Erosion/redeposition experiments on DIII-D and EAST

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**DIII-D** - DiMES Mo Erosion experiments

**EAST** - MAPES material migration experiment for ITER
- Fixed tile marker experiment

Sandia is a multi-program laboratory operated by Lockheed Martin Company, for the United States Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.
DiMES Mo Erosion experiments in DIII-D

**Objective**
- Local redeposition is expected to reduce net erosion.
- Measure both net and gross erosion of Mo at the OSP in DIII-D.
- This experiment provides a comparison of
  a) net vs. gross erosion and
  b) erosion vs. local redeposition.
- Net erosion is measured from the change in thickness of a thin Mo film determined by RBS.
- Gross erosion was determined from Mo I emission intensity, (not discussed here) N. Brooks et. al.
- Compared to simulations, J. Brooks et. al.

**Experimental Method**
- A thin Mo film 1 cm in diameter on silicon substrate was exposed to L-mode, low density, LSN, deuterium plasma in DIII-D.
- OSP was on DiMES from 1-5 sec, off during ramp up & down.
- Plasma conditions at OSP measured by Langmuir probes
  Te ≈ 30eV, Jsat ≈ 0.25A/cm² → ion flux ≈ 1.5x10^{18}/cm²s.
- Net Mo erosion & deposition measured by RBS (2MeV \(^4\)He),
  detection limit for Mo erosion \~ 10^{15} \text{ atoms/cm}² (1 monolayer).
- Deposition of D & C also measured by \(^3\)He NRA.

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*20th International Conference on Plasma-Surface Interactions*  
*Aachen, Germany, May 21-25, 2012*
Mo Erosion

8/1/2011 7 shots 28 sec

Mo film thickness before exposure to plasma

erosion

after exposure to plasma

2 MeV $^4$He RBS

Mo thickness \((10^{16} \text{ atoms/cm}^2)\)

Distance from center (mm)

Averaged spectra

Molybdenum

Silicon
Mo Erosion

Erosion is consistent with sputtering by ~ 1% C^{3+}
Mo deposition on graphite
(8/1/2011 experiment)

- Preferential Mo deposition downstream from source.
- Total amount of Mo on DiMES probe = $1.1 \pm 0.1 \times 10^{16}$ atoms.
- $19 \pm 2\%$ of eroded Mo still on DiMES cap indicates rapid re-erosion & transport of Mo from C.
- Surface is C+D+Mo mixed material, which influences erosion & redeposition.

E-folding length $\sim 2$ mm consistent with short MFP for ionization of sputtered Mo.
Deuterium and carbon deposition

- Co-deposit in PFZ ~ 1 µm thick with D/C=0.7 where Te < 10eV.
- D coverage elsewhere consistent with implantation into C undergoing net erosion.
- D coverage is lower on Mo than on C because it diffuses out as interstitial solute.
Direct measurement of gross and net erosion by IBA

- Experiment on 5/1/2012 included 10 mm and 1 mm diameter spots of Mo on Si disk.
- Si covered by 300 nm carbon film.
- Expect little local redeposition of Mo on 1 mm spot, i.e. measures gross erosion (J. Brooks REDEP)

Measured erosion: (from 1 shot):
Mo (1 cm) 1.9e16 atoms/cm²
Mo (1mm) 3.4e16 atoms/cm²
Carbon 33e16 atoms/cm²

Net/gross = 0.55
C erosion ~ 10 x Mo erosion

Similar exposures have been done for W & Al but post-exposure IBA is not yet available.
EAST/MAPES material migration experiment
(R. Pitts ITER)

Concern about steady state erosion/re-deposition in ITER

- On First Wall panels of blanket modules near top of the machine (secondary X-point region)
- Eroded material may redeposit locally along with tritium
- Codeposited tritium will be harder to remove than in the divertor (lower temperature and not designed for easy replacement)
- Conduct a controlled benchmark experiment for LIM-DIVIMP and ERO simulations being used for ITER on realistic FW panel shapes.
- Toroidally shaped tiles (like ITER FW)
- Instrumented for local plasma parameters
- Dedicated shot sequences with retractable probe (MAPES)
- Measure erosion of carbon film (as proxy for Be) on Mo tiles with He plasma to reduce chemical erosion.

Modelling of beryllium erosion–redeposition on ITER first wall panels
ITER first wall shaping

ITER FW panels shaped to protect leading edges and misalignments

Creates shadowed regions where impurity re-deposition can occur
EAST/MAPES material migration experiment

- Proxy for ITER first wall panel toroidal profile
- Will use Mo substrate tiles fabricated at ASIPP
- Carbon coating deposited at Sandia
- Plasma exposures on retractable MAPES in EAST
- Erosion & deposition determined by IBA at Sandia

Langmuir probes

20x30 cm
12 tiles
Blank test on uncoated tiles now underway in EAST to determine exposure conditions

- **Reciprocating probe**
- **Migration Tiles**

**CCD image**

- $R_{tr} = 2.335$ m
- $R_{tr} = 2.310$ m
- $R_{tr} = 2.300$ m

<table>
<thead>
<tr>
<th>Shot</th>
<th>$R_{tr}$ (main radius _ tile ridge )</th>
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<tbody>
<tr>
<td>41727</td>
<td>2.335 m</td>
</tr>
<tr>
<td>41728</td>
<td>2.310 m</td>
</tr>
<tr>
<td>41731</td>
<td>2.300 m</td>
</tr>
</tbody>
</table>

He-Plasma, Ohmic discharge, Double Null
$I_p \sim 300$ kA,
$IT \sim 8000$ A,
$R_{limiter} \sim 2.335$m
Mo tiles Carbon-coated & pre-exposure IBA at Sandia

- Carbon film deposited in Sandia magnetron sputter deposition system.
- Thin Ti interface layer for adhesion.
- C thickness measured by IBA (red dots) (1.5 MeV proton backscattering)
- Tiles now at ASIPP for exposure to plasma
- Post-exposure IBA will determine net erosion & deposition from change in C thickness.

Carbon thickness:
$1.5 \times 10^{19}$ atoms/cm$^2$ or 3 g/m$^2$ from proton energy loss $\Delta E$. 
Tiles with W marker under 2.5 µm SiC overlayer were prepared at ASIPP & exposed in EAST to ~ 6400 plasmas (with 1020 grams of Li injection). Tile pieces were analyzed at Sandia by:

\(^4\)He & H RBS for erosion & deposition

\(^3\)He & H NRA for D & Li deposition
Fixed tile marker experiment in EAST

Main results:
Most of the SiC overlayer & W marker were eroded,
Heavy deposition of Li & D in some areas.