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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Outline

- **Progress and plan of EAST experiments**
- **EAST PFMC project**
- **VPS-W/Cu PFMC**
- **Monoblock and Flat-type W/Cu-PFMC**
- **Summary**

EAST: Chinese Mega-science Project

Steady-state high-performance plasma: physics and technologies

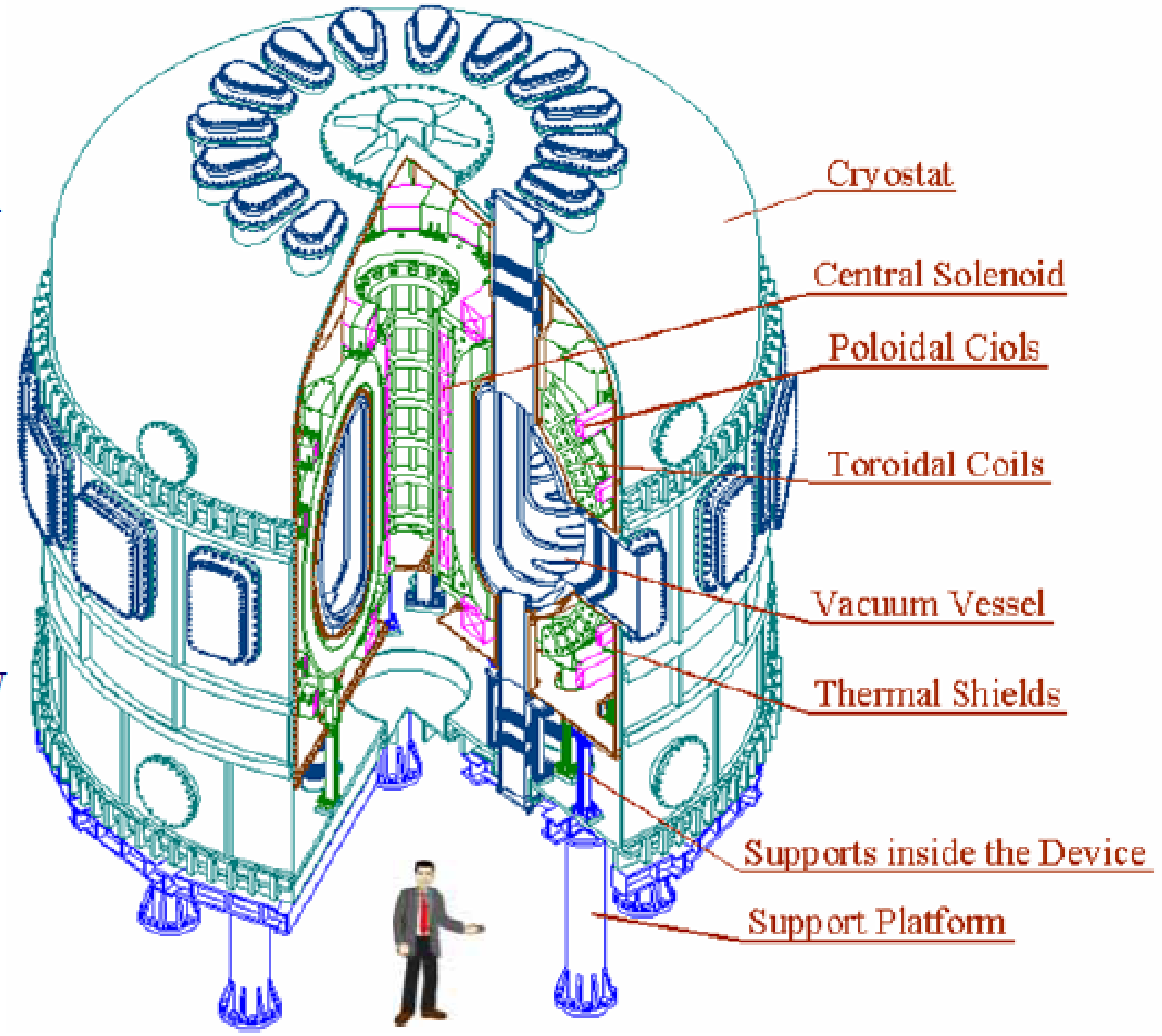
Main Parameters

Toroidal Field, B_o	3.5(4) T
Plasma Current, I_P	1(1.5) MA
Major Radius, R_o	1.7-1.9 m
Minor Radius, a	0.4-0.5 m
Aspect Ratio, R/a	4.25
Elongation, κ_x	≤ 2
Triangularity, δ_x	≤ 0.6

Heating andCurrent 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 → 0.6MA/6.4s H-mode

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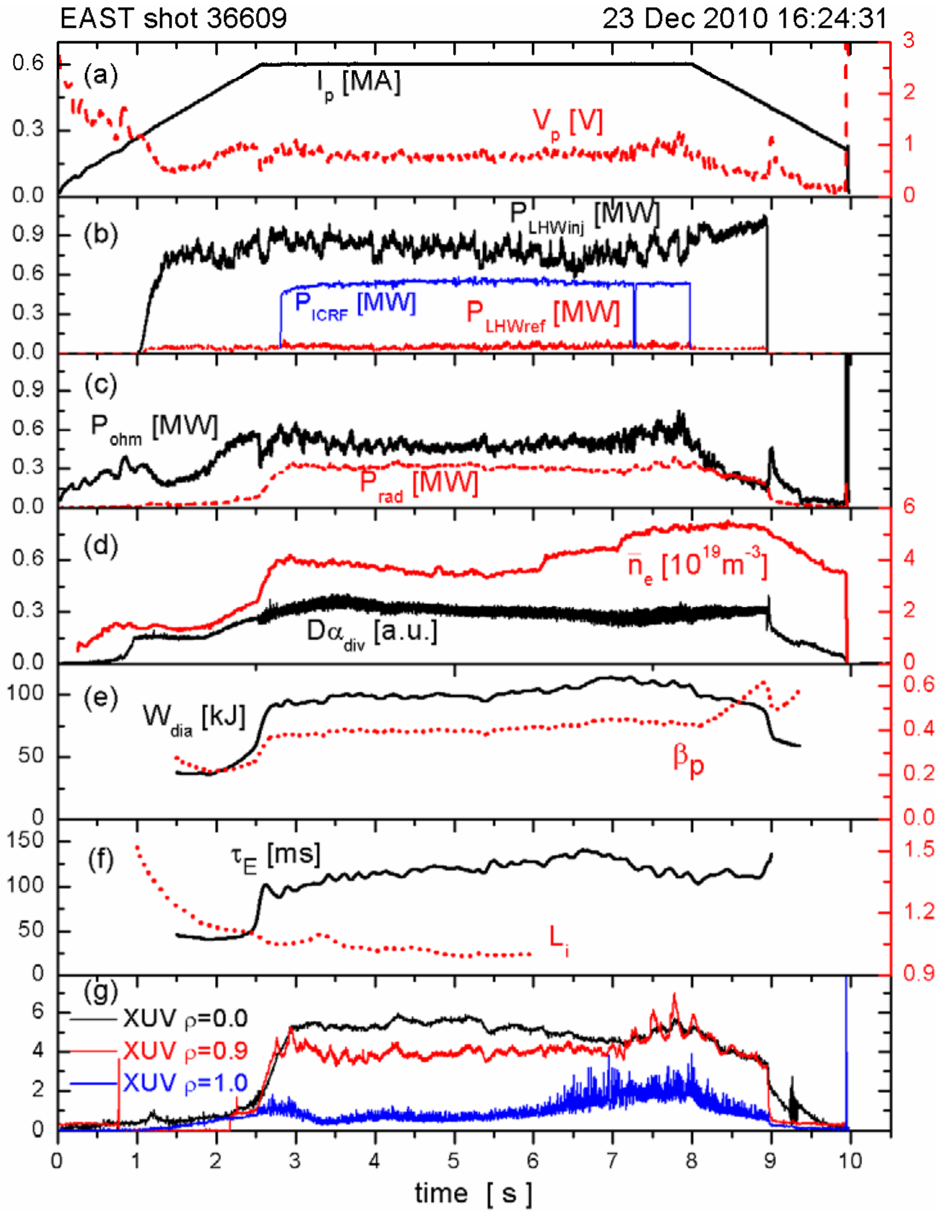

