Removal of Carbon Contamination using Hydrogen with Low-Power Downstream Plasma Cleaning

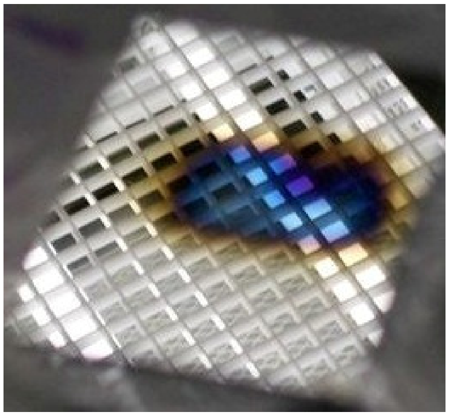
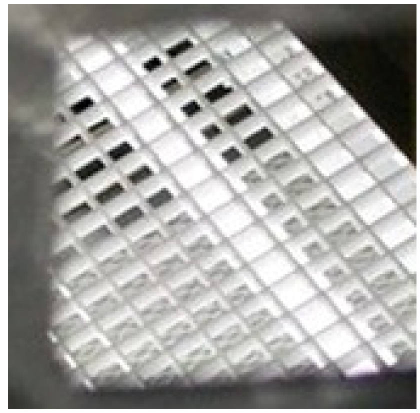
C. G. Morgan and R. Vane,
XEI Scientific, Inc., 1755 E. Bayshore Blvd., Redwood City, CA 94063

ABSTRACT

Carbon contamination on extreme ultraviolet (EUV) optics reduces their reflectivity. The use of a commercially available low power downstream plasma cleaner using room air has been shown to be effective in removing carbon contamination from EUV optics (Proc. SPIE, Vol. 7636, 76361Q(2010); doi:10.1117/12.846386). However, there is concern that removal of carbon contamination by oxidation may damage the capping layers of the optics. In particular, ruthenium capping layers may be susceptible to reaction with oxygen radicals. The previous experiments with low power downstream plasma were done on silicon capped EUV optics. In this paper, the use of gases other than room air, such as hydrogen with low power downstream plasma cleaning is explored to determine its effectiveness by using customized quartz crystal monitors. Preliminary data shows that hydrogen radicals are created using the low power RF source. The optical emission spectrum of the hydrogen plasma shows both hydrogen atoms and excited hydrogen molecules are produced. Cleaning effectiveness is measured by using a hydrocarbon contaminated tin-coated quartz crystal microbalance (QCM). Cleaning tests were done in a cylindrical chamber 30 cm diameter and 15 cm height. The hydrogen atoms also remove carbon contamination, although under different pressure conditions than oxygen radicals. The data shows that maximum cleaning occurs when the chamber pressure is at 100 mTorr. Cleaning rates were measured to be between 0.1 and 0.6 nm per minute with distances of 17 and 30 cm between the QCM and the plasma source and the forward RF power at 20 W. With a 30 W RF generator the cleaning rate increased by ~40%.

