Evaluating the SCOPE of Advanced Fuel Candidates from a Condenser Optic Perspective

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Motivation

Advanced fuels such as Li and Sn will condense on the collector optics. Can they be cleaned off in situ? Perhaps even during operation? SCOPE was designed to test this surface cleaning by plasma exposure concept. Initial results of both ion bombardment and plasma etching are presented here.

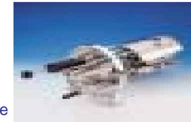
Surface Cleaning of Optics by Plasma Exposure: SCOPE Device

- **Multifunctional tool:**
  - Li+ capable Ion Gun
  - Versatile E-Beam Evaporator
  - Helicon Plasma Source

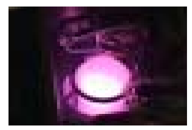
- Manufactured by Nonsequitur Technologies
- High current density 15 to 50 mA/cm² depending on spot size selected, total beam current of 250 nA
- Stable emission.
- Working distance to sample of 25 mm.
- No differential pumping required.
- Integral beam current Faraday cup measurement system

E-Beam Evaporator

- Manufactured by MDC Vacuum
- Rated for 3000 Watts of deposition power
- Li source with Mo liner, capable of using other source material.
- Pneumatic Shutter System
- Cooling roof that acts as a collimator and shield from unwanted deposition
- Integrated with Lab View



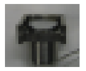
Helicon Plasma Source



- Manufactured by PMT
- MORI 200 Helicon Antenna
- Quartz Bell Jar surrounded by a Helicon antenna
- Radiates 13.56 MHz with a max power for 3000W
- External electromagnets provide necessary fields for higher RF power

Sample Heater

- Manufactured by Inficon
- Dual Sensor Head
- Water cooled
- Electrically Isolated from the Chamber so that it can be biased.
- Inline with a Deionizer for the cooling water.
- XTC/2 Deposition controller

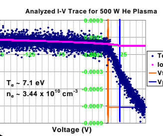


SCOPE Diagnostic Tools

Quartz Crystal Microbalance

- Manufactured by Inficon.
- Dual Sensor Head.
- Water cooled for signal stability.
- Used as a deposition monitor during evaporation, plasma cleaning, and sputtering measurements.
- Electrically Isolated from the Chamber so that it can be biased and an energy distribution of sputtered particles obtained.
- XTC/2 Deposition controller.

Langmuir Probe Analysis of Plasma



- RF compensated to allow for more accurate T_e and n_e measurement.
- Integrated sweeping voltage.
- Digital data capture and analysis.

SCOPE Plasma Cleaning

He Plasma Beam

- Earlier experiments showed that evaporative lithium flux mixed with residual oxygen and water contamination will lead to degradation of the optical element.
- Heating and forced evaporation are driving lithium diffusion into the mirror leading to reflectivity loss.
- While earlier experiments did not show evidence lithium with XPS, SEM image shows onset of surface degradation.

Encouraging results

- First testing at 100V substrate bias and exposure for 3 minutes shows removal of lithium surface contamination.
- Partial restoration of surface roughness to 0.72nm RMS.
- Some lithium presence still remaining.
- Quick estimation of surface balance:
  - Sputter yield for 100eV He on Li = 0.07
  - Measured ion flux diffuse plasma (no B-field) approximately 0.1 mA/cm²
  - Removal rate is approximately one atomic layer (about 3 A) every 10 seconds
  - Exposure time = 150 sec
- Removed most of the deposited lithium

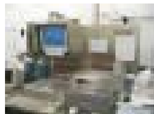


Figure 1. PlasmaTherm SLR-770 ICP RIE

PlasmaTherm SLR-770 Inductively Coupled Plasma Reactive Ion Etcher (ICP RIE), which was used for this study was shown in Fig. 1. The source power was chosen at 500W and bias power was varied between 10W and 100W. The maximum gas flow rate of the etcher was 24 sccm.

