Removal of Surface Contamination from EUV Mirrors using Low-Power Downstream Plasma Cleaning

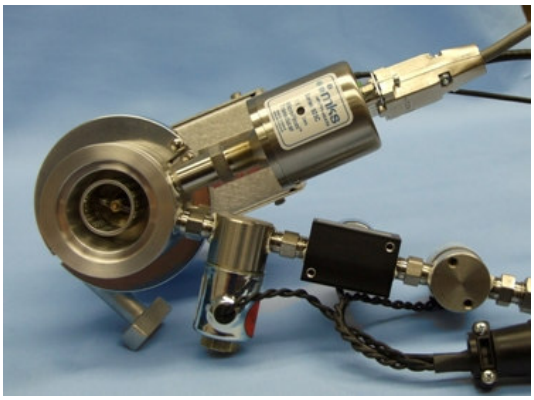
Christopher G. Morgan[a], Patrick P. Naulleau[b], Senajith B. Rekawa[b], Paul E. Denham[b], Brian H. Hoef[b], Michael S. Jones[b], and Ronald Vane[a]
[a]XEI Scientific, Inc., 1755 E. Bayshore Blvd., Redwood City, CA 94063
[b]Center for X-Ray Optics (CXRO), Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720

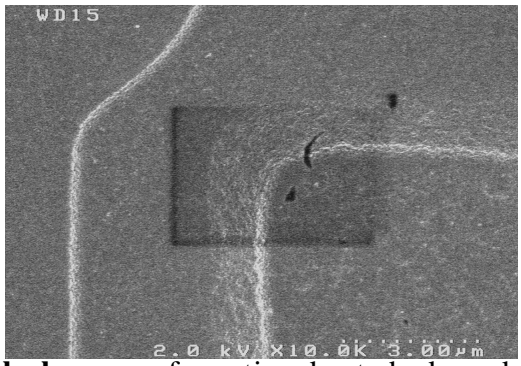
OVERVIEW

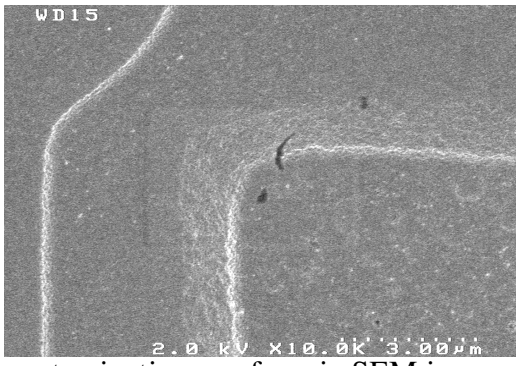
The problem of carbon contamination on extreme ultraviolet (EUV) optics, causing unacceptably low reflectivity in mirrors, must be solved before industry will adopt the technology on a production scale. Carbon contamination has also been a problem for the scanning electron microscopes (SEMs) leading to reduced image quality. The use of low power downstream plasma cleaner, the Evactron® De-Contaminator (D-C), has been shown to be effective in removing carbon contamination from SEMs. Experiments using the gold-coated quartz crystal microbalances (QCM)s and room air estimate the cleaning rate for a surface contaminated with hydrocarbons 15 cm from the plasma cleaner to be ~2-10 Å minute^{-1}. Using a silver-coated QCM, the flux of oxygen radicals was measured to be ~1.3x10^{15} radicals cm^{-2} s^{-1} with pure O_2 as the oxygen containing gas at 10 W, 0.2 Torr chamber pressure, and 20 cm from the plasma.

The Advance Light Source (ALS) is a third-generation synchrotron light source of ultraviolet and soft X-ray beams; the Center for X-Ray Optics (CXRO) maintains and operates tools for research at the ALS such as the SEMATECH-Berkeley Microfield Exposure Tool (MET). The quantity of oxygen radicals produced by the low-power downstream plasma cleaner is sufficient to remove contamination from EUV optics as demonstrated by the experiments at the CXRO. Additionally, their EUV reflectance measurements show that this method of cleaning optic does not reduce the reflectivity of the optic through formation of an oxide on the capping layer of the optic. The next step for testing the plasma cleaner is to install the unit on the MET. The installation is planned to occur in the near future. Once installed, the efficacy of *in situ* cleaning of the EUV optic can be measured, along with any problems which might occur due to using the plasma cleaner.

