Strategies for Cleaning EUV Optics, Masks and Vacuum Systems with Downstream Plasma Cleaning

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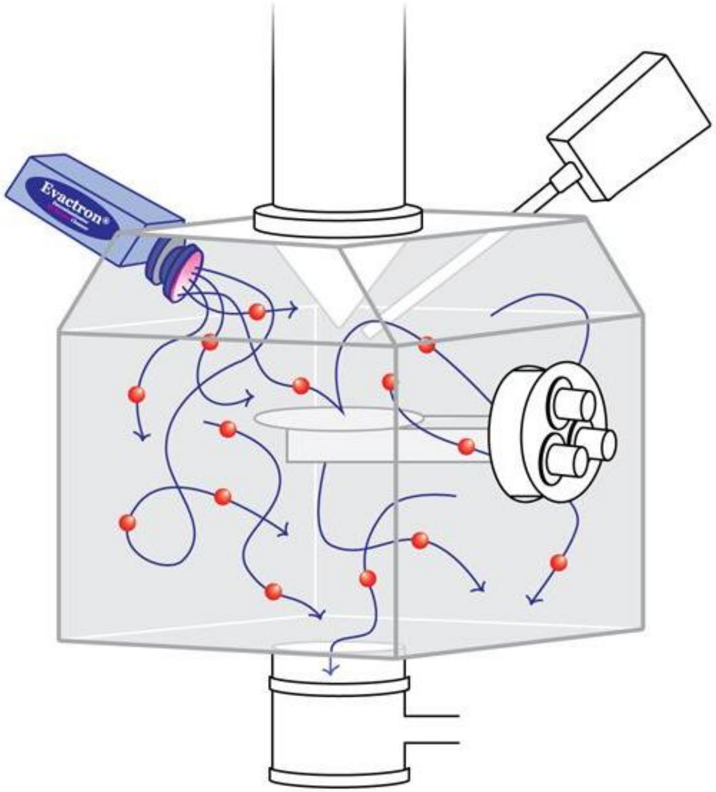
Introduction and Overview of Talk

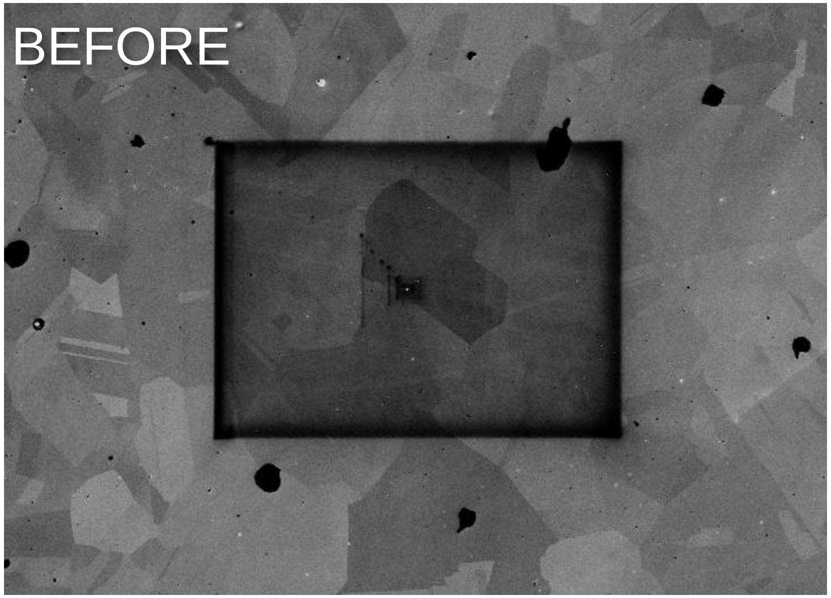
- Introduce <u>downstream plasma cleaning</u>.
- Strategies for cleaning hydrocarbon contamination in EUV Lithography chambers.
- <u>Large chamber cleaning</u> removes contamination from the entire chamber.
- <u>Localized cleaning</u> removes contamination from a specific area of the vacuum chamber (e.g. mirror or mask).

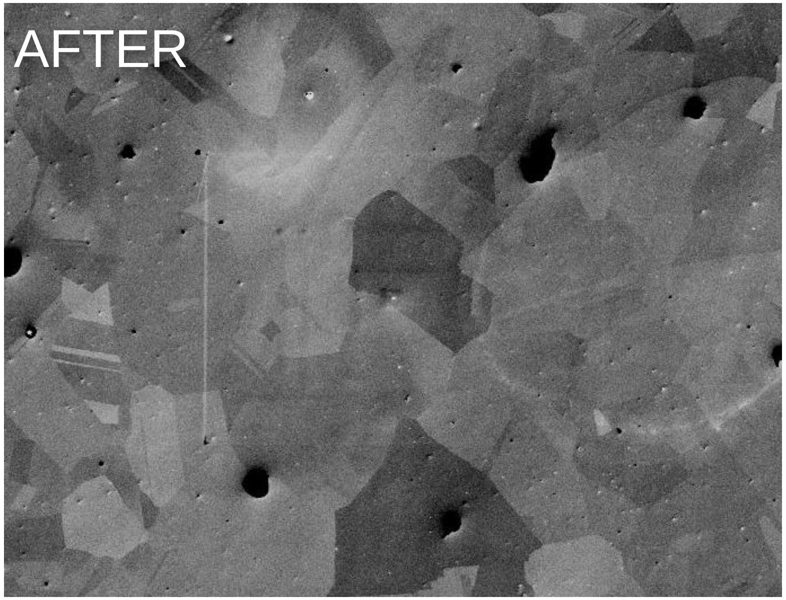
Downstream Plasma Cleaning

- The downstream plasma cleaner (PRS) is mounted on the left side of the chamber. Reactive gas radicals are created in the PRS.
- Radicals flow from the plasma cleaner to the pump port. They chemically react *inside the chamber* with encountered hydrocarbon contamination.
- Plasma is confined to the PRS. At 10 cm from the PRS, the temperature increase is <5ºC.