Power: **LHCD 2.45GHz, 1.3MW, ~14% transmission line loss; ICRF 20-70MHz, 1MW, effective coupling < 0.5 MW**

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

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

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!

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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/m^2

- **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/m^2

Application of SiC coated graphite tiles

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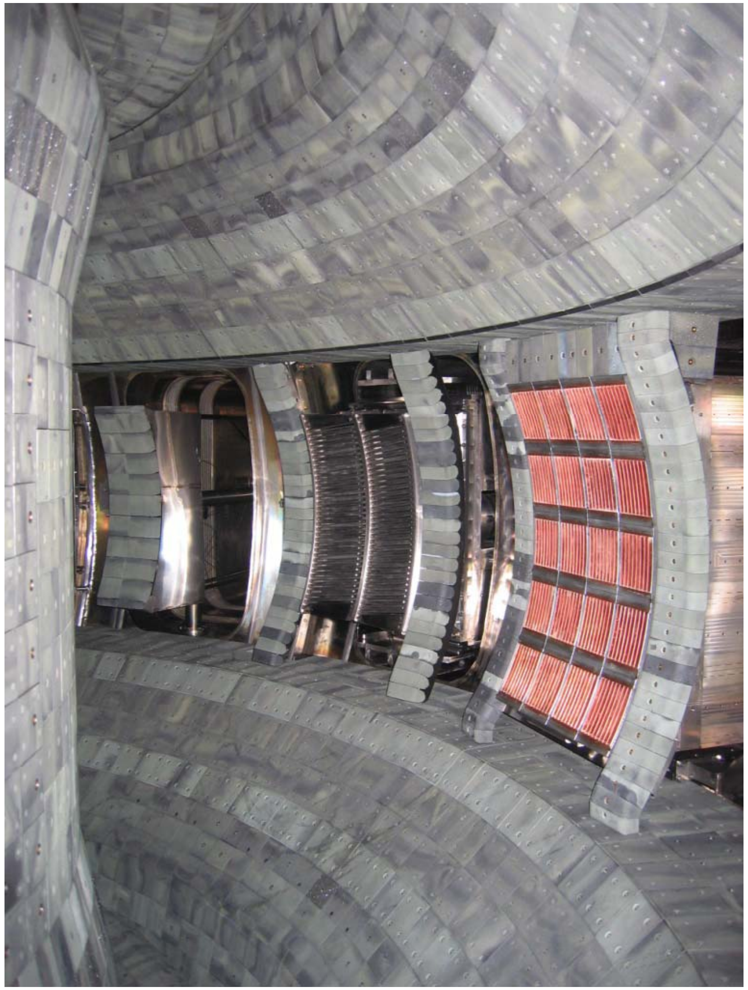
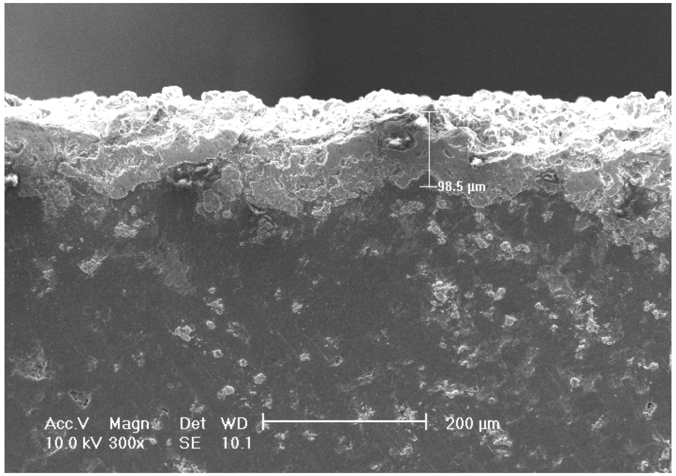
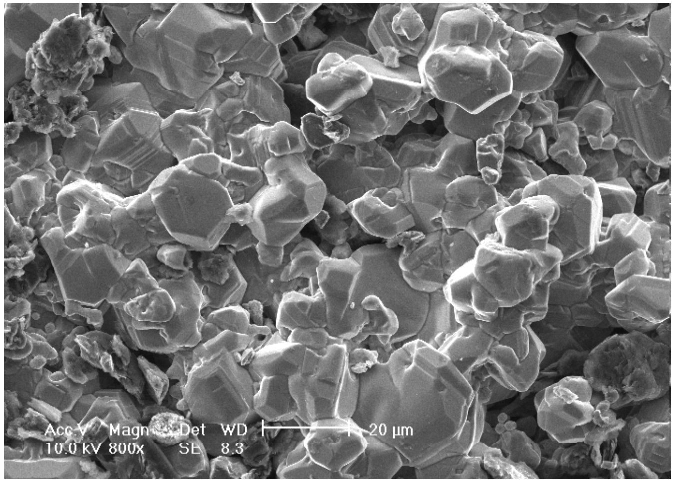
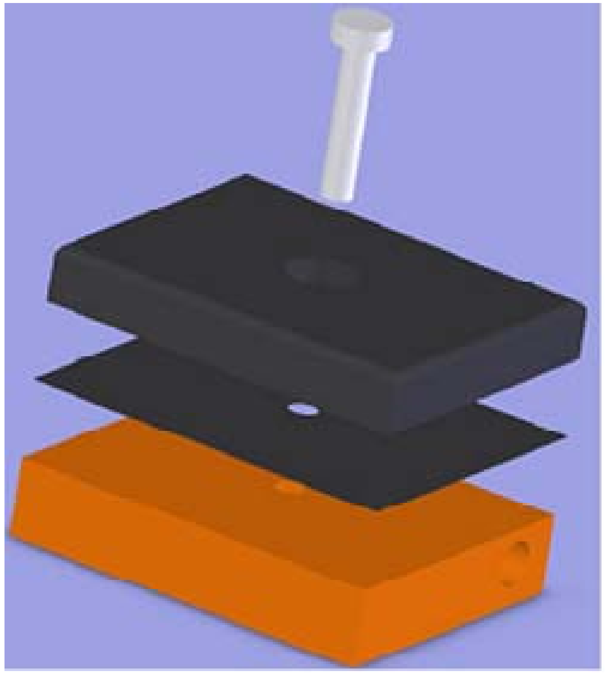
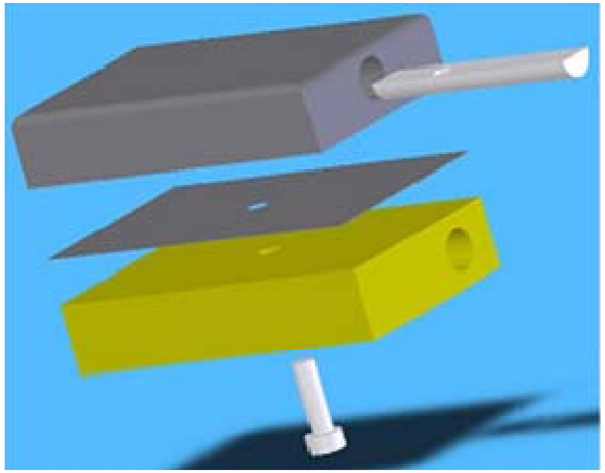










