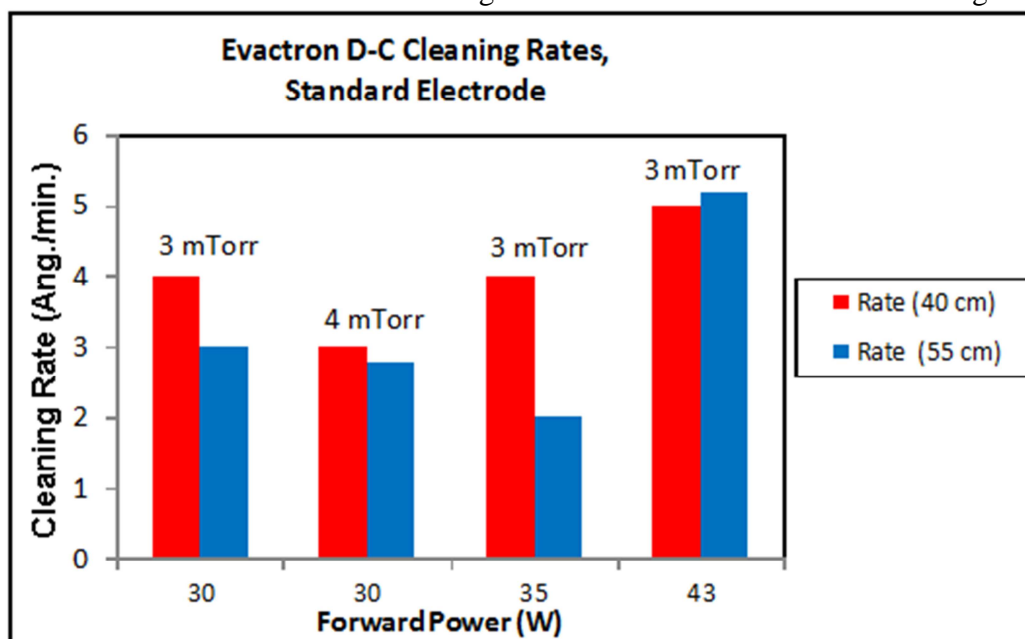
The contamination layer can be made by the following method: a small amount of mechanical pump oil is placed into an 11 cm long vacuum tube with a leak valve was attached to one end of the tube. The tube is attached to a small vacuum chamber (22 cm diameter and 14 cm height). Once the chamber was pumped down, the leak valve was adjusted so that the pressure in the chamber was roughly 0.3 Torr. The tube was then heated, and the deposition of HC onto the QCM was monitored using a QCM monitor. Once a sufficient layer has been deposited, the heating is stopped and the system is allowed to cool slightly. Previous experiments have found that for large layers of deposits (~50 nm), during the initial phase or remote plasma cleaning there is a period in which the contamination layer grows. Therefore, an Evactron D-C remote plasma is operated to allow the growth phase to run its course before starting cleaning rate measurements.



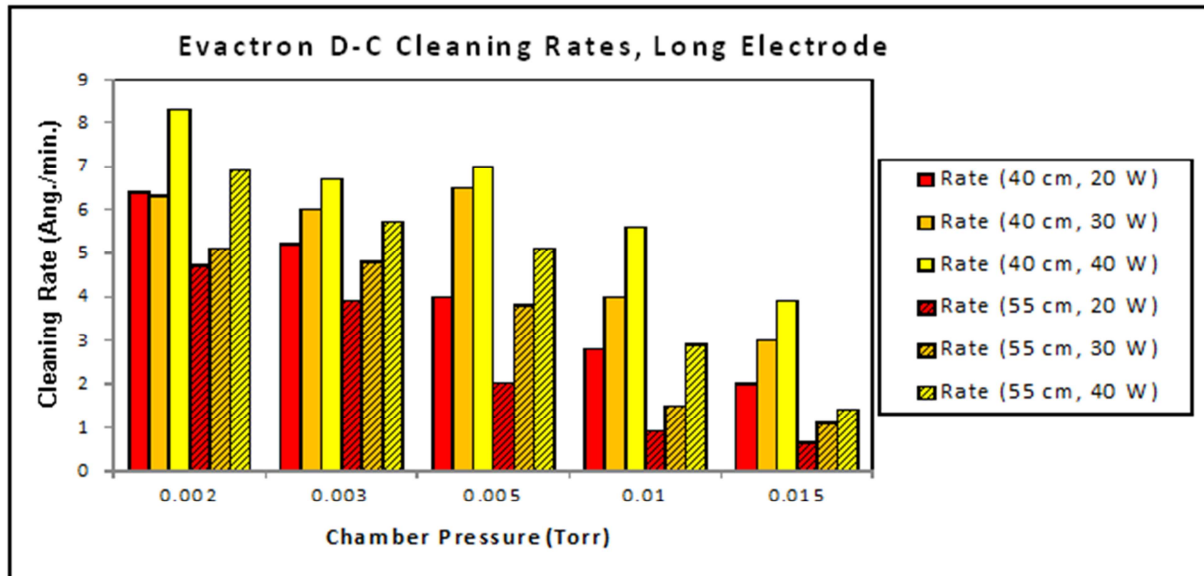
Quartz Crystal Microbalance and Holder (Detail)

Rates were determined with the QCMs at the 40 cm and 55 cm positions. The QCMs are positioned so that the active surface of the QCM is pointing away from the center line of the cylinder of the first section of the vacuum chamber. With the Evactron D-C positioned at the top of the vacuum system, as seen in Figure 3, the QCMs are close to the line-of-flow between the Evactron D-C, where the gas leak into the system occurs, and the vacuum port. For all experiments discussed in this paper, the TMP was run at low speed setting with the maximum rotational speed at 37 krpm. The plasma gas in all cases was room air.

