First CRP meeting
Plasma-wall Interaction with Reduced-activation Steel Surfaces in Fusion Devices

Study the interaction of RAFM steel with laboratory and EAST plasma conditions

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Outline

- Introduction
- Sample preparation & native hydrogen releasing
- Deuterium retention in steel related re-deposited layer
- Permeation experiments of CLF-1 steel
- Summary

Introduction– Participates and research topics

Lanzhou institute of Chemical Physics, CAS

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Dr. Qiao, Li

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Prof. Luo, Guang-Nan

Dr. Zhou, Haishan

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Prof. Lu, Guang-Hong

Dr. Yuan, Yue

Zhang, Xuexi Ph.D candidate

Xu, YuPing Ph.D candidate

Introduction– Participates and research topics

Lanzhou institute of Chemical Physics, CAS

Institute of Plasma Physics, CAS

BeiHang University

Research topics:

Erosion and D retention of RAFM steel exposed to laboratory plasma—LICP

Erosion of RAFM steel by exposure to ECR plasma source

Deuterium retention in RAFM steel and related re-deposition layer

Performance of RAFM steel exposure to EAST tokamak plasmas—ASIPP

Erosion and D retention of different RAFM steels using MAPES exposure

Simulation the D retention behavior in steel/iron—BeiHang

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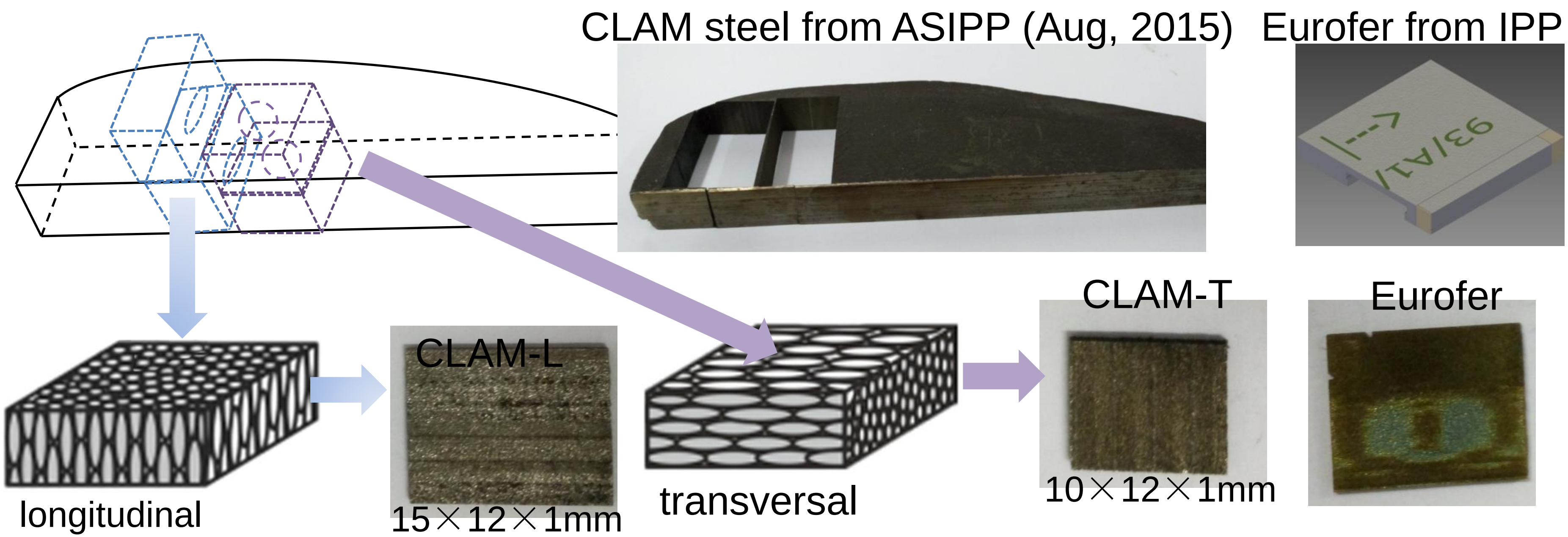
Sample preparation

Composition of RAFM steels (in wt.%) (Fe balance)