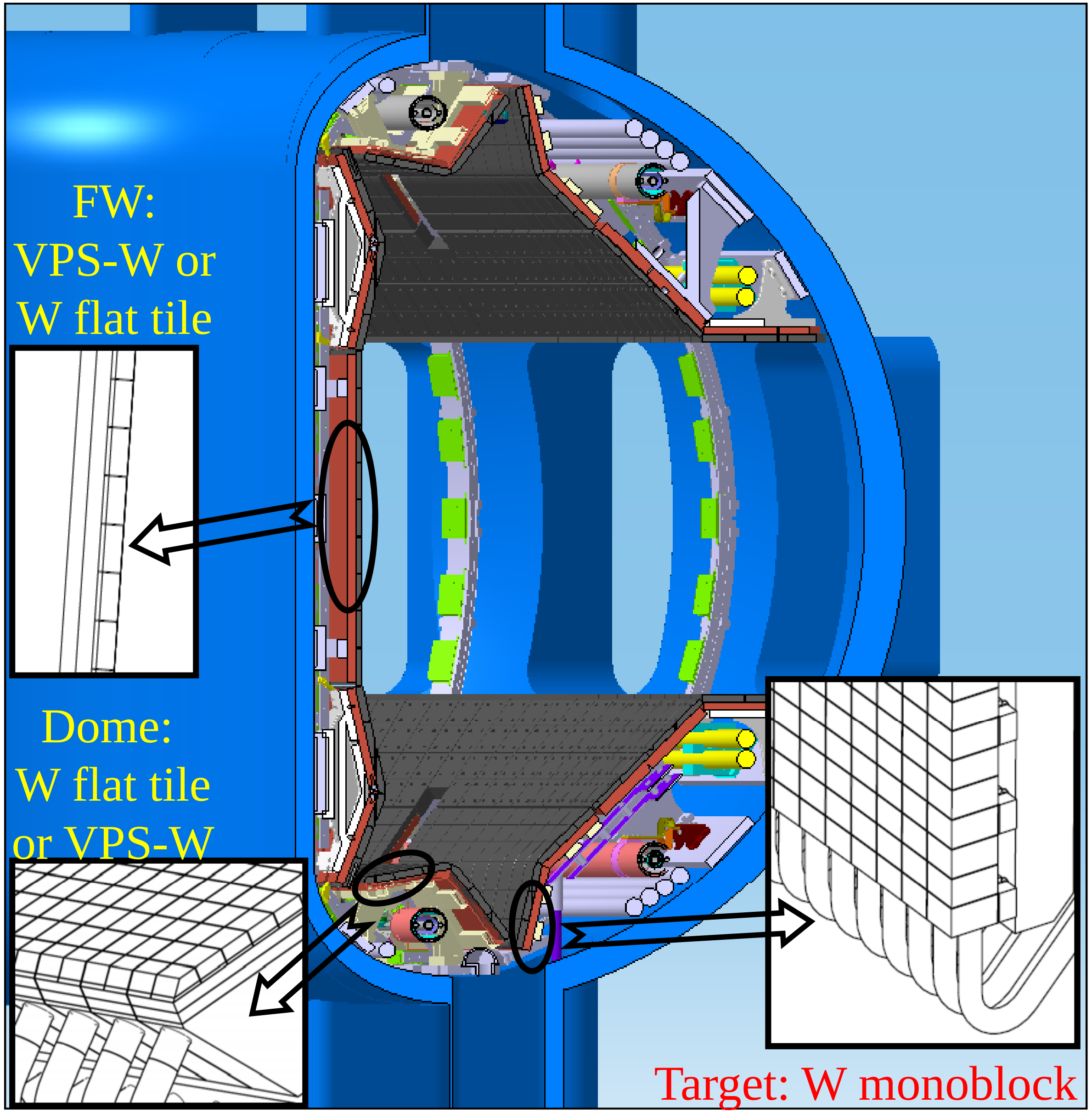
Significant improvements of the plasma performance observed and stable discharges over 100 seconds and H mode plasma achieved in EAST in 2010 campaign

EAST W/Cu-PFMC project

- 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 ~$10MW/m^2$
- **First wall**
  - VPS-W coatings on actively cooled Cu heat sink or the flat type PFC
  - Max. heat flux capability ~$2MW/m^2$



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VPS-W coatings (manufacturing)