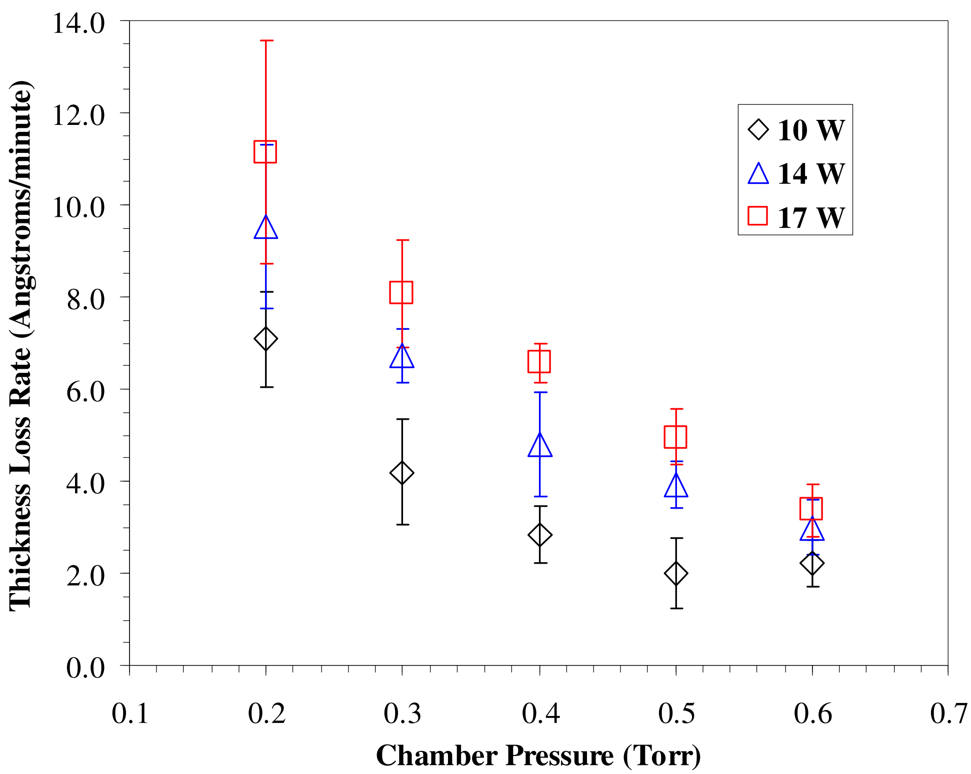
THE EVACTRON DE-CONTAMINATOR

The Evactron De-Contaminator is a low-power downstream plasma cleaner. The plasma source on the left has a valve assembly, a pressure sensor, a RF impedance match, and a hollow cathode electrode. The controller on the right has a 20 W, 13.56 MHz RF generator and a microprocessor controller.

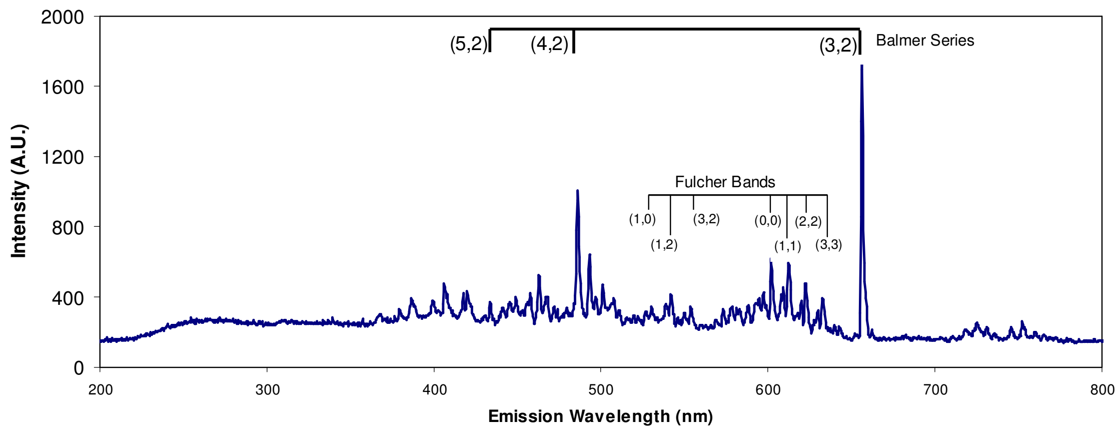
Previous tests of the Evactron De-Contaminator have shown that it can clean a silicon-capped EUV mirror such as the one above using room air without damage to the surface of the optic. The reflection seen on the optic is that of a fluorescent light on the ceiling above the optic. These pictures are courtesy of Patrick Naulleau of Lawrence Berkeley National Laboratory.

When room air is used as the oxygen containing gas, there is a steady increase in cleaning efficiency as pressure decreases. Also, as power increases between 10-17 W, there is a measurable increase in the cleaning rate. Each data point below is an average of runs at the particular power and pressure setting. Error bars show the standard deviations from these averages.