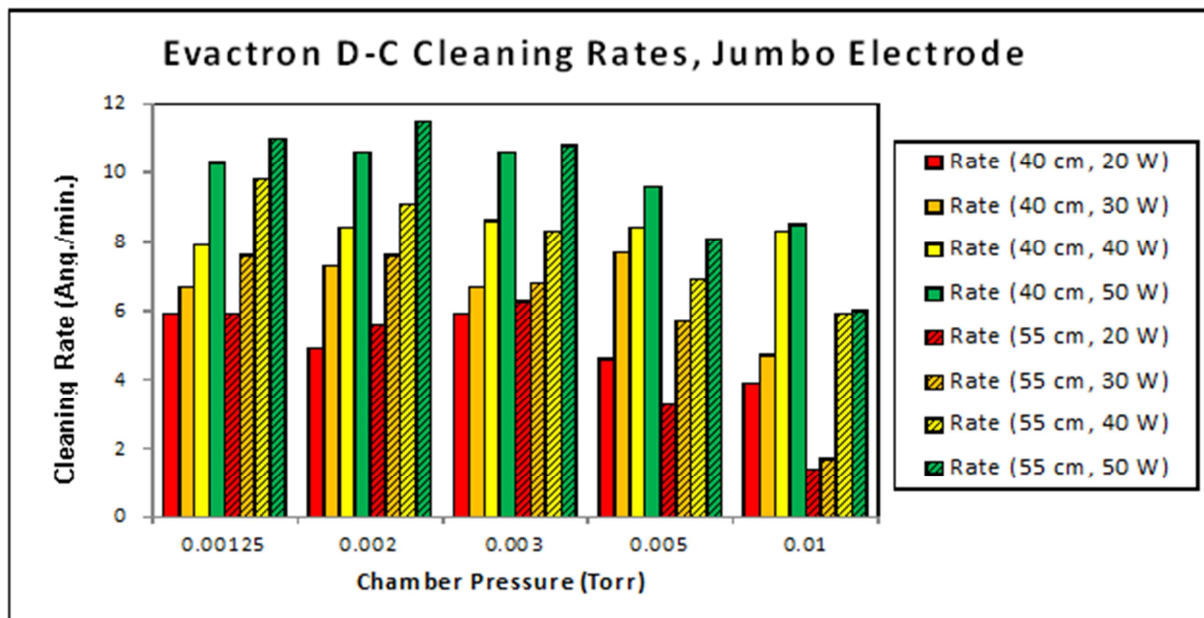
Four experiments were performed to determine the cleaning rates of the Evactron D-C with the standard electrode. The results are shown below. Above each set of data are the pressure readings taken using the pressure sensor on the “Tee” section of the vacuum chamber near the TMP. The maximum cleaning rate for the standard electrode is 5 Angstroms/minute.



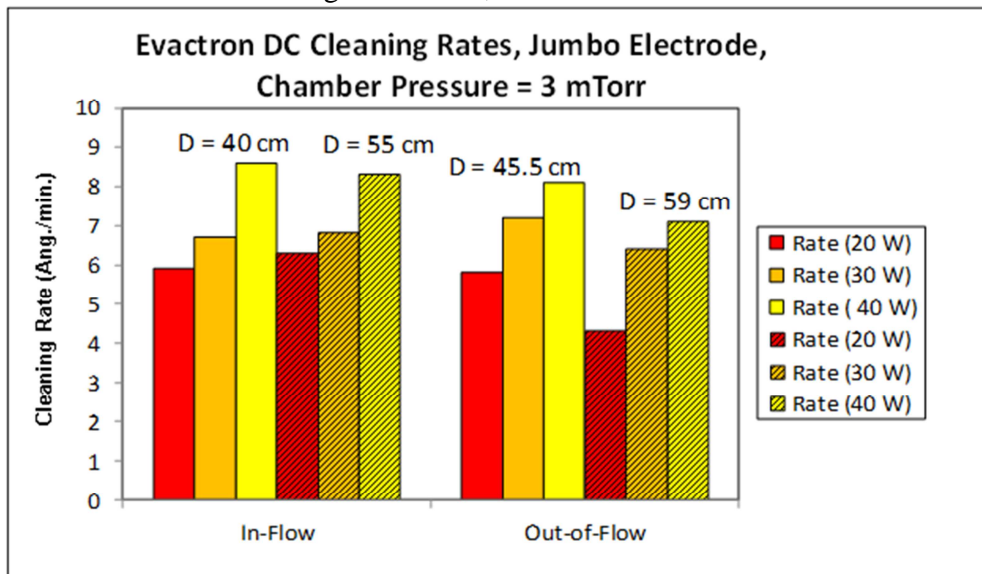
Cleaning rates using the “Long” electrode were measured at a pressure range from 2-15 mTorr, measured at the pressure sensor near the TMP, and a power range from 20-40 W. The data on the following page shows an increase in cleaning rates as the power is increased and the pressure is lowered, similar to what has been recorded in previous remote plasma cleaning experiments [5]. Another trend to note is that as the pressure increases the differences between the cleaning rates at 40 cm and 55 cm decrease. This trend confirms that more uniform cleaning in a large vacuum chamber will occur while operating the Evactron D-C at a lower pressure. With the long electrode the maximum cleaning rate obtained was around 8 Angstroms/minute at 40 cm and around 7 Angstroms/minute at 55 cm.