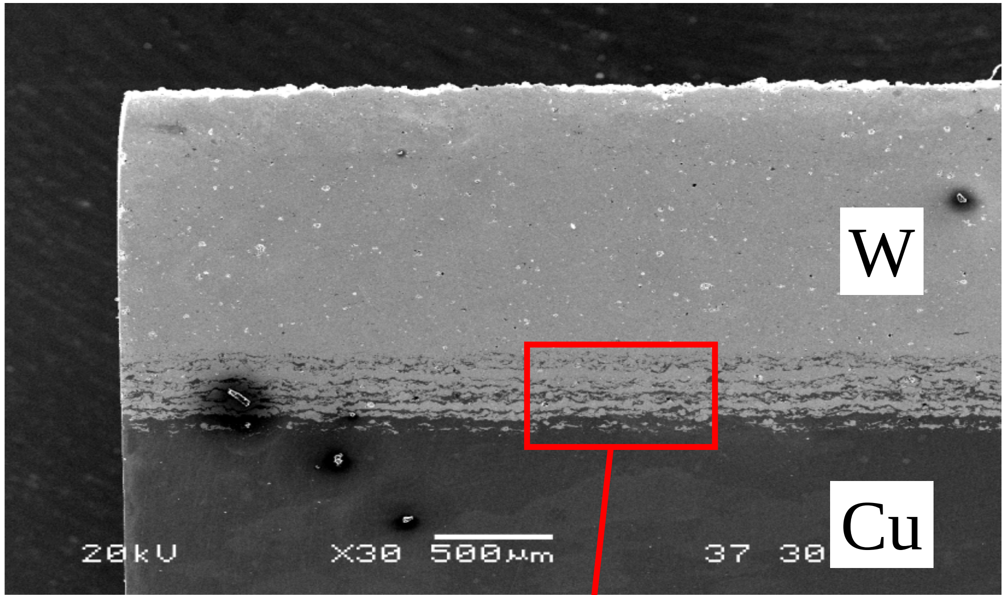
R & D of VPS-W coatings on Cu

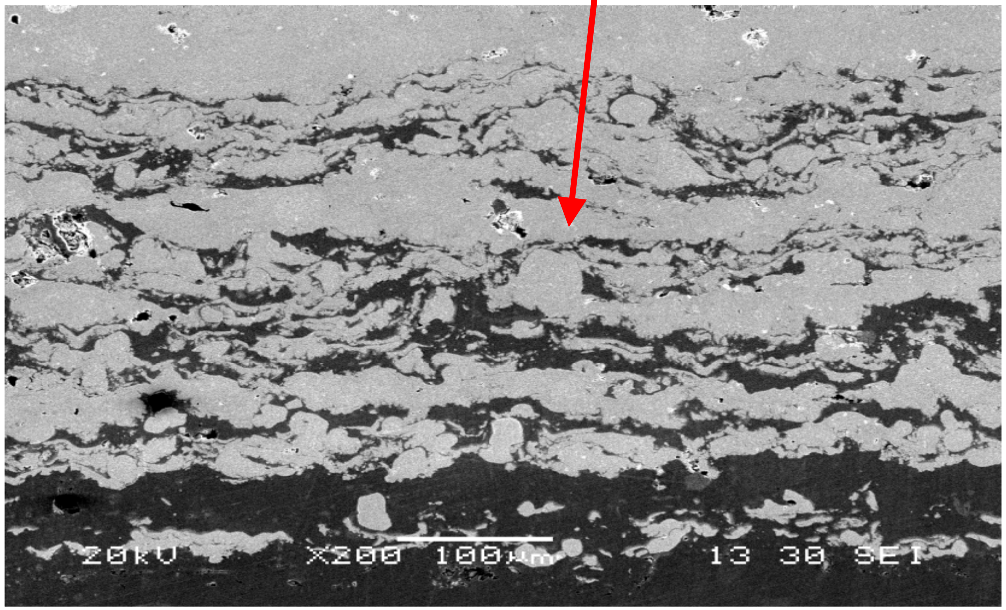
Via collaborations with Guangzhou Research Institute of Nonferrous Metals and Shanghai Institute of Ceramics, CAS

Process parameters listed below:

Current (A)	600-800
Voltage (V)	65-75
Power (kW)	40-60
Pressure (Torr)	80-120
Ar for plasma torch (l/m)	40-60
H_2 for plasma torch (l/m)	5-7
Ar for powder feeding (l/m)	3-5
Distance from nozzle to sample (mm)	200-300

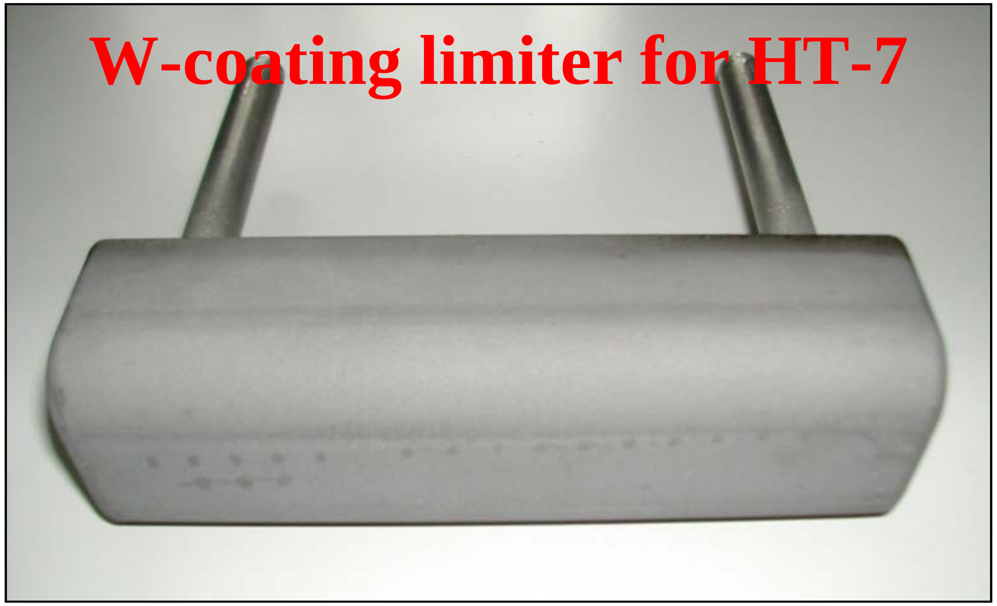
VPS-W coatings (properties)





Properties of VPS-W coatings

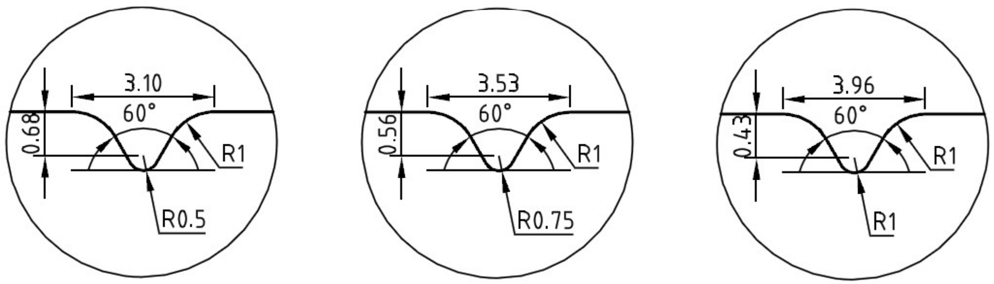
Thickness (mm)	1~1.5
Bonding strength (MPa)	40
Porosity (%)	~2.8
Thermal conductivity (W/m/K)	122
Oxygen content（wt%）	0.1