	C	Cr	W	Mn	V	Ta	N	P	S	O_2
Eurofer 97	**0.09-0.12**	**8.5-9.5**	**1.0-1.2**	**0.2-0.6**	**0.15-0.25**	**0.10-0.14**	**0.015-0.045**	**0.004-0.005**	**0.003-0.004**	**0.0013-0.0018**
F82H	**0.09**	**7.7**	**1.94**	**0.16**	**0.16**	**0.02**	**0.012**	**0.002**	**0.002**	**0.01**
CLAM (CLF-1)	**0.11**	**8.5**	**1.5**	**0.5**	**0.25**	**0.1**	**0.02**	**0.003**	**/**	**0.002**



Sample preparation

Eurofer97/CLAM Steels - Before polishing:

--- Technical finish of samples by the manufacture guaranteed an even thickness of all specimens

--- Ultrasonic cleaning and mechanical removing of possible layer from cutting procedure

Current polishing procedure

--- Polishing with increasingly fine-grained SiC grinding paper (P360-P800 -P200-P2000) (about 5 min each)

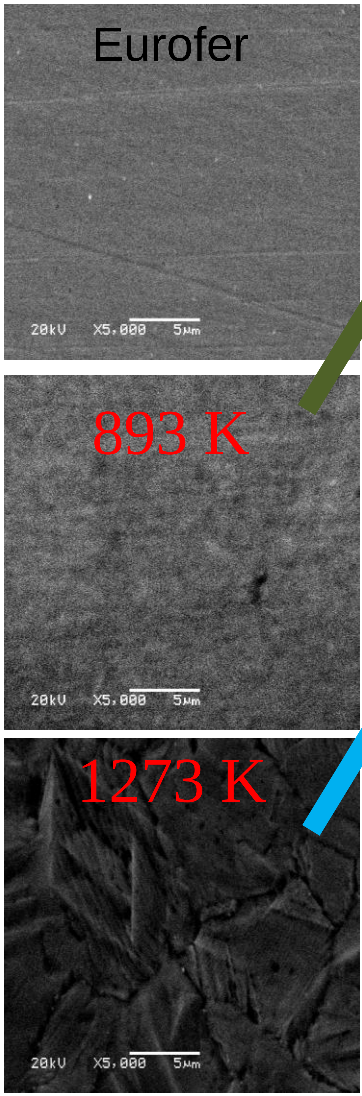
--- Nap cloth 20 min with diamond suspension, 2-3 sprayings and polishing

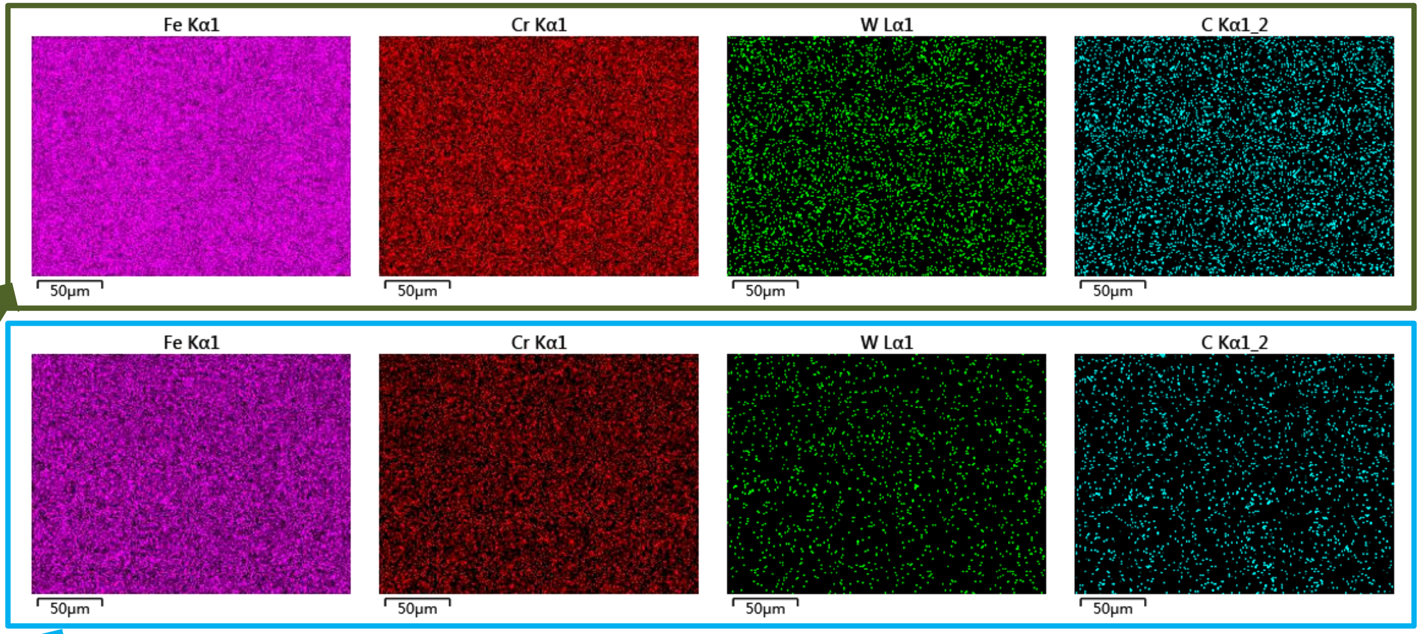
--- Nap cloth with 2.5% NaOH solution (in water) 10min