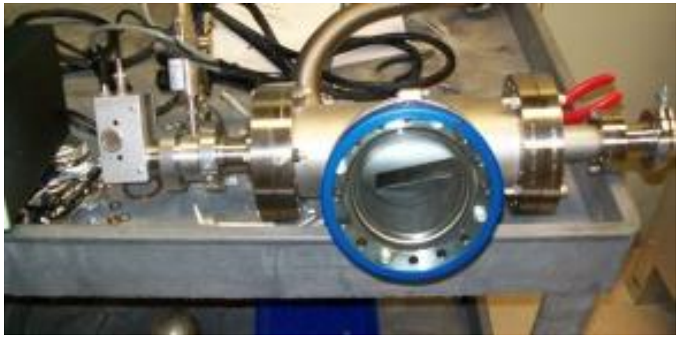
Electron Microscope Cleaning



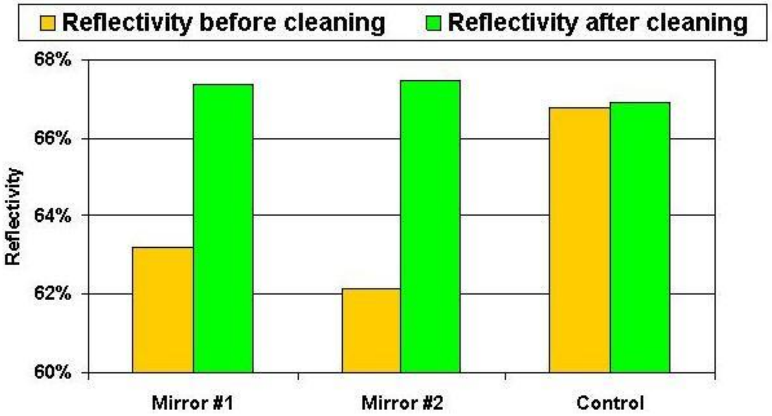


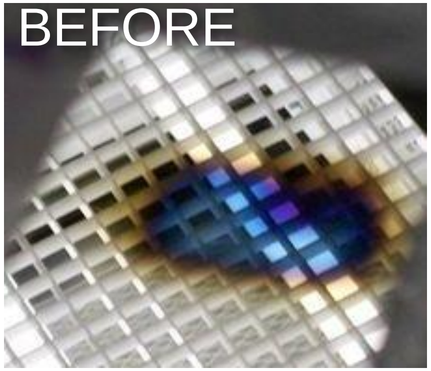
- **Carbon in SEM chamber deposits on sample during scan.**
- **SEM Carbon Contamination removed by downstream plasma cleaning.**

Cleaning Carbon from Si-capped EUV Optics



Test chamber at CXRO used for cleaning Si-capped EUV optics





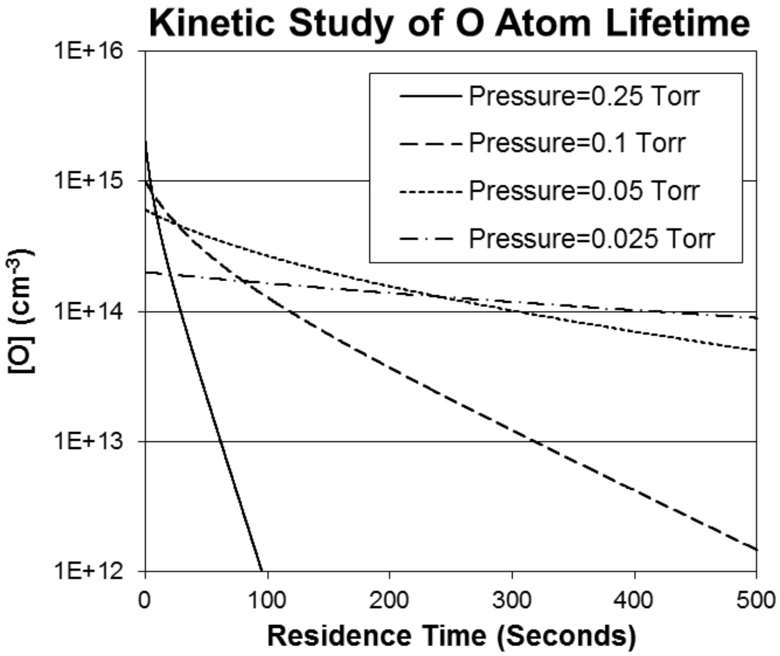
Senajith B. Rekawa, Paul E. Denham, Brian H. Hoef, Michael S. Jones, and Patrick P. Naulleau, CXRO, Lawrence Berkeley National Laboratory (Ref: SPIE Proc., Vol. 7636, 76361Q, 2010, doi: 10.1117/12.846386)

ML mirrors (#1 & #2) are contaminated prior to Evactron cleaning.
Control mirror was uncontaminated prior to Evactron cleaning.

Large Chamber Cleaning

The power and pressure of downstream plasma cleaning needs to be balanced:

- Higher power leads to more radicals being created in the plasma.
- Lower pressure leads to longer lifetimes of radicals in the vacuum chamber.



Plasma Gas=Room Air:

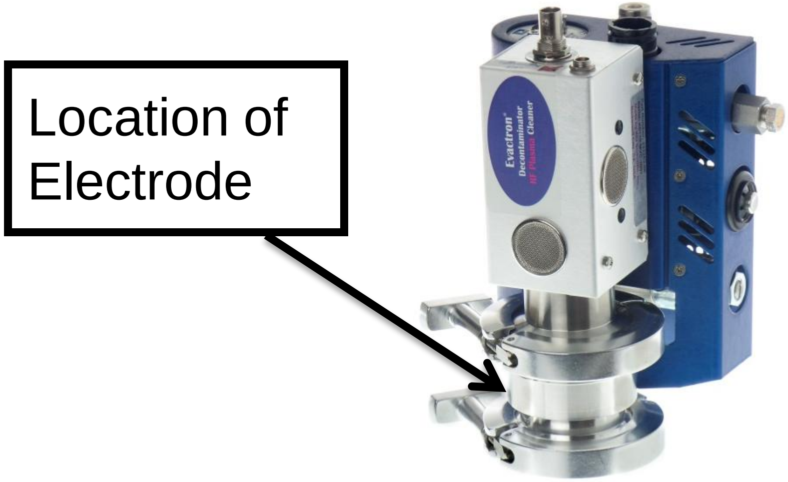
Reactions used:

