Design of Atomic Hydrogen Sources for Oxide Reduction and Carbon Elimination from EUV Mirrors

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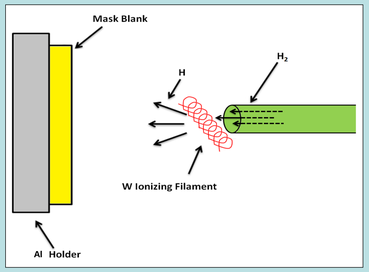
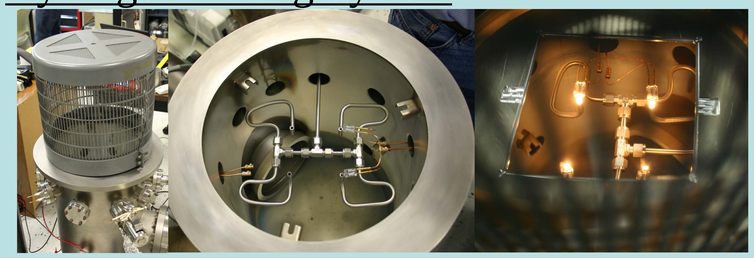
Abstract

EUV masks and mirrors are typically made of multiple alternating layers of molybdenum and silicon and terminated with a ruthenium capping layer to prevent the oxidation of the outermost silicon layer. Repetitive mask use leads to hydrocarbon contamination and oxidation of the ruthenium cap, which leads to EUV reflectivity loss. One method of removing carbon contamination and reducing surface oxides from the masks involves exposing the surface to atomic hydrogen. This presentation covers the rational design of an EUV mask cleaning system that produces atomic hydrogen by passing molecular hydrogen over a hot tungsten filament. Two systems were constructed: one for exposing 1.5” × 1.5” coupon samples and a second that is used to expose full-sized 6” × 6” mirrors. Analysis of the effectiveness of the reduction/cleaning process was performed by x-ray photoelectron spectroscopy analysis. The system for cleaning coupon samples has a single atomic hydrogen source and allows sample heating. The system for cleaning full-sized mirrors is designed with minimal mirror contact and incorporates four atomic hydrogen sources. Our data shows that the quad-source atomic hydrogen supply is scalable.

Hydrogen Dosing System

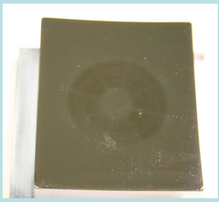




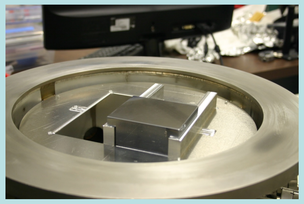
Samples are placed into an aluminium sample holder. Molecular hydrogen is leaked into the chamber with a tungsten filament at the opening of the hydrogen source. The filament dissociates the molecular hydrogen into atomic hydrogen.

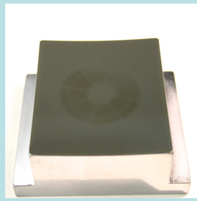
The system is a High Vacuum (HV) chamber with a base pressure of 10-8 Torr. It has been scaled up to quadruple outlets and retrofitted with an aluminium 6” × 6” mirror holder with a 1/8” lip.

