Development of W/Cu Divertor Components for EAST

G. -N. Luo on behalf of the PFM Group

ASIPP, Hefei, Anhui 230031, China

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Progress and plan of EAST experiments

EAST PFMC project

VPS-W/Cu PFMC

Monoblock and Flat-type W/Cu-PFMC

Summary
### Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toroidal Field, $B_0$</td>
<td>3.5(4) T</td>
</tr>
<tr>
<td>Plasma Current, $I_p$</td>
<td>1(1.5) MA</td>
</tr>
<tr>
<td>Major Radius, $R_o$</td>
<td>1.7-1.9 m</td>
</tr>
<tr>
<td>Minor Radius, $a$</td>
<td>0.4-0.5 m</td>
</tr>
<tr>
<td>Aspect Ratio, $R/a$</td>
<td>4.25</td>
</tr>
<tr>
<td>Elongation, $\kappa_x$</td>
<td>$\leq 2$</td>
</tr>
<tr>
<td>Triangularity, $\delta_x$</td>
<td>$\leq 0.6$</td>
</tr>
</tbody>
</table>

### Heating and Current Driving:

- ICRH: 4 (8) MW
- LHCD: 6 (10) MW
- NBI: 4 (8) MW
- ECRH: 0 (2) MW

- Pulse length: 1000 s

Configuration: DN, SN
EAST Progress $\rightarrow$ 0.6MA/6.4s H-mode

**ASIPP**

**Power:** LHCD 2.45GHz, 1.3MW, ~14% transmission line loss; ICRF 20-70MHz, 1MW, effective coupling < 0.5 MW

**PFC:** Doped graphite tiles with a ~100 μm SiC coating bolted to Cu heat sink

**Wall conditioning:** Lithium evaporation and lithium powder injection

**Pumping:** In-vessel cryopump, pumping speed ~75.6 m$^3$/s for D$_2$
## 5-Year Plan of EAST experiments

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ip(MA)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>LHCD(MW,CW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.45GHz</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>4.6GHz</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICRF(MW,CW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-75MHz</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>30-100MHz</td>
<td>1.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>NBI(MW,80keV,10s)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>ECRH(MW,140GHz,CW)</td>
<td>2.0</td>
<td>4.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>40</td>
<td>45</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Duration(s)</td>
<td>100</td>
<td>200</td>
<td>300</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>t-Hmode(s)</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>60</td>
<td>100</td>
</tr>
</tbody>
</table>

With over 20MW CW power and 50 diagnostics, EAST could play a key role for long pulse advanced high performance plasmas for ITER within next 5 years!
Progress and plan of EAST experiments

EAST PFMC project

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Summary
PFMC plan for EAST

- **Initial phase (2006-2007)**
  PFM ⇒ SS plate bolted to the support without active cooling

- **First phase (2008-2010)**
  PFM ⇒ SiC/C tiles bolted to Cu heat sink cooled actively, max. heat flux capability <2MW/m²

- **Transition phase (2011-2012)**
  FW ⇒ TZM tiles bolted to Cu heat sink cooled actively
  DIV ⇒ Same as 1st phase

- **Second phase (2013-)**
  PFCs ⇒ Actively-cooled W/Cu-PFC, max. heat flux capability ~10MW/m²
Application of SiC coated graphite tiles

Significant improvements of the plasma performance observed and stable discharges over 100 seconds and H mode plasma achieved in EAST in 2010 campaign.
To provide robust ITER-like PFC configuration and structure to withstand rapid increase in particle and power impact onto plasma-facing surfaces in EAST

The EAST H-mode and attractive steady-state regimes may provide relevant plasma conditions for ITER PFC technology validation

Extended plasma exposure will provide access to ITER critical issues, such as PFC lifetime (melting, cracking, etc.), tokamak operation on damaged metal surfaces, real time heat flux control, fuel retention and dust production

The project could bring answers in a timely manner for ITER full W divertor for the nuclear phase
Details of the W/Cu project

- **Divertor**
  - ITER-like configuration and structure, i.e., Monoblock targets and flat type dome
  - Max. heat flux capability of divertor targets ~10MW/m²

- **First wall**
  - VPS-W coatings on actively cooled Cu heat sink or the flat type PFC
  - Max. heat flux capability ~2MW/m²
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Summary
R & D of VPS-W coatings on Cu
Via collaborations with Guangzhou Research Institute of Nonferrous Metals and Shanghai Institute of Ceramics, CAS

