(MPT/1-2Ra) Overview on Decade Development of Plasma-Facing Components at ASIPP

and

(MPT/1-2Rb) Advances in Understanding of High-Z Materials Erosion & Re-deposition in Low-Z Wall Environment in DIII-D

G.-N Luo¹, R. Ding²

¹Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP)  
²Oak Ridge Associated Universities (ORAU)

26th IAEA Fusion Energy Conference, Kyoto, Japan, October 17–22, 2016
Overview on Decade Development of Plasma-Facing Components at ASIPP

(MPT/1-2Ra) by

G.-N. Luo¹,

with G. H. Liu², Q. Li¹, S. G. Qin², W. J. Wang¹, Y. L. Shi², C. Y. Xie¹, Z. M. Chen³, M. Missirlian⁴, D. Guilhem⁴, M. Richou⁴, T. Hirai⁵, F. Escourbiac⁵, D. M. Yao¹, J. L. Chen¹, T. J. Wang², J. Bucalossi⁴, M. Merola⁵, J. G. Li¹, EAST Team

¹Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), Hefei, China
²Advanced Technology & Materials Co. Ltd. (AT&M), Beijing, China
³Xi’an Jiaotong University (XJTU), Xi’an, Shanxi, China
⁴French Atomic Energy Commission (CEA), Saint-Paul-lez-Durance, France
⁵ITER Organization, Route de Vinon sur Verdon, 13067 Saint Paul lez Durance, France
PFM/C evolution in EAST

2008
Full C PFC

2012
Mo-FW + C-Div

2006
Full SS

1st plasma

2018~2019 / Full W PFC

W&C-Div+Mo-FW

2014
Mo

W

C

C

C

C

Mo
- ITER-like W monoblocks
  - divertor targets (10 MW/m²)
- Flat type W/Cu PFCs
  - divertor dome and baffles (5 MW/m²)

W/Cu upper divertor design
Flowchart of manufacturing

HIP technology is widely used in the bonding of W/Cu and Cu/CuCrZr.
ITER-like monoblock W/Cu PFC

- W/Cu monoblocks are prepared employing HIP (900 °C, 100 MPa).
- W/Cu PFUs are manufactured successfully by HIP (600 °C, 100 MPa). Properties of CuCrZr after HIP satisfy the requirement.
- US-NDT results: Bondings between monoblocks/OFC/CuCrZr are excellent.
Casting + HIP: The interface of W/Cu were joined by casting. (1200°C), and then the interface of Cu/CuCrZr was bonded by HIP at lower temperature of 500~600°C.

NDT results: bondings between W tiles/OFC/CuCrZr plate are excellent.
US-NDT for W/Cu PFCs

- Single probe: scanning the inner surface.
- The defects of $\Phi1 \text{ mm}$ in the interface of W/Cu and Cu/CuCuZr was detected clearly using this set-up.
- 15000 W/Cu mono-blocks and 720 PFUs tested.

- More than 30000 W/Cu slices and 240 flat PFUs have been tested by this set-up with detection limit of $\Phi1 \text{ mm}$. 
High heat flux test of W/Cu PFCs

In cooperation with

### Flat type mock-ups

- **FT-1** withstood 102 cycles at 10 MW/m$^2$, 102 cycles at 15 MW/m$^2$, 302 cycles at 20 MW/m$^2$.
- **FT-2** withstood 302 cycles at 10 MW/m$^2$, 102 cycles at 15 MW/m$^2$, 102 cycles at 20 MW/m$^2$.

### Monoblock mock-ups

- 6 small scale monoblock mock-ups were tested on IDTF (ITER Divertor Test Facility).
- All the mock-ups withstood 5000 cycles at 10 MW/m$^2$ and 1000 cycles at 20 MW/m$^2$ in accordance with the qualification program.
**Grand view of the W/Cu divertor for EAST**

- HIP + e-welding + NDTs
- Technology R&D!

**PFCs+CB assembly:** 80
- **IVT/OVT/DOME:** 80 each
- **Monoblock PFUs:** 720
- **Monoblock W:** 15,000
- **Flat-type PFUs:** 240
- **Flat W tiles:** 24,000
- **E-beam seam:** > 4000
- **W raw powders:** > 10 tons
- **CuCrZr plates:** > 8 tons
- **CuCrZr tubes:** 720 pcs/360m

**W/Cu PFCs for EAST upper divertor**
Improving NDT for welding seam of tube-plate joints inspection

Optimizing cooling tube connection using bellows

Performing baking and high pressure helium leak check on whole assembled div. modules

In 2014 EAST campaign, first commissioning of the upper W/Cu divertor failed.

In the 2015 and 2016 spring campaigns, the W/Cu upper divertor withstood more severe irradiation by EAST plasma and no similar leaks occurred.

Performance of W/Cu divertor during campaigns
The W/Cu upper divertor for EAST was finished in the spring of 2014. HIP technology was used in the bonding of W/Cu and Cu/CuCrZr. NDT quality control system has been established for quality control;

In collaboration with IO and CEA teams, we have demonstrated capability to resist 5000 cycles at 10 MW/m\(^2\) plus 1000 cycles at 20 MW/m\(^2\) for small scale monoblock mockups, and surprisingly over 300 cycles at 20 MW/m\(^2\) for the flat-type ones.

Commissioning of the EAST W/Cu divertor in 2014 was unsatisfactory and then several practical measures were implemented, which has improved welding quality and general reliability significantly.

The experience and lessons learned from batch production and commissioning are valuable for ITER engineering validation and tungsten-related plasma physics.