$O + O + M \rightarrow O_2 + M$

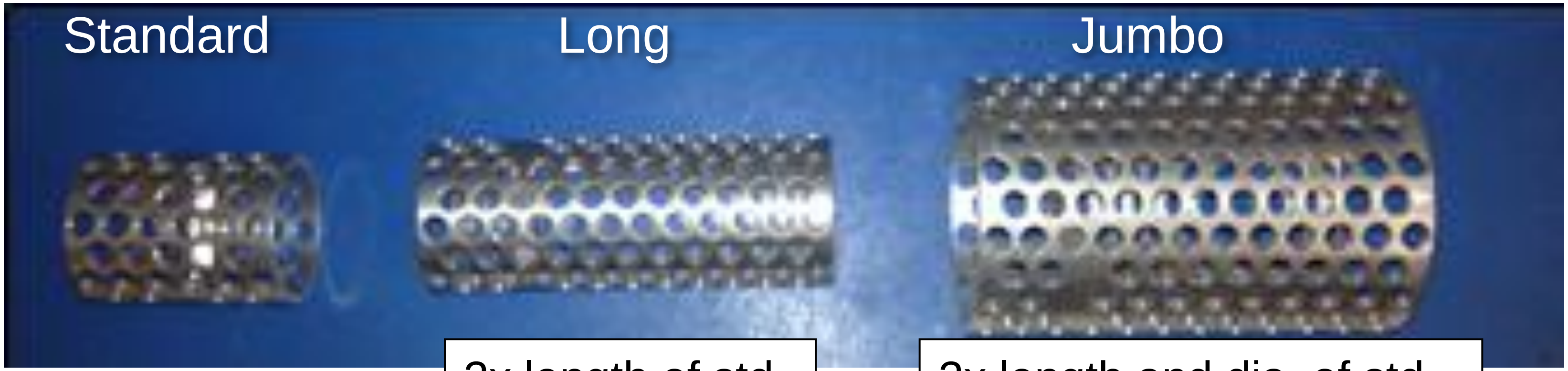
$O + O_2 + M \rightarrow O_3 + M$

$O_3 + O \rightarrow 2O_2$

Evactron De-Contaminator Electrodes



- XEI has created new larger Evactron De-Contaminators which scale with electrode size.
- Larger electrodes create a more stable plasma at lower pressures and higher powers.
- Std. electrode is 23 mm dia. and 30 mm in length.



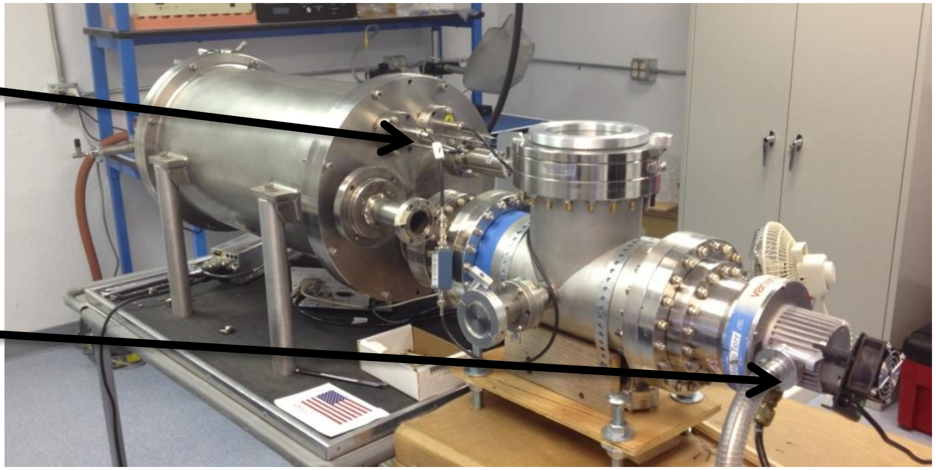
2x length of std.

2x length and dia. of std.

Large Test Chamber at XEI Scientific

- Large Cylindrical Chamber is 35.5 cm diameter and 63.5 cm long
- “Tee” Chamber is 33 cm long and inner diameters are 14 cm
- With adapters, cleaning distances of up to 1 m can be measured