Process parameters listed below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (A)</td>
<td>600-800</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>65-75</td>
</tr>
<tr>
<td>Power (kW)</td>
<td>40-60</td>
</tr>
<tr>
<td>Pressure (Torr)</td>
<td>80-120</td>
</tr>
<tr>
<td>Ar for plasma torch (l/m)</td>
<td>40-60</td>
</tr>
<tr>
<td>H₂ for plasma torch (l/m)</td>
<td>5-7</td>
</tr>
<tr>
<td>Ar for powder feeding (l/m)</td>
<td>3-5</td>
</tr>
<tr>
<td>Distance from nozzle to sample (mm)</td>
<td>200-300</td>
</tr>
</tbody>
</table>
## VPS-W coatings (properties)

**Properties of VPS-W coatings**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (mm)</td>
<td>1~1.5</td>
</tr>
<tr>
<td>Bonding strength (MPa)</td>
<td>40</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>~2.8</td>
</tr>
<tr>
<td>Thermal conductivity (W/m/K)</td>
<td>122</td>
</tr>
<tr>
<td>Oxygen content (wt%)</td>
<td>0.1</td>
</tr>
</tbody>
</table>

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**W-coating limiter for HT-7**
Castellation design for W-coating/Cu PFC

• Castellation structure
  – To relieve the constraints to reduce thermal stress and prohibit the spreading of cracks in the tungsten coatings
  – To be made at the surface of the heat sink before preparation of the interlayer and pure W coatings
  – To spray large areas of tungsten coating in the surface of the heat sink with this castellation concept

• Main issues
  – Thermal stress concentration at the gap bottom and corner
  – Melting of W coatings at the leading edges of gaps
  – Gap shape and dimension optimization
The maximum of the residual stress is located in the area of copper side adjacent to the joint interface.

For shape-V design, there's a serious stress concentration in the bottom of the groove, which makes this area weak.

The design of U-shape groove can partly resolve this problem.
W-coating/Cu mock-ups testing

• Small scale mock-ups
  (40mm × 40mm × 28mm)
  – To evaluate the thermal fatigue resistance of the W/Cu PFC
  – Castellation structure
  – Interlayer structures

• Large scale mock-ups
  (80mm × 120mm × 28mm)
  – To demonstrate the thermal performance of the W/Cu PFC under EAST specific thermal load
  – To demonstrate the reliability of the large scale bonding technology
  – To calculate the heat removal efficiency
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Summary
Recently, efforts to achieve ITER-like Monoblock W/Cu PFC were made in collaboration with domestic companies and universities.

W/Cu monoblocks have been successfully prepared by means of HIP technology.

W/Cu bonding strength: 146Mpa
Spiral scanning ultrasonic NDT of W/Cu interface employed and excellent quality of the W/Cu interface achieved.
Batch Production Capability

ITER Divertor:

~ 100,000 CFC monoblocks (~ 28×20×18 mm);
~ 500,000 W monoblocks (~ 28×12×8 mm) and W flat tiles (~20×12×8 mm)

EAST:

~ 100,000 W monoblocks and W flat tiles, depending on late detailed design
Brazing welding of the monoblocks to the CuCrZr cooling tube and NDT testing are being developed, and HHF testing also underway.
Flat-type W/Cu PFMC

- Flat-type W/Cu PFC has also been being explored by means of brazing technology
- Good quality of the W/Cu interface also obtained
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Summary
## Simplified schedule

### Structure Design
- 2011: Structure Design
- 2012: Technology optimization of PFCs
- 2013: Mockup testing HHF & EAST
- 2014: Manufacturing & Assembly (lower divertor)
- 2015: First plasma campaign

### Manufacturing & Assembly
- 2011: Structure Design
- 2012: Technology optimization of PFCs
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### Key controlling factors
- Technology optimization
  - two types of W blocks welding to CuCrZr heat sink, and VPS-W coating PFCs
- Plasma optimization
  - plasma heating and control, H-mode (type I ELMs) and divertor physics

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2011-5-11  
PFMC-13/FEMas-1, Rosenheim, Germany, May 10-13

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Summary

• W/Cu divertor project for EAST is one of key factors to achieve the scientific missions towards steady-state high-performance plasmas, and may provide relevant plasma conditions for ITER PFC technology validation.

• The project aims at realizing ITER-like PFMC configuration and structure. Batch production of monoblocks has been achieved. Welding of monoblocks to cooling tube and flat type PFC (including W-coating PFC) are under R & D.

• 5 years to achieve a full W plasma facing surfaces in EAST, depending on both technology maturity and plasma control.
Thanks for your attention!