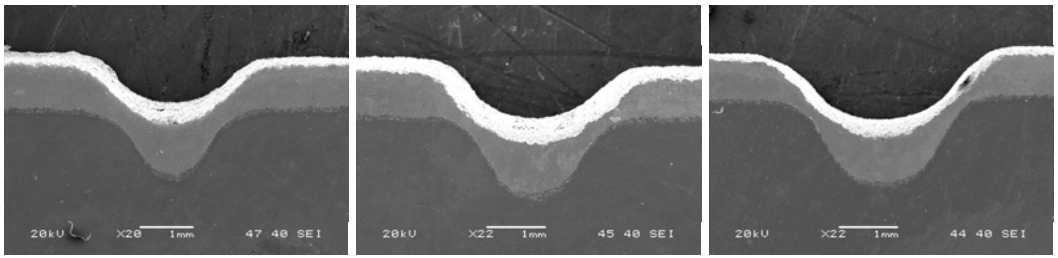


Castellation design for W-coating/Cu PFC

- **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

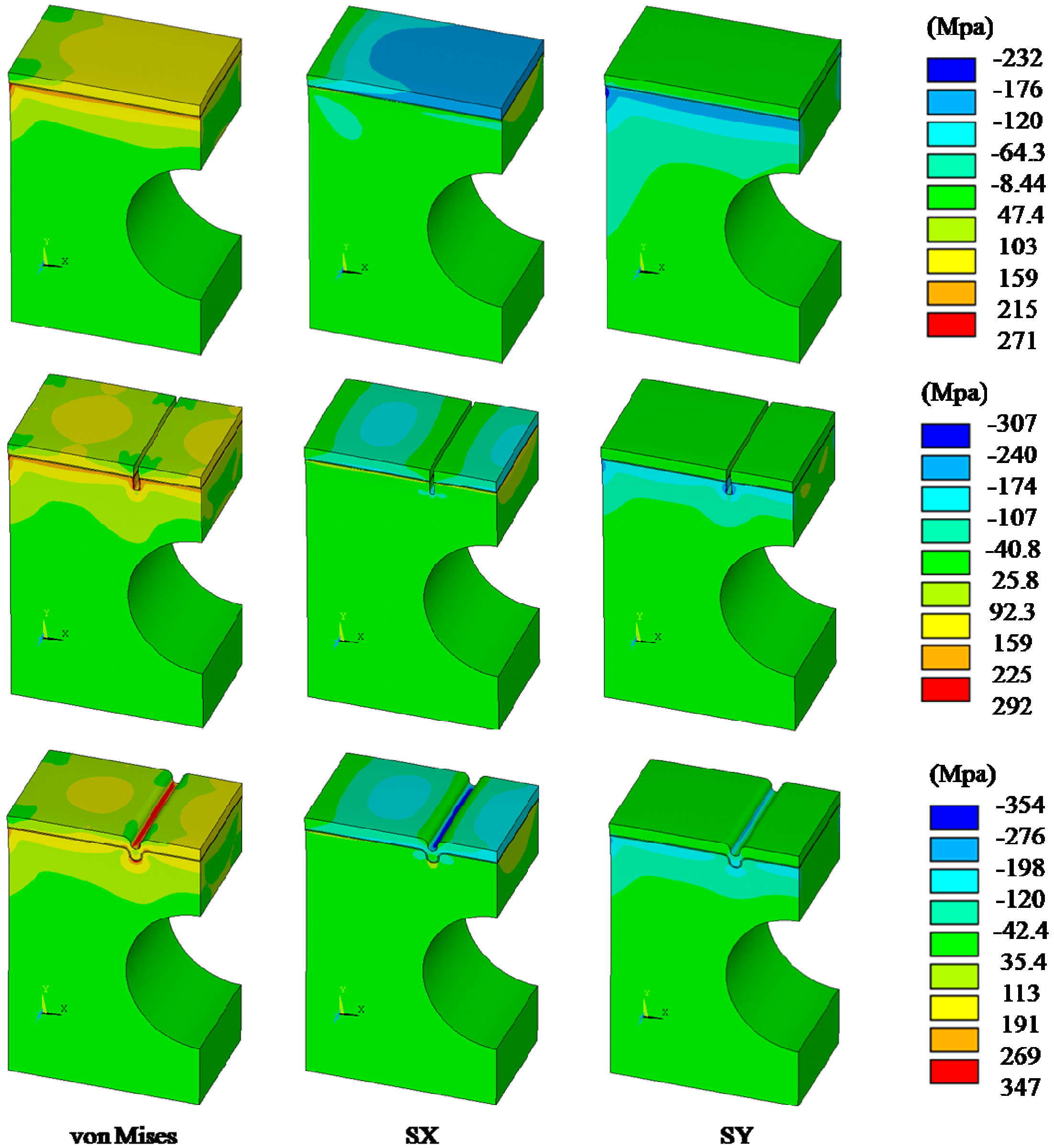
- **Main issues**
  - Thermal stress concentration at the gap bottom and corner
  - Melting of W coatings at the leading edges of gaps
  - Gap shape and dimension optimization





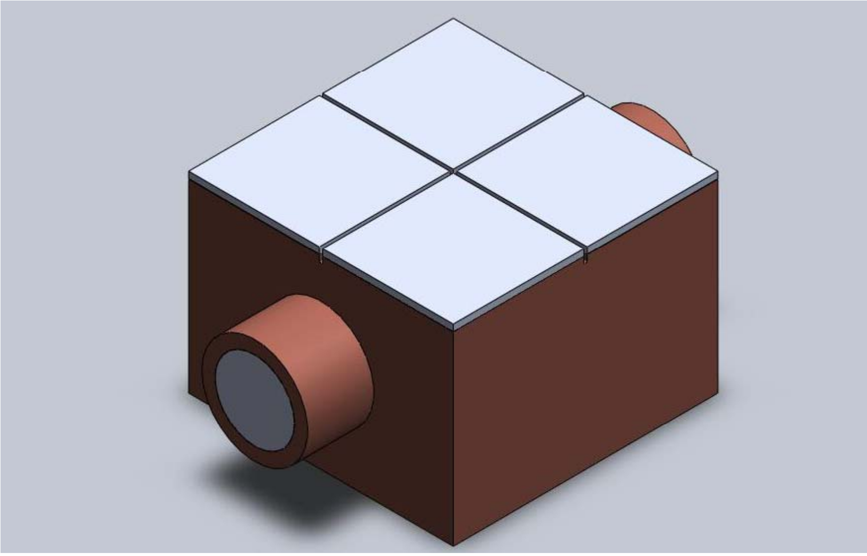
Thermal stress analysis (ANSYS code)