Downstream Plasma Cleaner



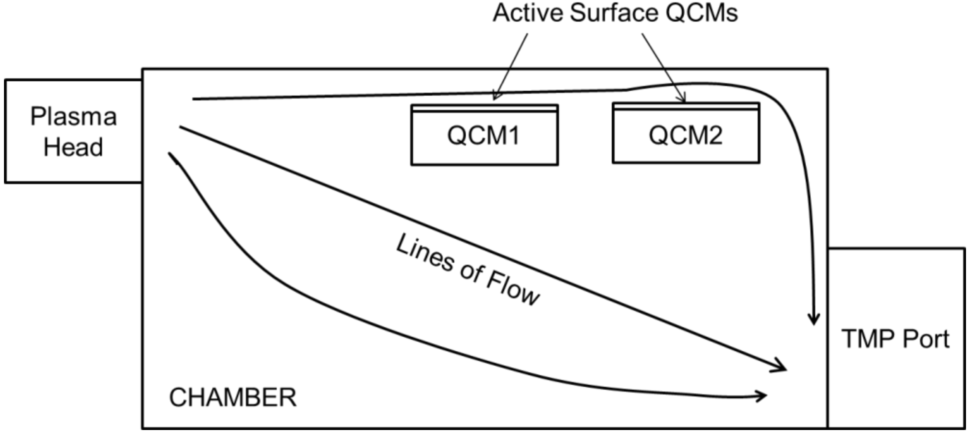
QCM Feed-throughs

TMP

Measuring Cleaning Rates in Large Chamber

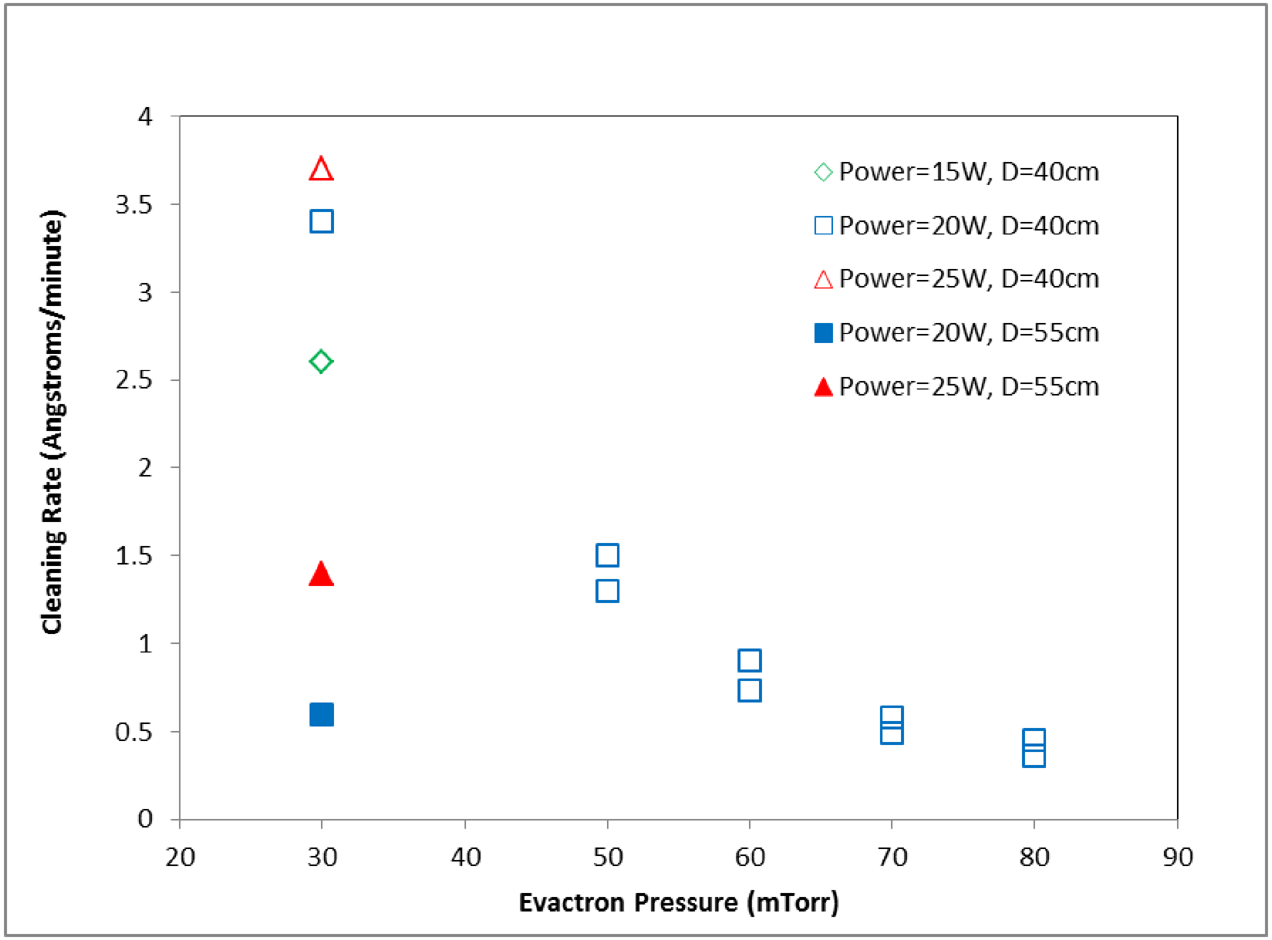
- XEI has developed a cleaning standard using a quartz crystal microbalance (QCM)
- In separate chamber, a QCM is coated with pump oil by evaporation in vacuum.
- The contaminated QCM is transferred to the large chamber for cleaning.

(Ref: Morgan et al., Microscopy Today, 15, 5, 22, 2007)



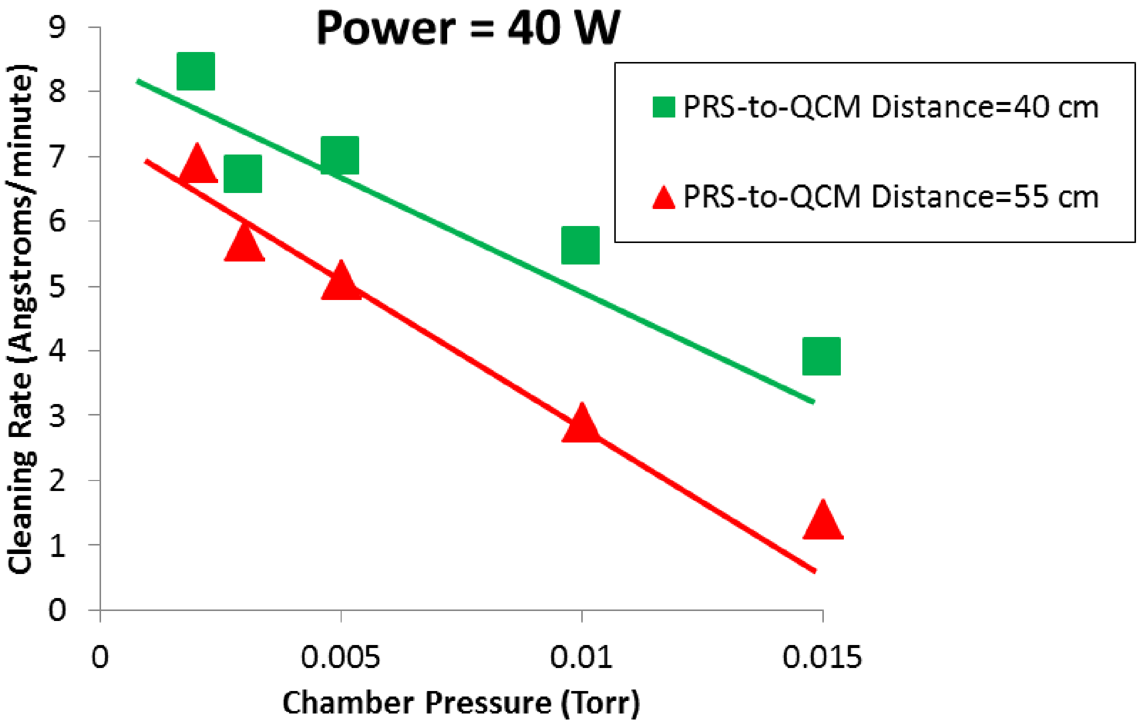
QCMs are placed so that they are in the line-of-flow of oxygen radicals in chamber

Results: Large Chamber Cleaning with “Standard” Electrode



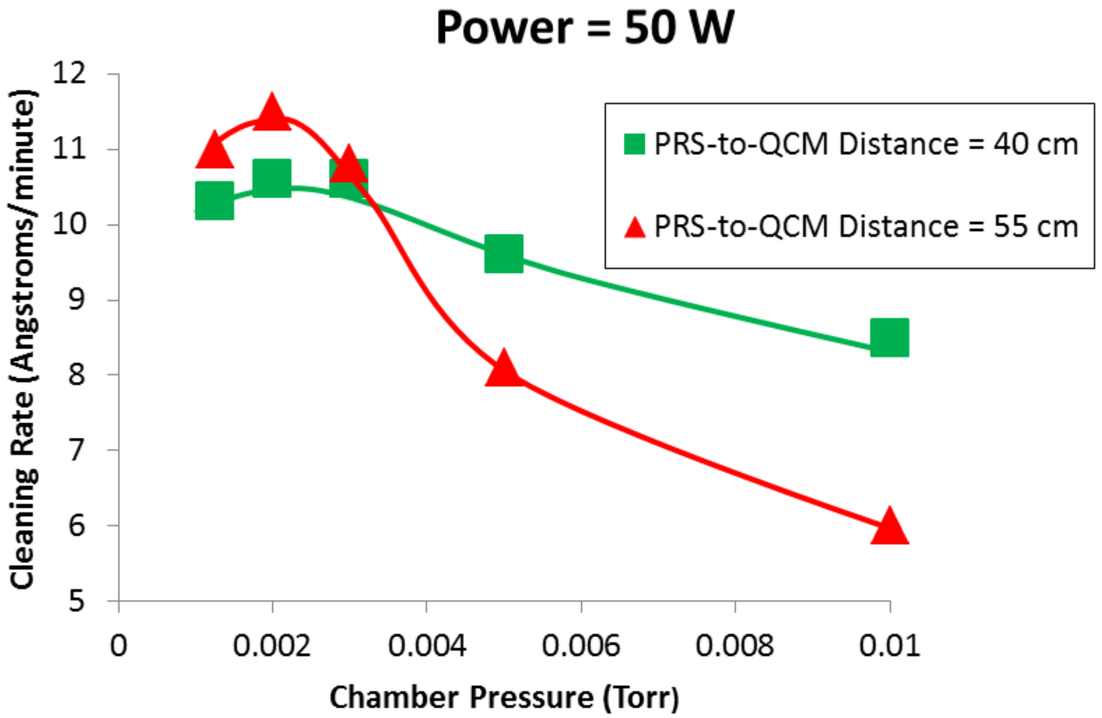
- Chamber pressure between 5 – 40 mTorr. Cleaning rates improve as pressure is lowered.
- RF Power limited to 25 W.