**Disclaimer:** The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.
Advances in Understanding of High-Z Material Erosion and Re-deposition in Low-Z Wall Environment in DIII-D (MPT/1-2Rb) by

R. Ding\textsuperscript{1},

with D.L. Rudakov\textsuperscript{2}, P.C. Stangeby\textsuperscript{3}, W.R. Wampler\textsuperscript{4}, T. Abrams\textsuperscript{1}, S. Brezinsek\textsuperscript{5}, A. Briesemeister\textsuperscript{6}, I. Bykov\textsuperscript{2}, V.S. Chan\textsuperscript{7}, C.P. Chrobak\textsuperscript{7}, J.D. Elder\textsuperscript{3}, H.Y. Guo\textsuperscript{7}, J. Guterl\textsuperscript{1}, A. Kirschner\textsuperscript{5}, C.J. Lasnier\textsuperscript{8}, A.W. Leonard\textsuperscript{7}, M.A. Makowski\textsuperscript{8}, A. G. McLean\textsuperscript{8}, P.B. Snyder\textsuperscript{7}, D.M. Thomas\textsuperscript{7}, D. Tskhakaya\textsuperscript{9}, E.A. Unterberg\textsuperscript{6}, H.Q. Wang\textsuperscript{1} and J.G. Watkins\textsuperscript{4}

\textsuperscript{1}Oak Ridge Associated Universities
\textsuperscript{2}University of California San Diego
\textsuperscript{3}University of Toronto, Institute for Aerospace Studies
\textsuperscript{4}Sandia National Laboratory
\textsuperscript{5}Forschungszentrum Jülich
\textsuperscript{6}Oak Ridge National Laboratory
\textsuperscript{7}General Atomics
\textsuperscript{8}Lawrence Livermore National Laboratory
\textsuperscript{9}University of Innsbruck

Presented at the

26\textsuperscript{th} IAEA Fusion Energy Conference

Kyoto, Japan

October 17–22, 2016

Work supported in part by the US DOE under DE-AC05-06OR23100, DE-FG02-07ER54917, DE-AC04-94AL85000, DE-AC05-00OR22725, DE-FC02-04ER54698, and DE-AC52007NA27344.
Pre-characterized Samples Exposed to Reproducible Well-diagnosed Plasma Discharges Using DiMES

- **Understanding of High-Z material erosion**
  - Sheath effect
  - Background impurities

- **DIII-D Experiments**
  - Thin Mo/W coating sample
  - Net erosion & redeposition measured via Rutherford backscattering (RBS)
  - 1 cm sample + 1 mm samples to measure net + gross erosion
  - Gross erosion measured also spectroscopically using S/XB coefficient

- **The 3D Monte Carlo code ERO**
  - Plasma-surface interaction
  - Local impurity transport
  - OEDGE background plasma as input: \( n_e, T_e, E_{\parallel}, v_{\parallel} \)
The High Redeposition Ratio from ERO Simulation Strongly Depends on Magnetic Pre-sheath Electric Field

- **Magnetic pre-sheath** dominates for small angle between B and surface
  - Strong E field
  - $n_e$ decay with potential drop

- **Larger gyroradius** due to strong E field enhances the prompt redeposition

- Decreasing the sheath potential drop can suppress both gross and net erosion Rate
  - The redeposition ratios are not reduced because the density is increased at the same time
  - The gross erosion rate is reduced for lower ion incident energy
Modifying Sheath Potential by External Biasing Changes Mo Gross Erosion Rate Significantly

- Central graphite with Mo coating biased
- Gross erosion measured by spectroscopy (Mo I 550 nm)
- Mo erosion suppressed with positive biasing (below RBS detection limit)
Higher C Concentration in Background Plasma Leads to Lower Net Erosion Rate

- Assuming 1.8% of C\textsuperscript{3+} concentration in plasma, ERO modeled net erosion rates agree well with the measured values.
- Net erosion profiles of both Mo and W are well reproduced by ERO modeling.
- W net erosion rate is much lower than Mo for its lower sputtering yield and higher redeposition ratio due to shorter ionization length.

\[
\begin{align*}
  n_e &= 1.5 \times 10^{19} \text{ m}^{-3} \\
  T_e &= 31 \text{ eV}
\end{align*}
\]
Local Methane Gas Injection can Turn the Surface into a Net Deposition Area

- $^{13}$CH$_4$ injected ~12 cm upstream from the center of the DiMES (1.8 Torr-1/s)
- The samples imaged by an absolutely calibrated camera (MoI, CH, CI, CII)
- A carbon coating created on the Mo sample protecting the Mo from erosion
- More $^{13}$C deposited in radial inboard direction is mainly due to the ExB drift
- Higher $D_\perp$ leads to broader profile and lower $^{13}$C deposition on DiMES
OEDGE/ERO Modeling Demonstrates that Inter-ELM W Erosion is Well Explained by C→W Sputtering

- High-resolution inter-ELM W erosion profiles were measured by monitoring WI 400.9 nm line intensity with OSP sweeping
- charge-state-resolved carbon ion flux in the background plasma is calculated using the OEDGE code
Section summary

• Improved understanding of erosion and redeposition of high-Z materials in a mixed materials environment in DIII-D was achieved

• Dedicated experiments coupled with ERO modeling highlight the roles of the sheath potential and background impurities in determining high-Z material erosion

• The high-Z materials erosion can be actively controlled with electrical biasing, as well as by local gas puffing

• The experimental results are well reproduced by the OEDGE/ERO simulations, allowing better predictions for ITER and future devices
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