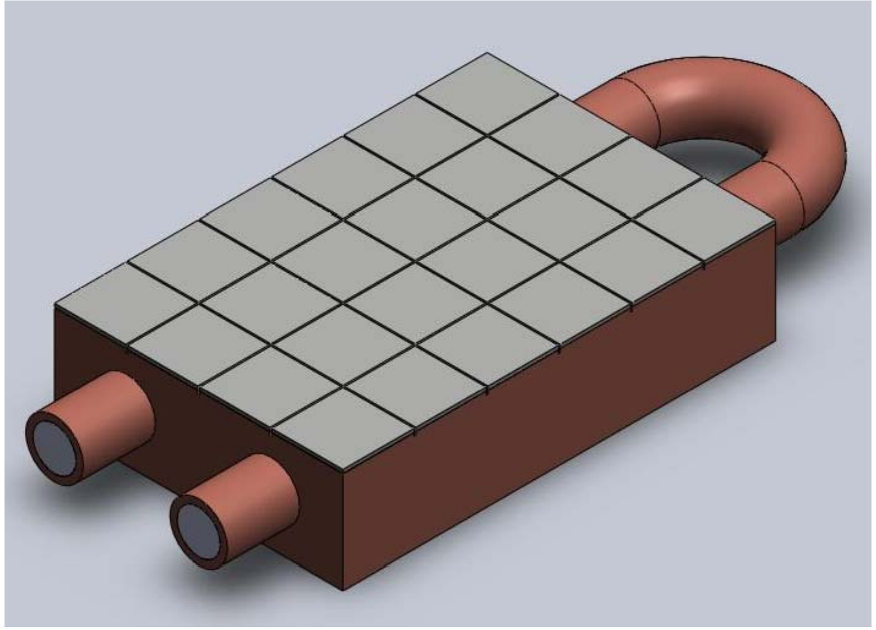
- **The maximum of the residual stress is located in the area of copper side adjacent to the joint interface**
- **For shape-V design, there's a serious stress concentration in the bottom of the groove, which makes this area weak**
- **The design of U－shape groove can partly resolve this problem**



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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ITER-like Monoblock W/Cu PFMC

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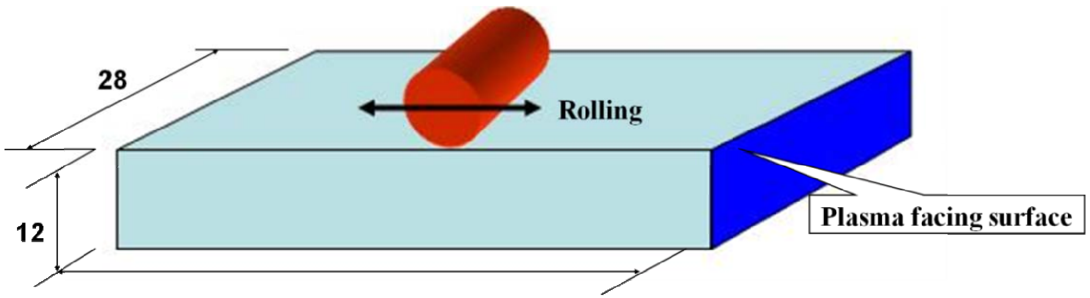
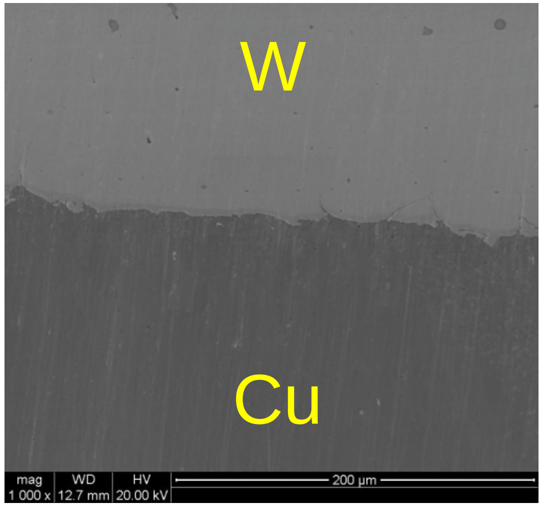
- Recently, efforts to achieve ITER-like Monoblock W/Cu PFC were made in collaboration with domestic companies and universities
- W/Cu monoblocks have been successfully prepared by means of HIP technology