Results: Large Chamber Cleaning with “Long” Electrode



- QCMs are 40 cm and 55 cm from plasma source.
- RF Power is unstable above 40 W and below 2 mTorr chamber pressure.
- Cleaning rates at both distances converge at 2 mTorr chamber pressure.

Results: Large Chamber Cleaning with “Jumbo” Electrode



- QCMs are 40 cm and 55 cm from plasma source.
- Cleaning rates at both distances are optimum (>1 nm/min. at 50W) and comparable when chamber pressure is below 2 mTorr.

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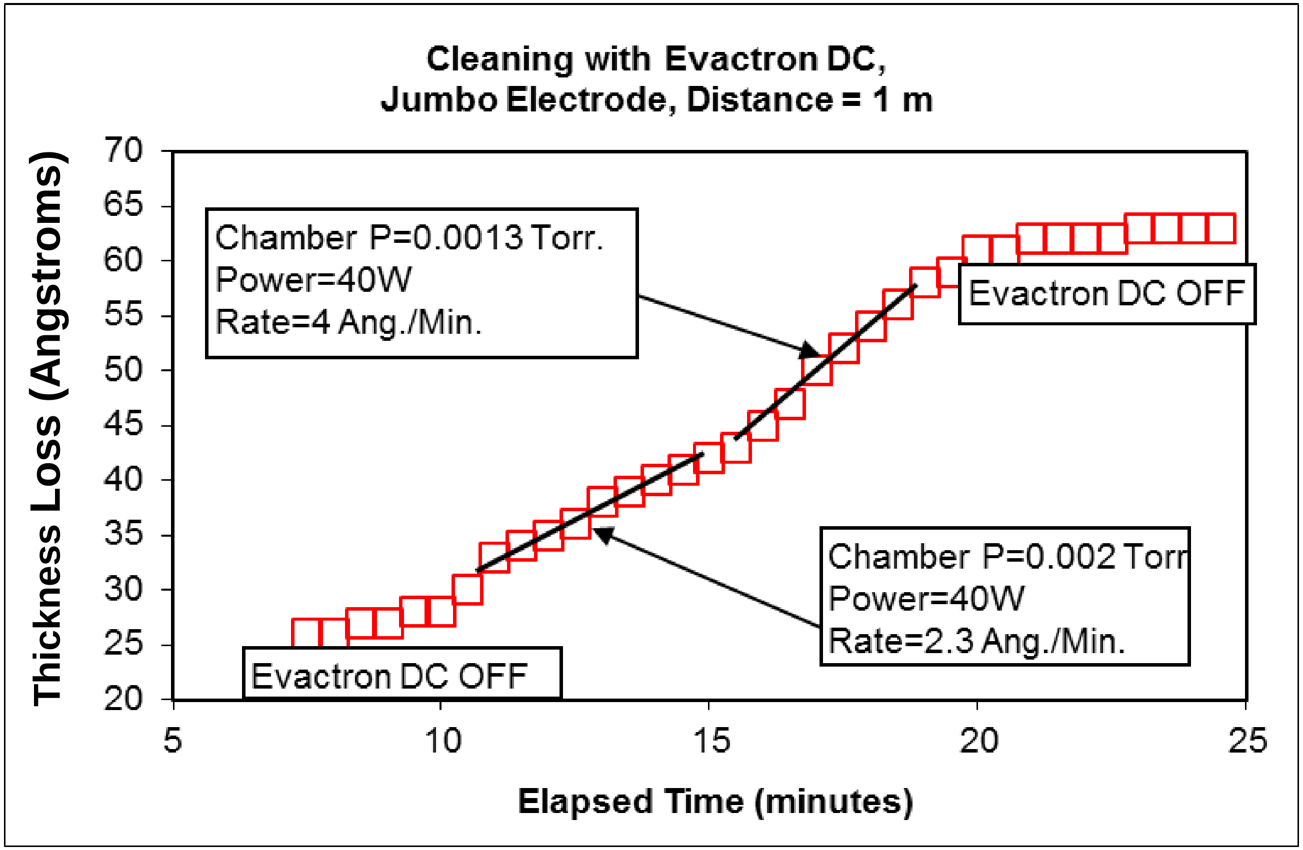
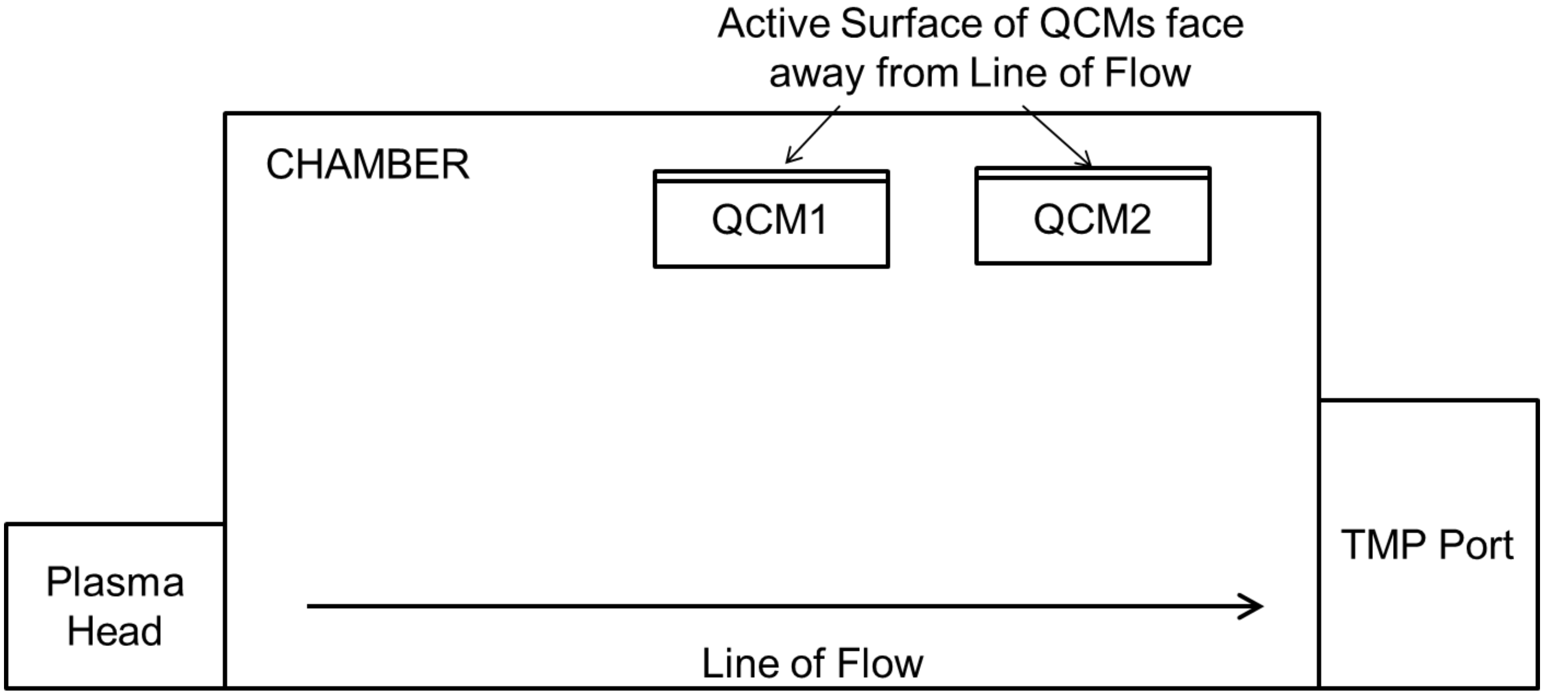
Cleaning at 1 meter from Source