Hydrogen Reduction on EUV Mirror

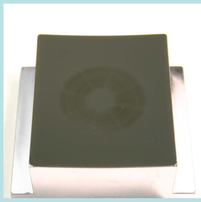


Before





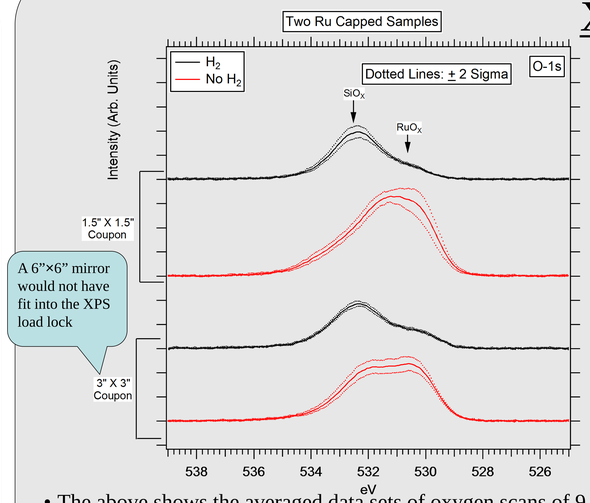
80 mins



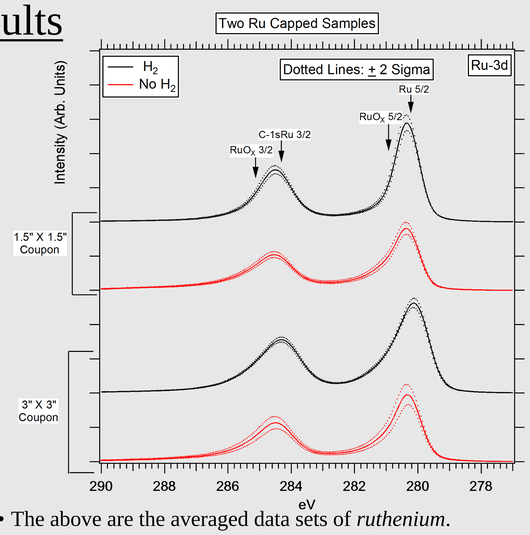
Overnight

Attempted hydrogen reduction on a concave EUV mirror. On the left is the state of the mirror before hydrogen reduction. Middle-left shows how it was mounted with adaptor pieces to fit in the 6” × 6” mirror holder. After 80 mins atomic H exposure, the surface is significantly clearer, but the black ‘donut’ still remains. XPS indicates that it is likely SiO_2 and surface-bound hydrocarbons which atomic H is not as efficient at volatilizing. The next goal will be a two-step cleaning process: volatilizing with atomic O and then reducing the surface with atomic H.

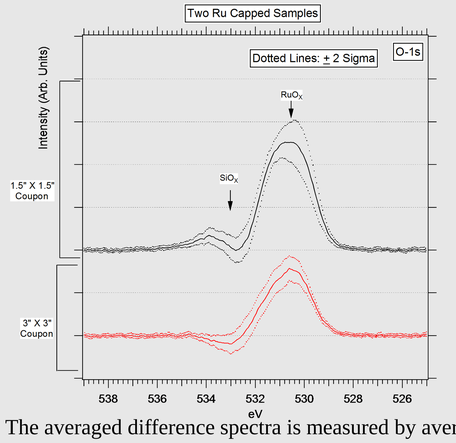
XPS Results



- The above shows the averaged data sets of oxygen scans of 9 different locations on a 1.5”×1.5” and 3”×3” EUV mirror. A 6”×6” mirror would not have fit into the XPS load lock.
- The dotted traces indicate the 95.45% (2 σ) confidence intervals. Note the strong reduction of RuO_x.
- SiO_2 did not reduce. Temperatures of 1450°C required. Normally, C is an industrial SiO_2 reductant.

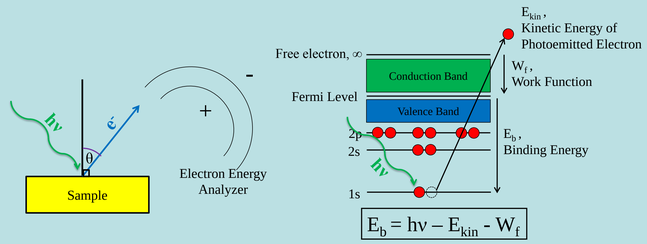


- The above are the averaged data sets of *ruthenium*.
- Note the stronger Ru 3/2 and 5/2 peaks after H exposure, indicating that RuO_x has been reduced.



- The averaged difference spectra is measured by averaging $intensity_{before}$ - $intensity_{after}$. Positive values indicate a reduction of the species.
- The 3”×3” coupon also shows a reduction in RuO_x. The ‘increase’ in SiO_2 is interpreted as a thinner capping layer (Ru vs RuO_x), leading to a stronger sub-capping layer SiO_2 signal.
- For the 1.5”×1.5” coupon, the slight ‘reduction’ of SiO_2 is likely a scaling issue.

How XPS Works



High energy monochromatic photons strike the sample and eject electrons. The binding energy of the electrons is equal to the energy of the incident photon energy minus the kinetic energy of the photoelectron and the work function of the sample. The spectra of binding energies are then compared to literature values for elemental and chemical state analysis.

By changing the detection angle, it is possible to change the surface sensitivity. The angle is measured off of the surface normal (the greater the angle, the more surface sensitive the measurement is).

Summary

- A single-source atomic hydrogen system for the surface reduction of EUV optics was upscaled to a quad-source hydrogen system. This allows it to accommodate full-scale 6” × 6” EUV mirrors.
- The uniformity of surface reduction was characterized by XPS at nine different locations on the EUV mirror. RuO_x showed a marked decrease at all points.
- The SiO_2 signal remained. This is likely because hydrogen-based reduction of SiO_2 requires temperatures of around 1450°C. It will also produce gaseous SiO, which is undesirable.

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