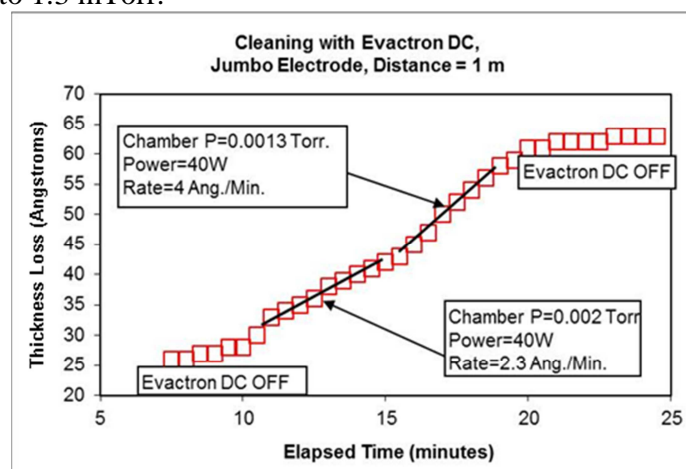
With the “Jumbo” electrode, the Evactron D-C can operate at chamber pressures down to 1.25 Torr (measured near the TMP) and powers up to 50 W, as seen in the figure below. The larger electrode creates a larger plasma volume. The cleaning rates in excess of 1 nm/minute at 50 W of power are seen at and below 3 mTorr chamber pressures measured near the TMP. At or below 3 mTorr chamber pressure the cleaning rates at 40 cm and 55 cm are closely matched, also confirming that more uniform cleaning is obtain below this chamber pressure. Also below this pressure level the cleaning rates do not increase, suggesting that for distances between 40-55 cm away from the plasma source pressures lower than 2 mTorr will not further increase the rate of cleaning.



Results of the non-line-of-flow experiments are shown in the graph below. All experiments were done with the “Jumbo” electrode, with the chamber pressure measured near the TMP at 3 mTorr, and with an RF power range between 20-40 W. The QCMs are in the same location as in the line-of-flow experiments, which mean that during the non-line-of-flow experiment they are now 45.5 and 59 cm from the Evactron D-C port. For the QCM closest to the Evactron D-C, the cleaning rates are comparable between the line-of-flow and non-line-of-flow positions. For the QCM furthest away, the non-line-of-flow cleaning rate is 32% less than the line-of-flow cleaning rate at 20 W RF power. When the power is increased to above 30 W, the difference between the cleaning rates is 6%, and at 40 W the difference is 15%.



The QCM was also placed in the “Tee” chamber near the TMP ~1 m away from the Evactron D-C. As seen in the figure below, at 40 W RF power and 2 mTorr chamber pressure (measured near the TMP and the QCM), the cleaning rate is measured at ~2 Angstroms/minute. Decreasing the chamber pressure to 1.3 mTorr increases the cleaning rate to ~4 Angstroms/minute. Although there is not a change in the difference in cleaning rates for distances from the plasma source between 40 and 55 cm when the chamber pressure is below 3 mTorr, there is an increase in the cleaning rate at 1 m distance from the source when the pressure is decreased from 2 to 1.3 mTorr.



Conclusion:

New prototypes of the Evactron D-C have been shown to provide excellent cleaning of large chambers such as those used in CD-SEMs and EUV tools. These prototypes have a more powerful RF power generator and a larger hollow cathode. At 0.5 m from the Evactron D-C plasma source cleaning rates greater than 1 nm/minute have been measured. At 1 m away from the plasma source, chamber pressure at 1.3 mTorr, and 40 W RF power, a cleaning rate of 0.4 nm/minute has been measured. Also, uniform cleaning over a range of 15 cm has been seen when the chamber pressure is below 3 mTorr. Future work will focus on several outstanding tasks. First, a beta version of the Evactron D-C with the “Jumbo” source has recently been developed with a more streamlined footprint. Initial tests indicate even greater cleaning rates. Second, plasma gases such as hydrogen gas need to be tested. Third, the effect of different pumping speeds, which in turn affects the flow rate through the Evactron plasma, needs to be explored in order to provide a more complete picture of how the new Evactron D-C operates.