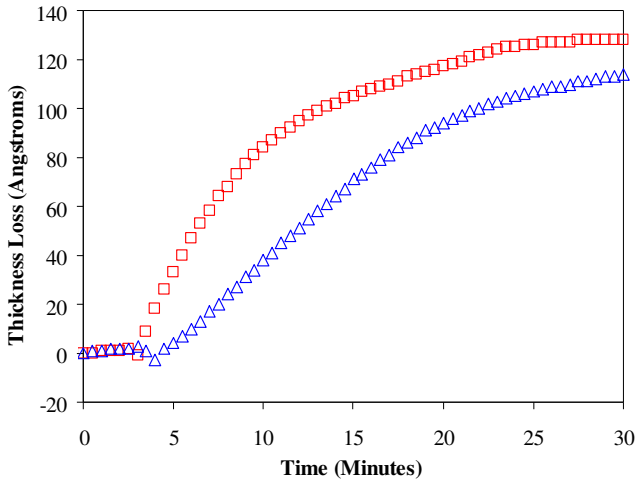
Evactron D-C: A Low-Power Downstream Plasma Cleaner



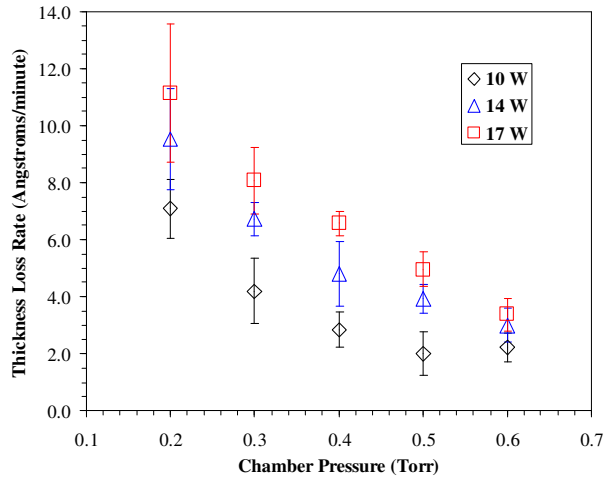




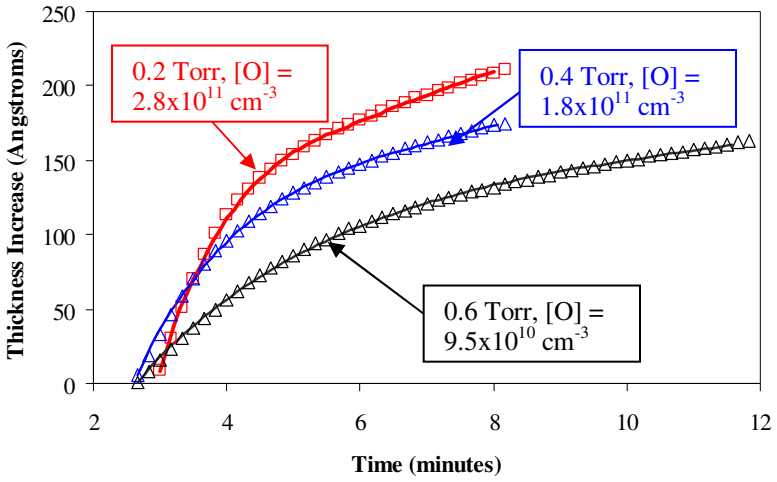
Black square formation due to hydrocarbon contamination can form in SEM image as seen in the top left figure. The **black square** in SEM image on the top right was removed by 10 minutes Evactron cleaning.



Contamination thickness loss from a gold-coated QCM with ~100 Å pump oil plotted as a function of time for various gas mixtures. The red squares (□) are data points of the trace when pure oxygen gas was used, and the blue triangles (Δ) are data points of the trace when a 30% mixture of oxygen in nitrogen was used.

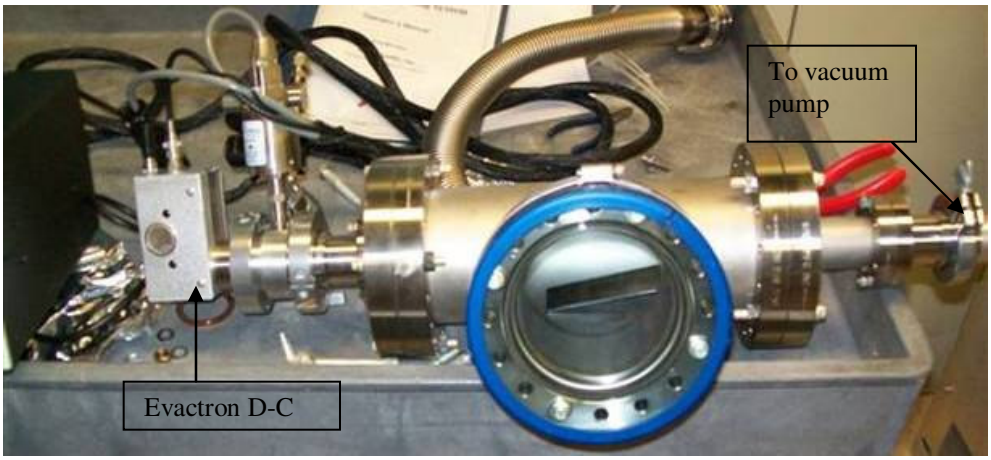


Cleaning rates at various forward RF power levels and vacuum chamber pressures. Room air is used as the oxygen containing gas. Data points at each power/pressure combination are averages of several runs. Error bars are first standard deviations from these averages.