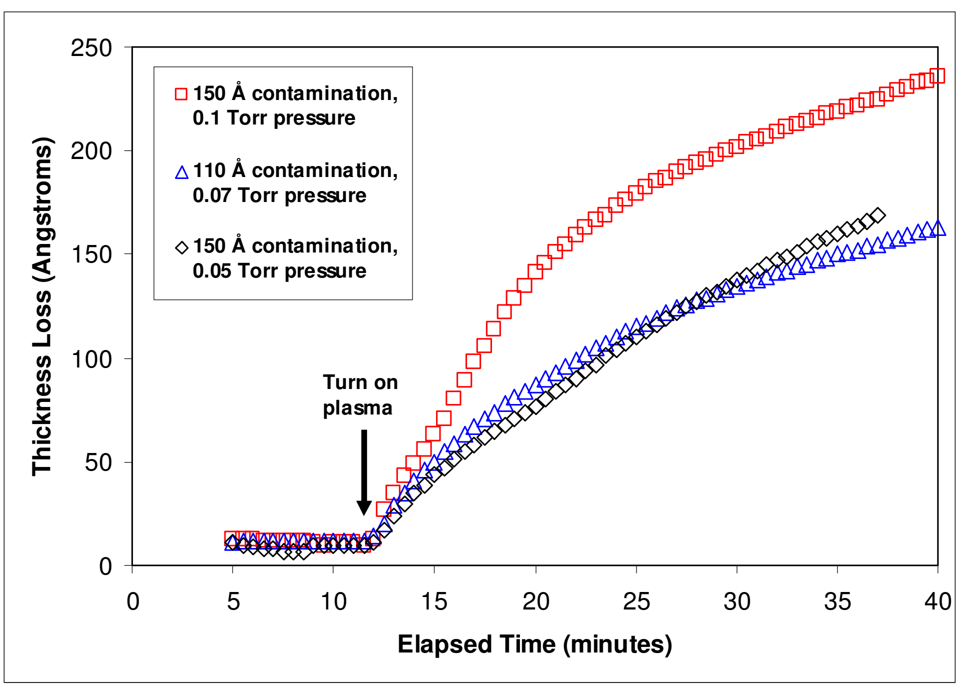


TESTS WITH HYDROGEN GAS

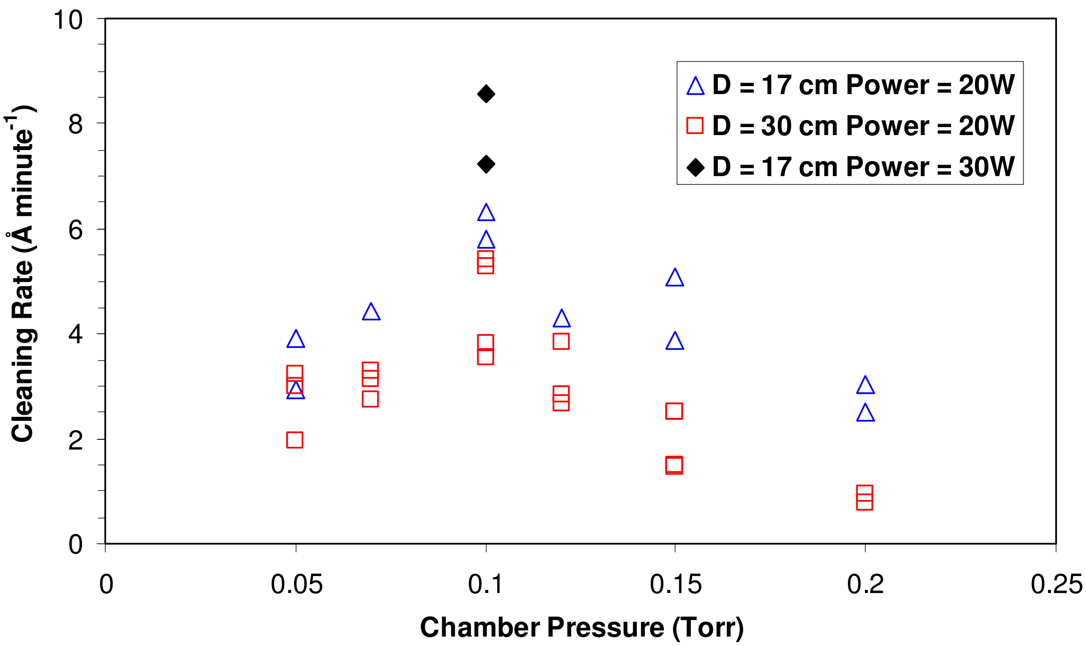
Below is an emission spectrum of the hydrogen plasma in the Evactron De-Contaminator. The operating conditions are: chamber pressure=100 mTorr and the plasma power=20 W. Prior to lighting the plasma, the chamber was flushed with hydrogen for 10 minutes at 0.5 Torr. The first three Balmer hydrogen atoms lines are seen in the spectrum, along with the Fulcher alpha bands between 520-650 nm. Other features are either Rydberg transitions of hydrogen or other Fulcher lines. Transitions due to N_2, N_2^+, OH, O, or NO are not seen in the spectrum, indicating that these species or their precursors are only minimally present in the plasma.



Pump oil removal data taken with a quartz crystal monitor and a tin-coated QCM is shown in the graph. All data are recorded with the QCM 17 cm from the 20 W RF plasma. Each trace is taken at different pressures as indicated in the graph. Also, different amounts of hydrocarbons are loaded onto the QCM prior for every run.



To determine how the cleaning efficiency changes at different pressures, a series of removal runs were done. The results are summarized in the graph below. For these runs, more than 50 nm of contamination were loaded on the QCM. Almost all measurements were made with the RF power at 20 W, except for two runs which were done with a new RF generator set to 30 W. The results of these runs are shown in the graph below left. Maximum efficiency for hydrocarbon removal is at 100 mTorr. As expected, the cleaning rate decreases the further the QCM is from the plasma.



There is an increase in cleaning efficiency if the power goes from 20 to 30 W. We expect that this increase in cleaning efficiency will continue as the power delivered to the RF plasma increases. The RF generator can deliver up to 65 W of forward RF power.

We have shown that a low power RF generator can create hydrogen radicals and clean hydrocarbon contamination at least 30 cm away. Future work will be to improve the QCM method of determining cleaning efficiency and to test cleaning at higher RF power.