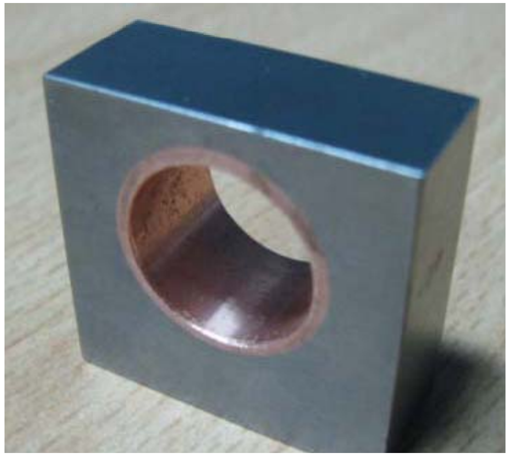


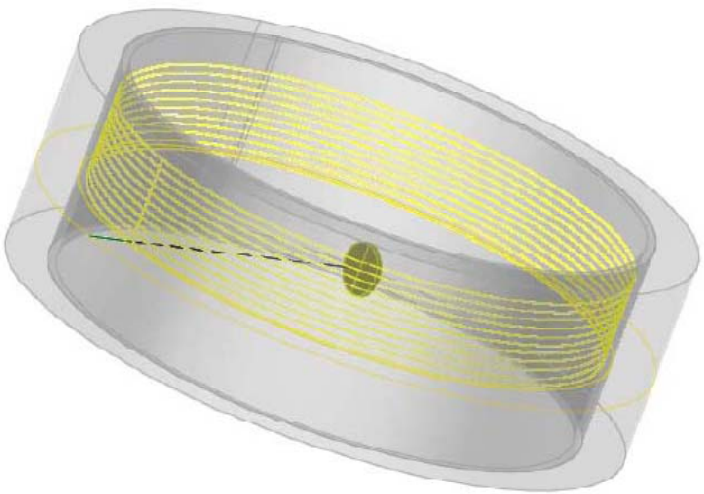


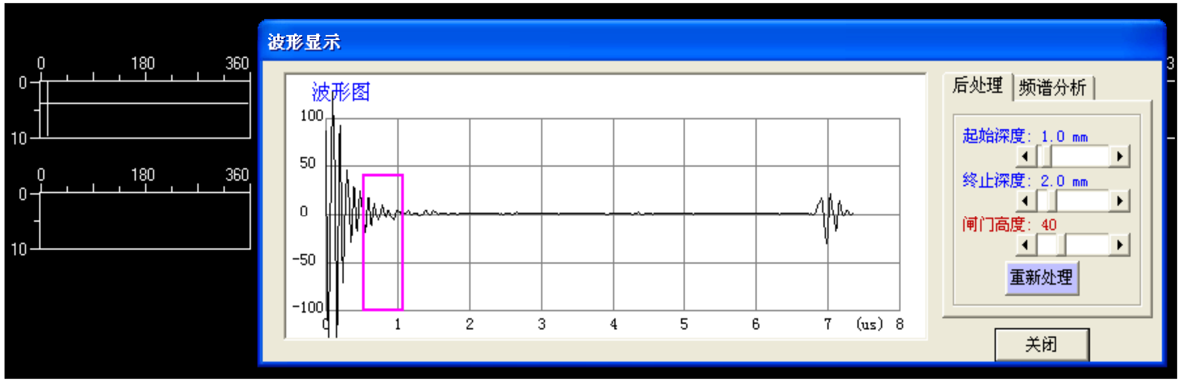
W/Cu bonding strength: 146Mpa

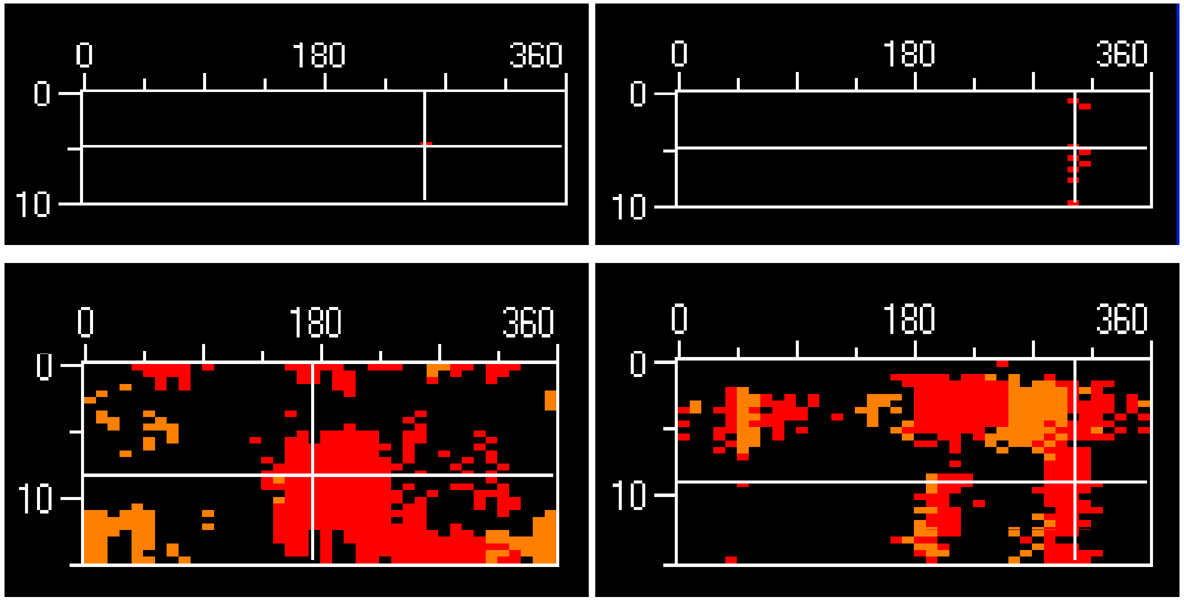
ITER-like Monoblock W/Cu PFMC

Spiral scanning ultrasonic NDT of W/Cu interface employed and excellent quality of the W/Cu interface achieved

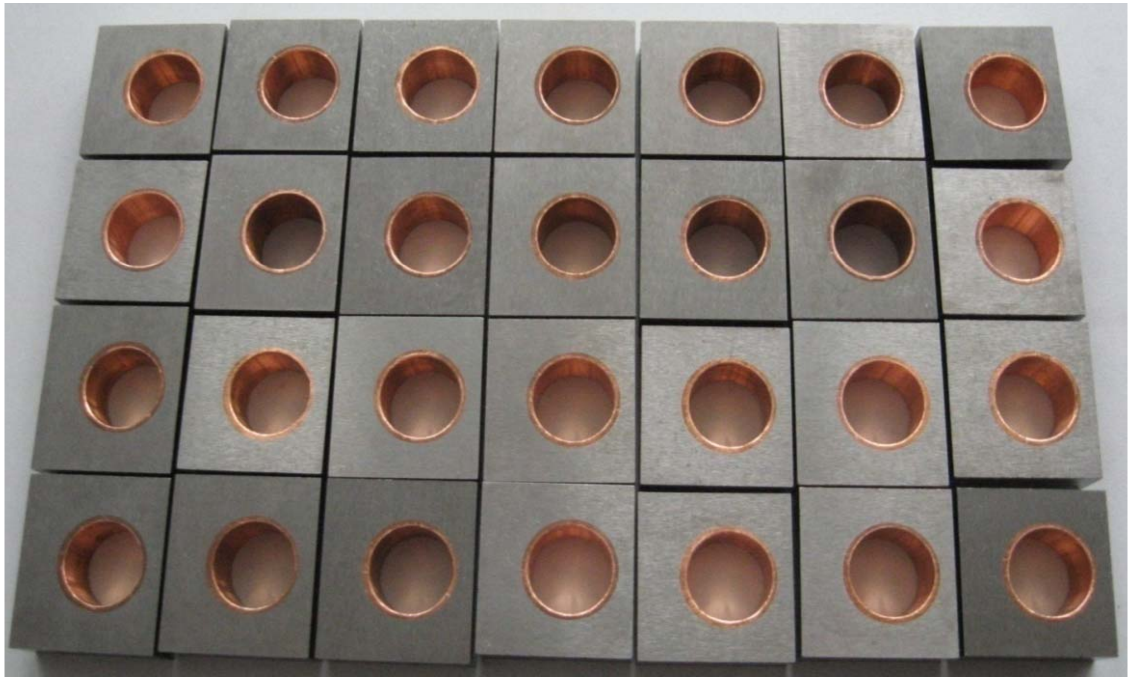








Batch Production Capability



ITER Divertor:

~ 100,000 CFC monoblocks (~ 28×20×18 mm);