Rate of 0.4 nm/minute is seen at chamber pressure of 1.3 mTorr.

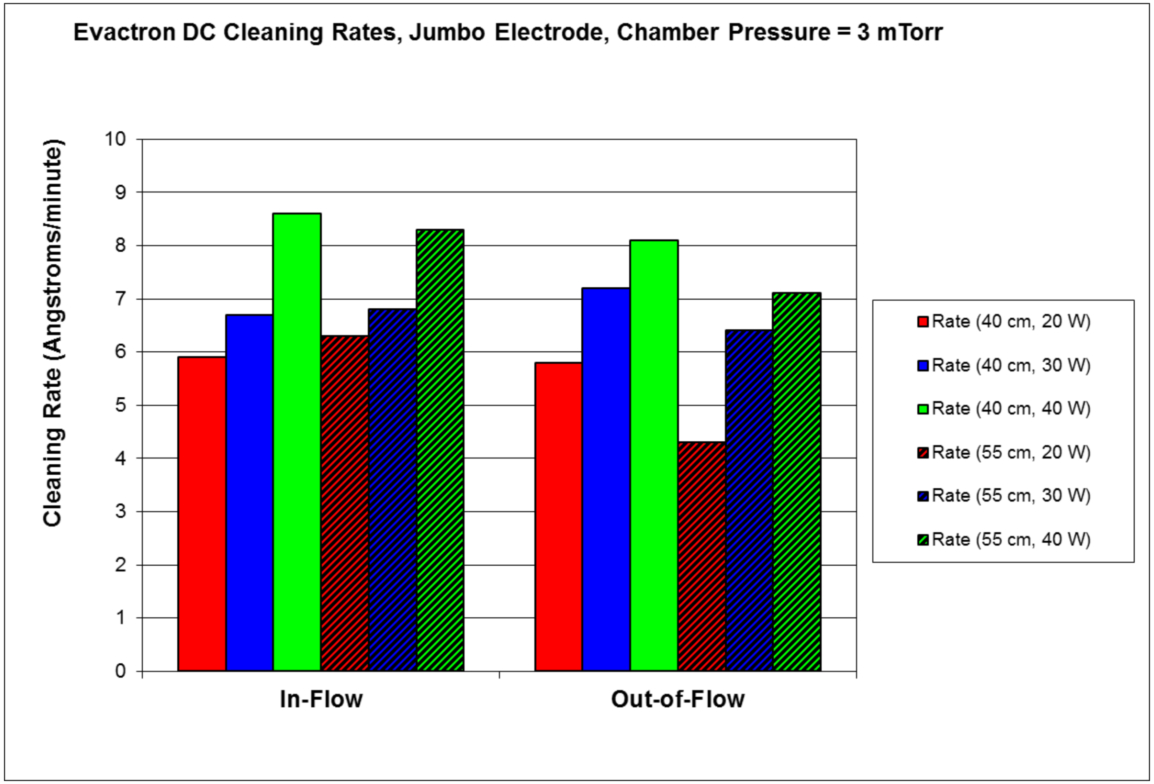
Out of Line-of-Flow Cleaning (I)



- The Plasma Source is moved from the top of the chamber to the bottom.
- The QCMs are now pointing away from the Line of Flow.

Out of Line-of-Flow Cleaning (II)