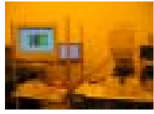


Figure 2. Wyko NT 1000 optical 3D profiler

The samples were masked by another thin wafer and etched for a short time period. The etched depth was measured by optical profiler (Wyko NT1000 optical 3D profiler manual metrology system by Veeco Inc.) Wyko NT1000 using non-contact interferometry was shown in Fig. 2. For the samples which are too thick and opaque, a physical contact profiler (Deepak Surface Profiler) was used alternatively.

For the experiments, CHF_3 and Cl_2 were used for plasma etching with Ar buffer gas. Sn, SiO_2, Mo, Si, Si_3N_4 were tested with several recipes. SiO_2 was identified as a likely etch stop material for mirror capping layers. However, it was shown that SiO_2 etch rate with CHF_3 was very high compared with Cl_2 in Table.1.

[illegible]	[illegible]	[illegible]	[illegible]	Rate of Etching				
Pressure	[illegible]	Power	[illegible]	Sn	SiO_2	Mo	Si	Si_3N_4
[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table.1. The etch rate of materials with Cl2 and CHF3. Rate of etching was evaluate in [nm/min]

Temperature effect?

With high substrate temperature, the etch rate dropped down. For an instance, under the condition of 10mTorr pressure, 10 sccm Ar flow rate, 500W power, 120V bias with 20 sccm Cl2 gas, the etch rate of Mo at 50 °C decreased as a factor of 5 compared to room temperature. High temperature would prohibit gas from staying on the sample to react each other.

Varying a bias?

The materials' etch rate varied according to bias voltage as shown in Fig.3. As a bias decreases, the etch rate was also reduced. At low bias Sn's etch rate was still high whereas SiO2's etch rate had reduced too small to be measured. Y axis of the figure is the 'estimated etch rate'. For some samples, of which thickness was so small and etch rate was high such as a Sn, the etching for a reasonable duration was impossible. Thus, for a low bias, thick samples and physical profiler were used. The following figures shows the selected reliable depth profiles from the optical profiler.

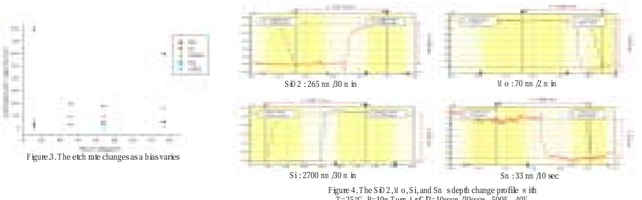


Figure 3. The etch rate changes as a bias varies

Figure 4. The SiO2, Mo, Si, and Sn s depth change profile with T=25°C, P=10m Torr, Ar/Cl2=10sccm/20sccm, 500W, 40V

Preliminary etch rate of Sn and SiO_2 with Cl_2

The etch rate at low bias was evaluated for Cl_2 on Sn and SiO_2. For a reliable value, thick samples were etched for a long period. For different bias voltages, 4V, 40V, 80V and 120V, the etch rate results were shown in the Fig.5.
Very noticeable at around 0V, the etch rate of SiO_2 was imperceptible whereas Sn etched significantly with Cl_2.

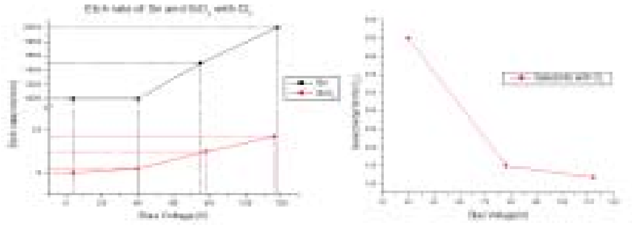


Figure 5. The etch rate of Sn and SiO2 with Cl2 for 4V, 40V, 80V and 120V

Figure 6. The selectivity comparison with Cl2

The selectivity between Sn and SiO_2, that is the ratio of etch rate of Sn and SiO_2, are shown in Fig. 6. for 40V, 80V and 120V. At very low voltage close to 0V, the selectivity could not be plotted because SiO_2 didn't etch at all even for 20min. The selectivity at 0V was much higher than at 40V.

Acknowledgement

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