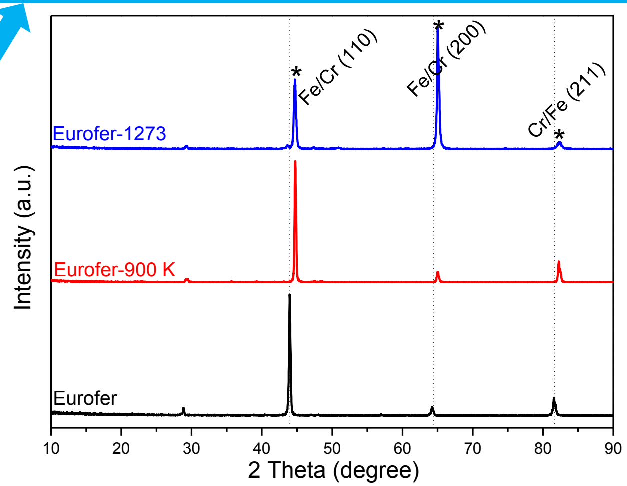
--- 5 min flushing with water on the Nap cloth

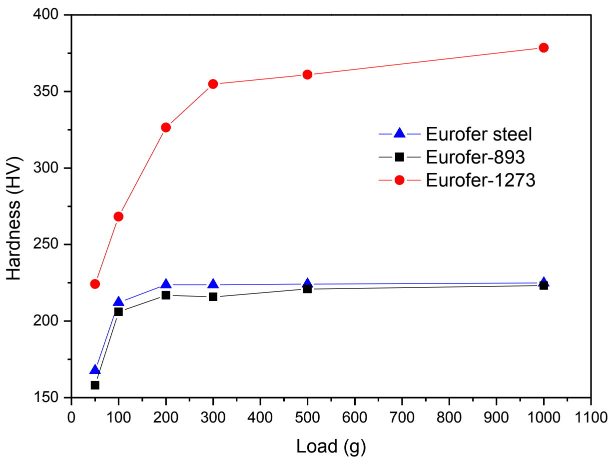
--- ALL 6 sides are polished with a main side polished to a mirror-like surface