Jumbo Electrode, Chamber pressure = 3 mTorr, RF Power = 20, 30, 40 W



Only a slight decrease seen at 55 cm between In-flow and Out-of-flow results

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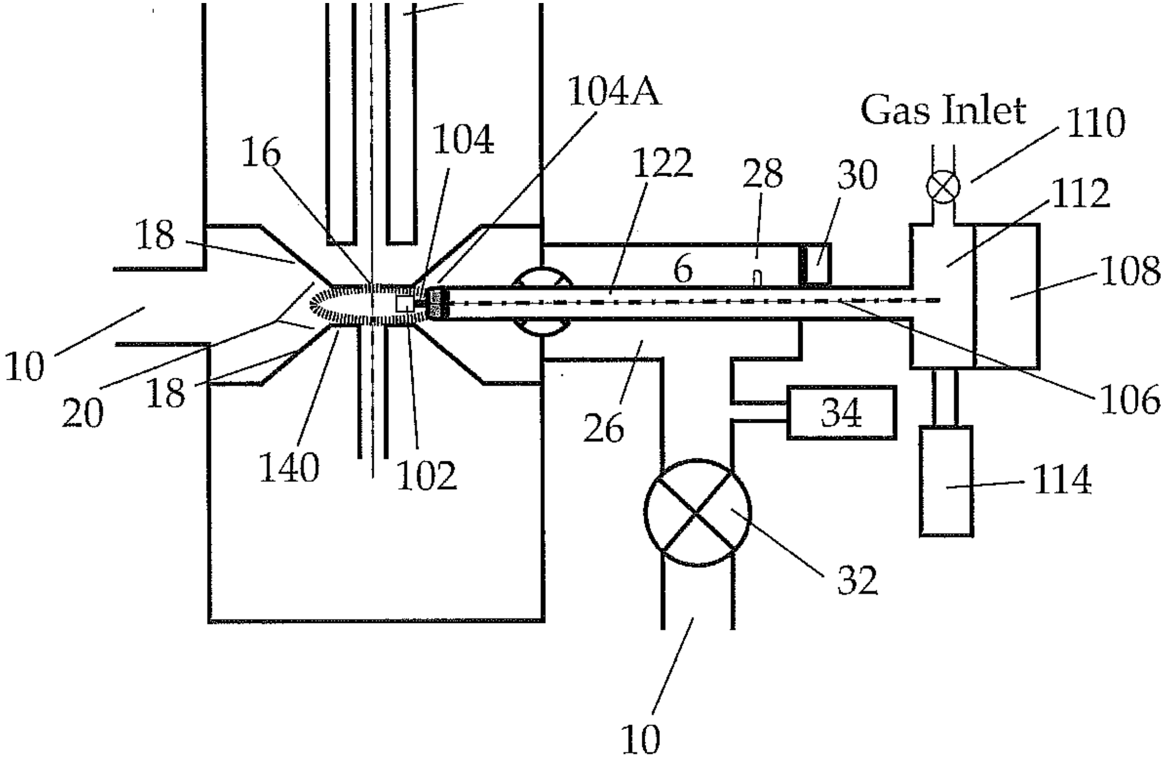
Summary of Large Chamber Cleaning Work

- Cleaning of large chambers is possible with a Prototype Evactron system capable of running at 50W forward power and at chamber pressures of <3 mTorr.
- Cleaning rates of >1 nm/minute have been measured 55 cm distance from the plasma head.
- Cleaning rates of 0.4 nm/minute have been measured at 1 m distance.
- Uniform cleaning of the chamber has been demonstrated.

Localized Cleaning Example: TEM Chamber

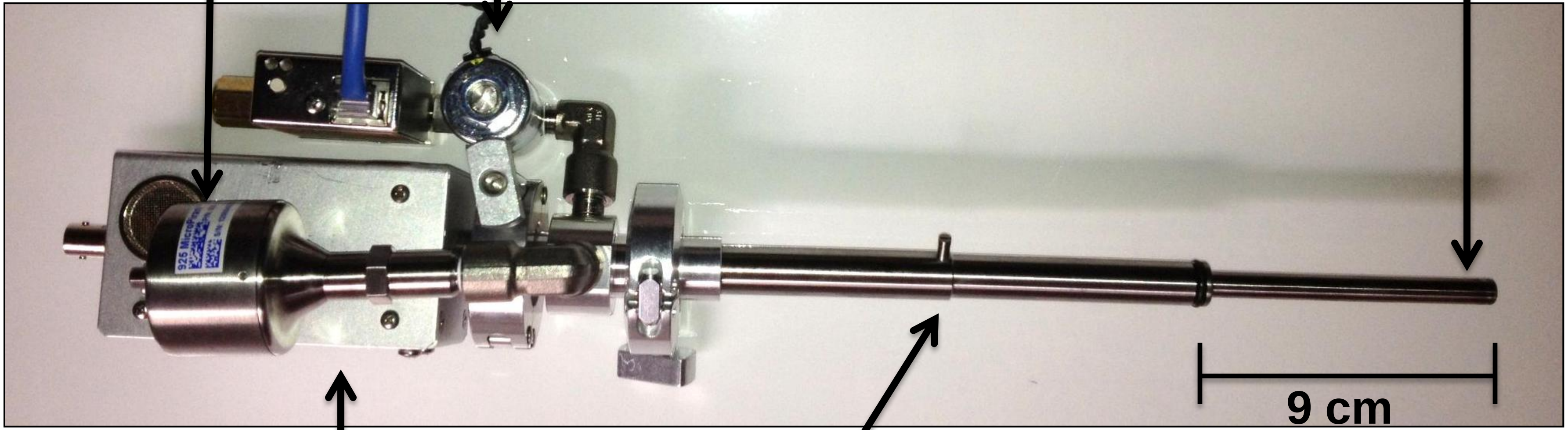
TEM = Transmission Electron Microscope



- Pole piece region of TEM chambers need cleaning in order to prevent build-up of carbon during imaging.
- Plasma cleaning delivered to pole piece region removes carbon.

Patent Application Pending

TEM Wand (Hitachi HT)



