Effect of the Surface Temperature on Net Carbon Deposition and Deuterium Co-deposition in the DIII-D Divertor

Presented by
Dmitry Rudakov (UCSD)
for the DiMES Team
and Collaborators

Presented at the
47th APS-DPP Meeting
Denver, Colorado

October 24–28, 2005
An international multi-institutional team

W. Jacob, K. Krieger, M. Mayer, J. Roth *Max-Planck-Institut fuer Plasmaphysik*

A. Litnovsky, V. Philipps, P. Wienhold, G. Sergienko *Forschungszentrum Jülich*

J. Boedo, R. Doerner, E. Hollmann, R. Moyer *University of California, San Diego*

W. West, C. Wong, N. Brooks, T. Evans, R. LaHaye *General Atomics*

P. Stangeby, A. McLean, S. Lisgo *University of Toronto Institute for Aerospace Studies*

R. Bastasz, J. Whaley *Sandia National Laboratories, Livermore*

J. Watkins, W. Wampler *Sandia National Laboratories, Albuquerque*

S. Allen, M. Fenstermacher, M. Groth, C. Lasnier *Lawrence Livermore National Laboratory*

D. Whyte *University of Wisconsin, Madison*

J. Brooks *Argonne National Laboratory*

P. Oelhafenc *Institute of Physics, University of Basel, Switzerland*
Divertor Material Evaluation System - DiMES

- DiMES system is used to insert material samples in the lower divertor of DIII-D for erosion and deposition studies

- A newly developed *in situ* sample heating capability allows us to study the temperature dependence of erosion/deposition
Why study temperature dependence of erosion/deposition?
At high surface temperatures chemical erosion is increased.

- Chemical erosion rate of hydrocarbon films increases with surface temperature peaking at around 400°C.
- By heating the surface it may be possible to reduce/prevent deposition of hydrocarbon films.
- We have recently obtained experimental evidence of deposition rate reduction at elevated temperature in DIII-D divertor.
- Two separate experiments will be reviewed in this talk.

Motivation

- Tritium co-deposition/retention is one of the most critical issues for ITER
- High-priority ITPA topic
- One of the most troublesome carbon deposition regions for trapping tritium are the narrow tile gaps since such regions are not accessible to many of the proposed T-recovery methods
- In DIII-D co-deposition of deuterium (as a proxy for tritium) can be studied in a simulated tile gap using DiMES
- Altering the tile temperature may affect C deposition and D co-deposition rates

Originally proposed by Wolfgang Jacob
Max-Planck-Institut fuer Plasmaphysik, Germany
Concept features:

- radially oriented gap
- deposition on the silicon wafers
- defined geometry for modeling of the deposition profile

Built in heater and thermocouple for *in situ* temperature control
Two exposures at different temperatures were performed

- Lower Single Null Simple-As-Possible Plasma (SAPP) shape
- DiMES located near the detached Outer Strike Point (OSP)
- Two exposures were performed, first at ~ 30º C, second at 200º C
- Each exposure was to 9 highly reproducible high-density L mode shots for a total exposure time of about 32 seconds
Non-heated versus heated exposures: plasma-facing surface

Non-heated

- There were visible signs of plasma contact on the sample face upon removal, most likely deposits
- No net erosion/deposition measurements were available

Heated

- No visible signs of plasma contact on the sample face upon removal
- A graphite button with implanted Si marker was built in the sample face to measure net erosion/deposition on the plasma-facing surface
A high erosion rate was measured on the heated sample

- Ion Beam Analysis (IBA) at SNL Albuquerque has shown a total net erosion of about 90 nm on the depth marked button from heated exposure.

- This corresponds to a net erosion rate of ~3 nm/sec – rather high!

- We did not have erosion/deposition measurements on the non-heated sample, but it looked like there was some net deposition.