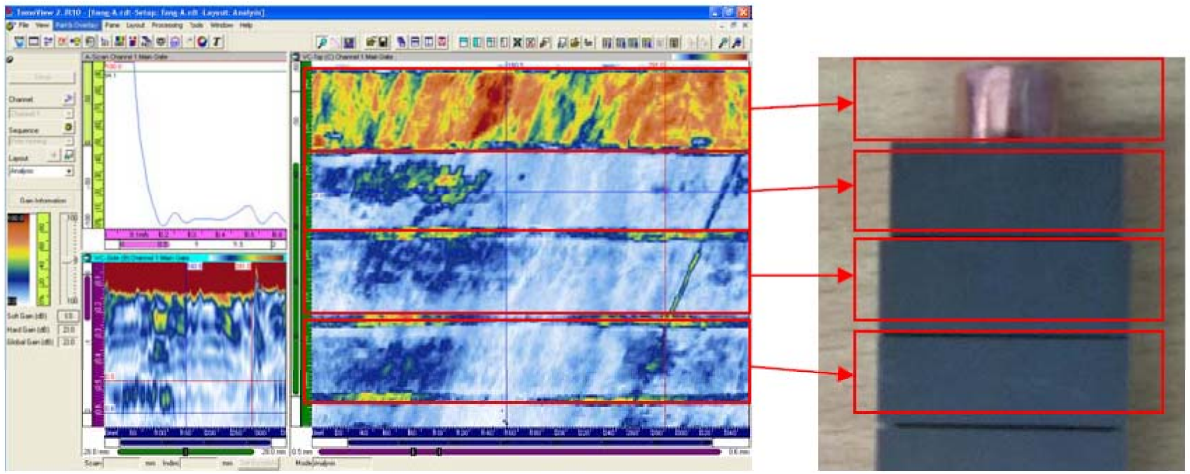
~ 500,000 W monoblocks (~ 28×12×8 mm) and W flat tiles (~20×12×8 mm)

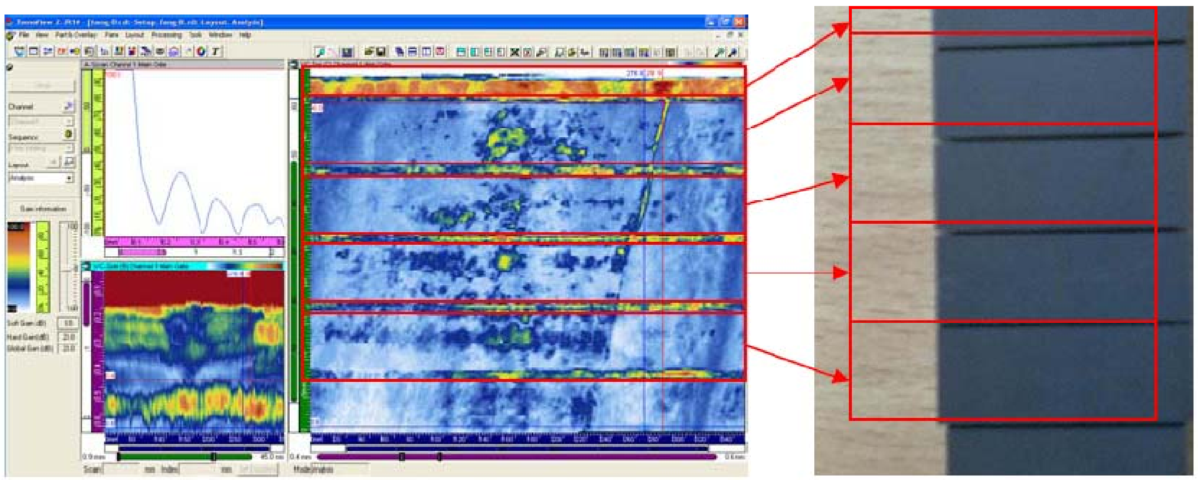
EAST:

~ 100,000 W monoblocks and W flat tiles, depending on late detailed design

ITER-like Monoblock W/Cu PFMC

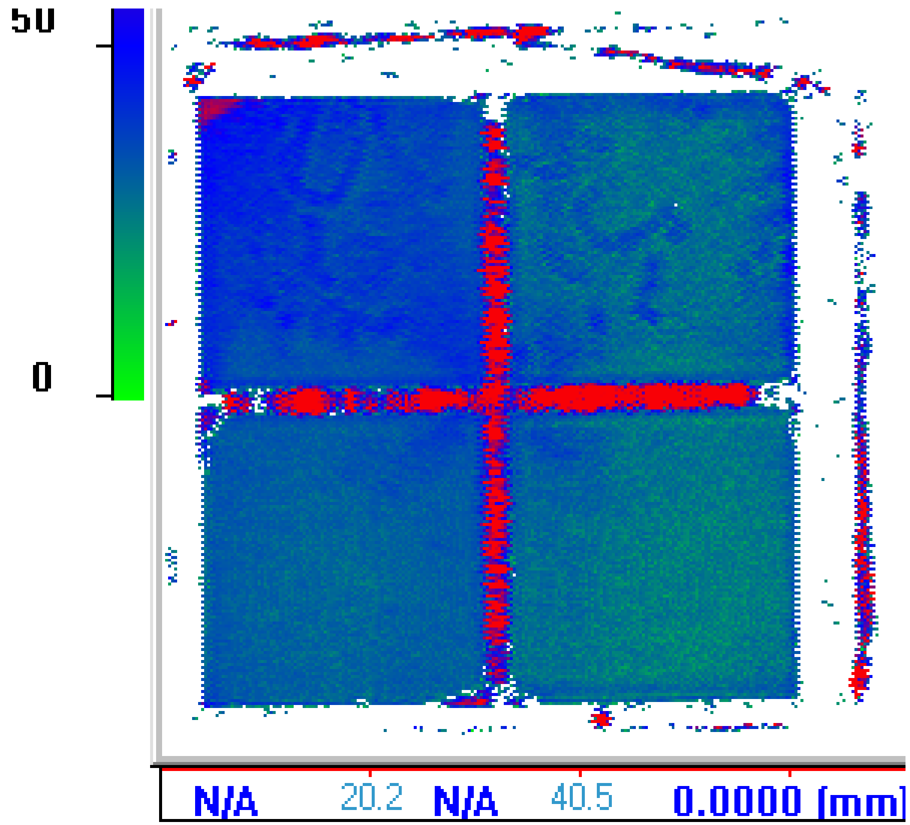
Brazing welding of the monoblocks to the CuCrZr cooling tube and NDT testing are being developed, and HHF testing also underway





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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Simplified schedule

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2011 | 2012 | 2013 | 2014 | 2015

Structure Design

Technology optimization of PFCs

Mockup testing HHF & EAST

Manufacturing & Assembly (lower divertor)

First plasma campaign

Assembly (upper divertor)

Second plasma campaign

Assembly (FW)

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

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!