Valve Assembly

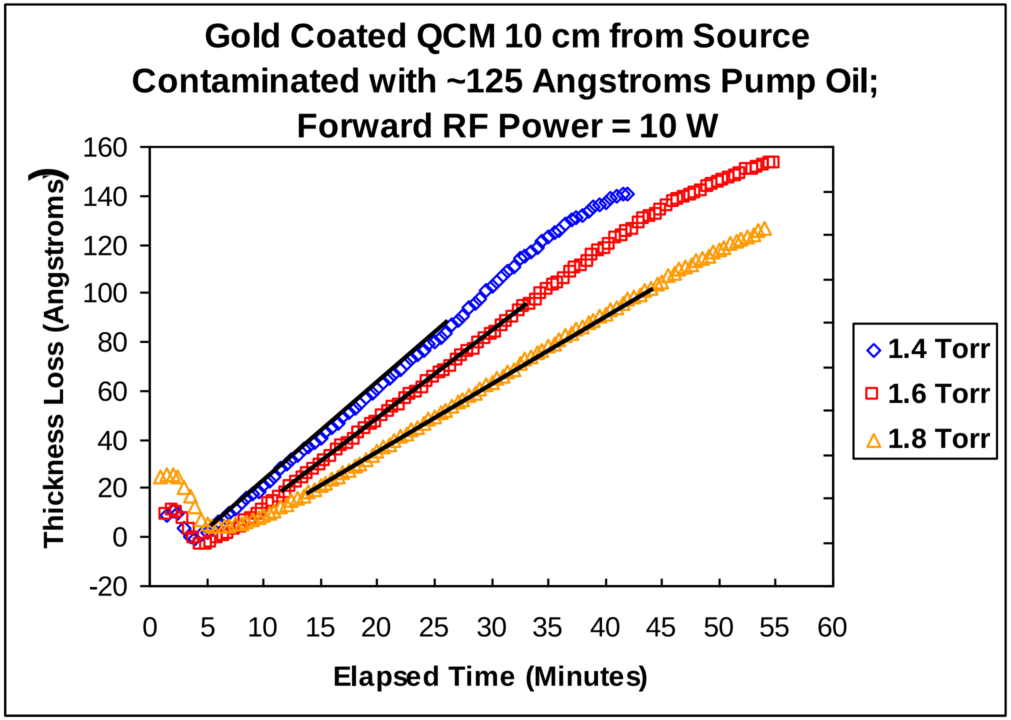
Pressure Sensor

Electrode (within tube) Opening = 8 mm

Sample Rod

Impedance Match

Cleaning Rates for TEM Wand



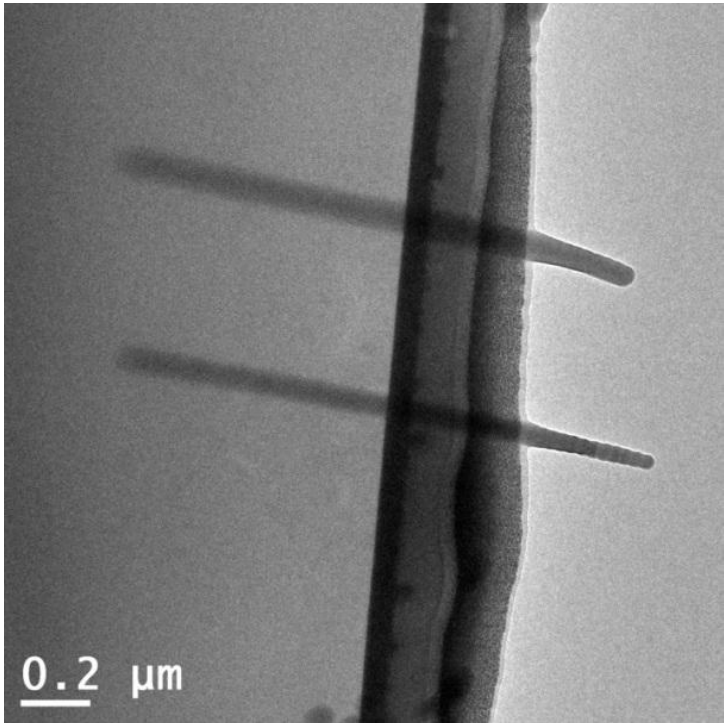
Gold Coated QCM 10 cm from Source
Contaminated with ~125 Angstroms Pump Oil;
Forward RF Power = 10 W

Cleaning Rates with TEM Wand, QCM is 10 cm from Source

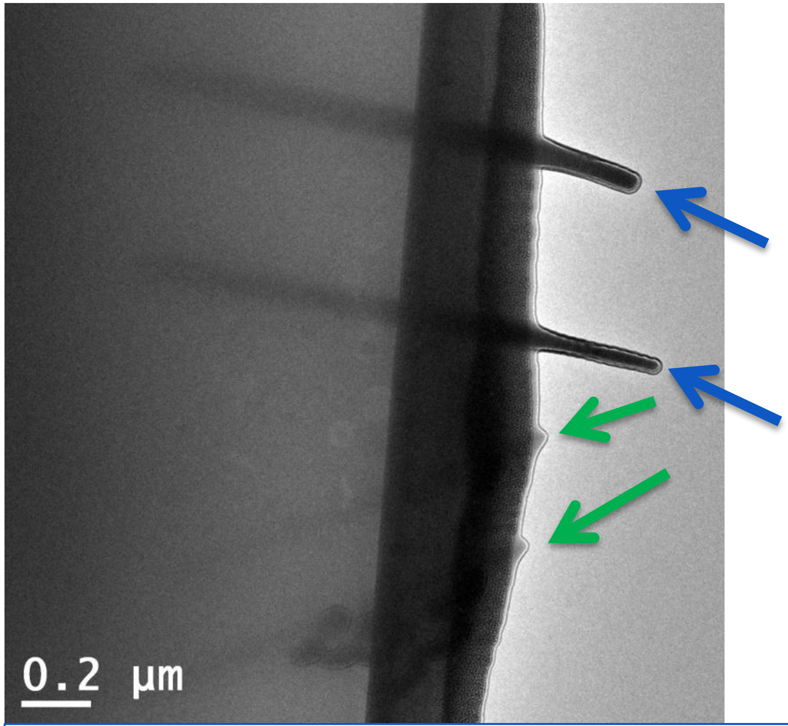
Press. (Torr)	Rate (10 W) (Å/min.)	Rate (17 W) (Å/min.)
1.4	4.0	7.7
1.6	3.6	8.1
1.8	3.2	6.1

- Pressure measured at back of the TEM Wand
- Cleaning rate at 10 W sufficient to remove contamination in pole piece region

Results in a TEM



Carbon buildup during TEM imaging



Top Arrows **(blue)**
Previous carbon buildup
Bottom Arrows **(green)**
Much less carbon buildup during TEM imaging

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Summary of Localized Plasma Cleaning Work

- A plasma can be generated at the end of a rod so that local cleaning can occur in the required area
  - Proven via C removal from TEM systems.
- These systems operate at lower power and still produce effective cleaning.
- These systems can be configurable for any geometry needed.
  - Solid rod can be replaced with flexible tether to place cleaning tool in most effective location.

Future Work

- Hydrogen Cleaning
  - XEI is expanding preliminary work using hydrogen plasma
  - Ru-capped ML coupons will also be tested to check for damage
- Particles
  - XEI is working with SEMATECH to build systems that introduce no particles during operation

Thank you

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Any Questions ?

The Evactron® De-Contaminator

Plasma Radical Source (PRS)

- EUV specific product available to address EUVL system requirements.
- Automated cleaning sequence makes device easy for customer to use and simple for OEMs to integrate into their systems.

Evactron® De-Contaminator

Plasma Radical Source (PRS) includes

- KF40 or CF275 fitting
- Valve assembly for metered flow of gas
- Pressure sensor
- RF impedance matching network
- Unique, patented RF electrode (not seen)

Controller includes

- Microprocessor control of PRS
- Compact 13.56 MHz RF generator
- 110-240 V, 50-60 Hz VAC
- External control with RS 232 serial connection – USB dongle available