- No net erosion was observed in other experiments with detached divertor:
  - A depth-marked DiMES sample exposed later to 7 comparable high-density SAPP L-mode discharges (but with OSP sweeps) showed no measurable erosion.
  - Previous DiMES experiments in detached H-mode showed net deposition around OSP and in the PF zone [Whyte et al., Nucl. Fusion 41 (2001) 1243]

The observed erosion must be due to the elevated temperature.
Carbon deposition inside the gap was a factor of 2 - 4 lower in the heated exposure.

- C deposition inside the gap was ~ 2 - 4 times lower in the heated exposure.
- Some of the carbon in heated exposure may have been absorbed into the wafers to form silicon carbide.

IBA data courtesy of K. Krieger, Ellipsometry courtesy of W. Jacob.
D co-deposition inside the gap was an order of magnitude lower in the heated exposure

Potentially a good news for ITER:
   it may be possible to control WHERE the T co-deposition would occur

IBA data courtesy of K. Krieger
Motivation

- Optical mirrors are foreseen in ITER for many diagnostics, and will be used in infrared, visible and ultraviolet wavelength ranges
- High-priority ITPA topic
- Mirrors in the ITER divertor will likely suffer from deposition, and dedicated experiments in tokamak divertors are urgently needed
- Using DiMES, we had a chance to perform first ever tests of ITER-relevant mirrors in a tokamak divertor under well-diagnosed plasma conditions
Mirror DiMES experimental concept and design

Molybdenum Mirrors

Protective lap

Thermocouple

45°

Heater

Stainless steel holder

Mirrors supplied by A. Litnovsky of Forschungszentrum Jülich
Mirror DiMES exposure geometry

- Lower Single Null SAPP-like shape
- DiMES located at the Private Flux Region
- Piggyback on C13 injection experiment: highly reproducible partially-detached (PDD) ELMing H-mode discharges
Two exposures at different temperatures

• First set of mirrors was exposed at about $30^\circ$ C to 6 discharges for a total of $\sim 25$ sec

• Visible deposits were found on both mirrors and holder elements upon removal

• The second mirror set was exposed to 17 discharges for a total of $\sim 70$ sec at elevated temperature changing from $140^\circ$ C to $80^\circ$ C (planned exposure at $400^\circ$ C but heater failed)

• Upon removal, virtually no deposits were visible on the mirrors

• Some of the deposits formed on the mirror holder elements in the previous exposures were gone
Deposition is suppressed at elevated temperature.

Non-heated mirrors

Upstream

Downstream

Heated mirrors

$140^\circ\text{C} \rightarrow 85^\circ\text{C}$.

Secondary Ion Mass Spectrometry (SIMS) measurements locations

 Courtesy of A. Litnovsky
SIMS shows significant C deposition on the cold mirror and virtually no deposits on the heated mirror.

![Graph showing deposition rate](image)

- **2 keV Cs⁺ beam**
- **~93 nm* (estimation from spectral ellipsometry)**
- **Cold mirror**
- **Heated mirror**
- **Intensity, a. u.**
- **Sputter time, s (measure of film thickness)**

Deposition rate of ~ 4 nm/sec at room temperature.

Potentially a very good news for ITER: it may be possible to avoid deposition by moderate heating of diagnostic mirrors.

*Courtesy of A. Litnovsky*
Summary of results

- At 200º C we observed net carbon erosion at a rate of ~ 3 nm/sec from a plasma-facing surface under detached conditions, where normally net deposition is observed.

- At 200º C carbon deposition down a simulated tile gap was reduced by about a factor of 2 - 4 and D co-deposition by an order of magnitude compared to those at room temperature.

- Carbon deposition was observed on molybdenum mirrors recessed below the divertor floor at room temperature and was fully suppressed at elevated temperature between 140 and 80º C.

More experiments are needed!
Our results are in agreement with AUG divertor data\textsuperscript{1} and lab tests\textsuperscript{2}.

Heatable collectors in AUG divertor

Data used:

Courtesy of A. Litnovsky