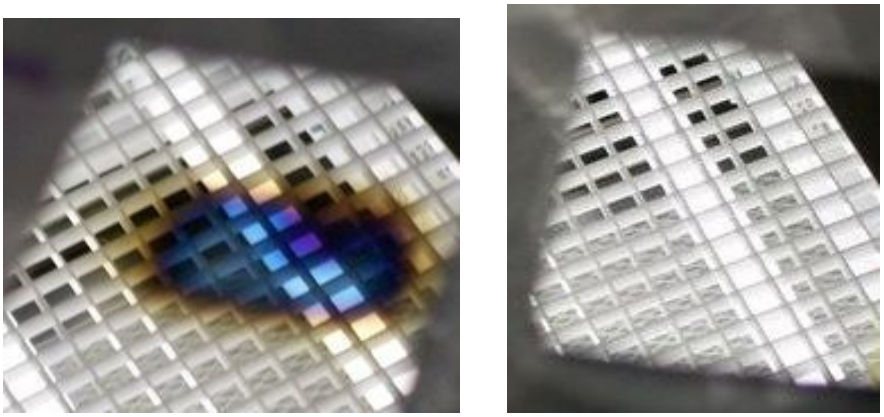


The thickness increase on a silver-coated QCM is due to oxygen radicals created by the plasma cleaner. Solid lines with the same color as the data points are Deal-Grove model fits to the traces at that corresponding pressure.

EXPERIMENTS WITH EVACTRON D-C AND EUV OPTICS

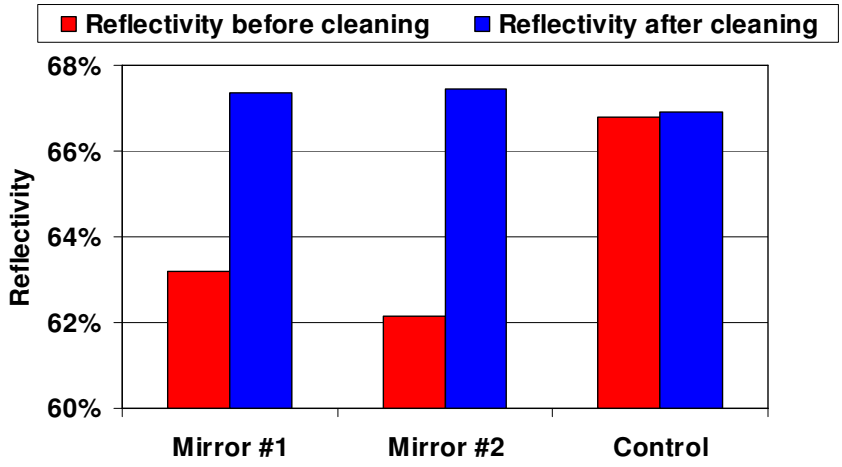


The plasma cleaner installed on a vacuum test chamber at the CXRO as shown in the picture to the left.



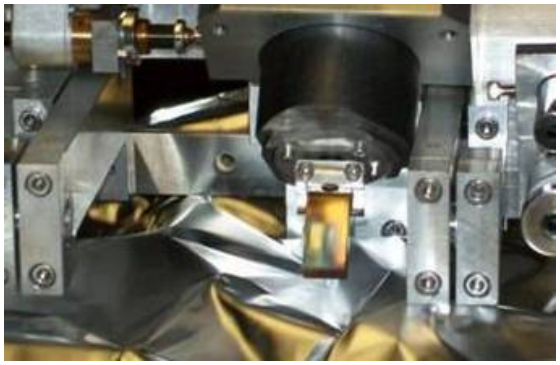
The picture on the left is an EUV optic from an ALS tool showing visible carbon contamination which built up during its use. The picture on the right is the EUV optic

after cleaning with the Evactron D-C. Typical conditions for Evactron cleaning are 2 hours exposure, 0.3 Torr chamber pressure, forward RF power = 15 W. EUV optics are silicon terminated.

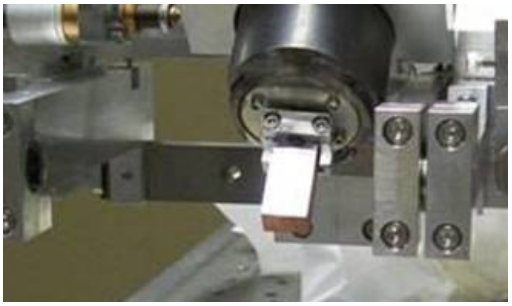


Reflectance data on two EUV mirrors contaminated by adhesive tape and on a third uncontaminated mirror (Contol). The reflectance measurements were performed using the EUV and Soft X-Ray Reflectrometer at the ALS.

Before Evactron Cleaning



After Evactron Cleaning



Pictures taken of other EUV optics before and after Evactron cleaning.