Sample preparation

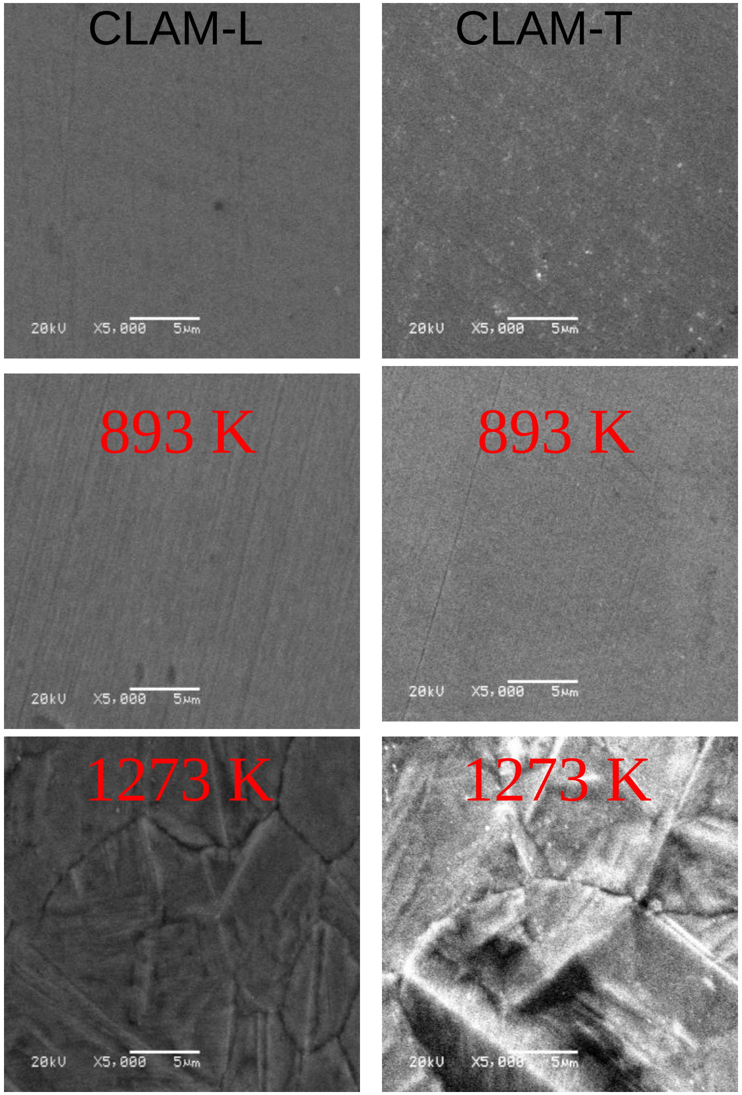


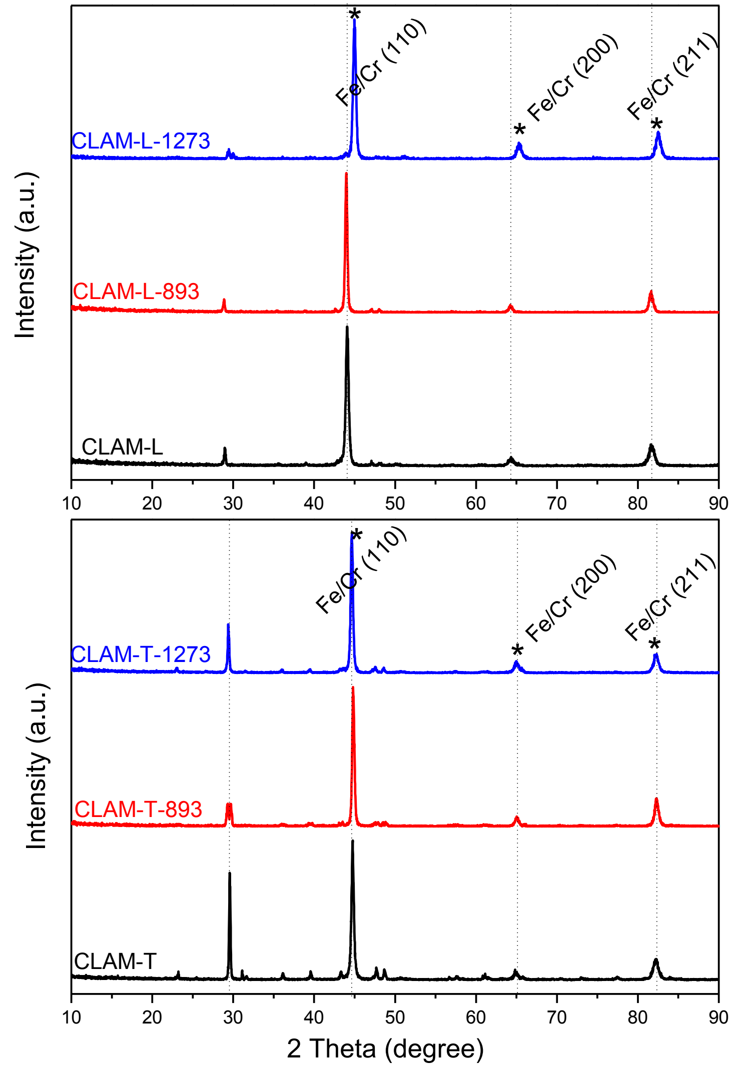




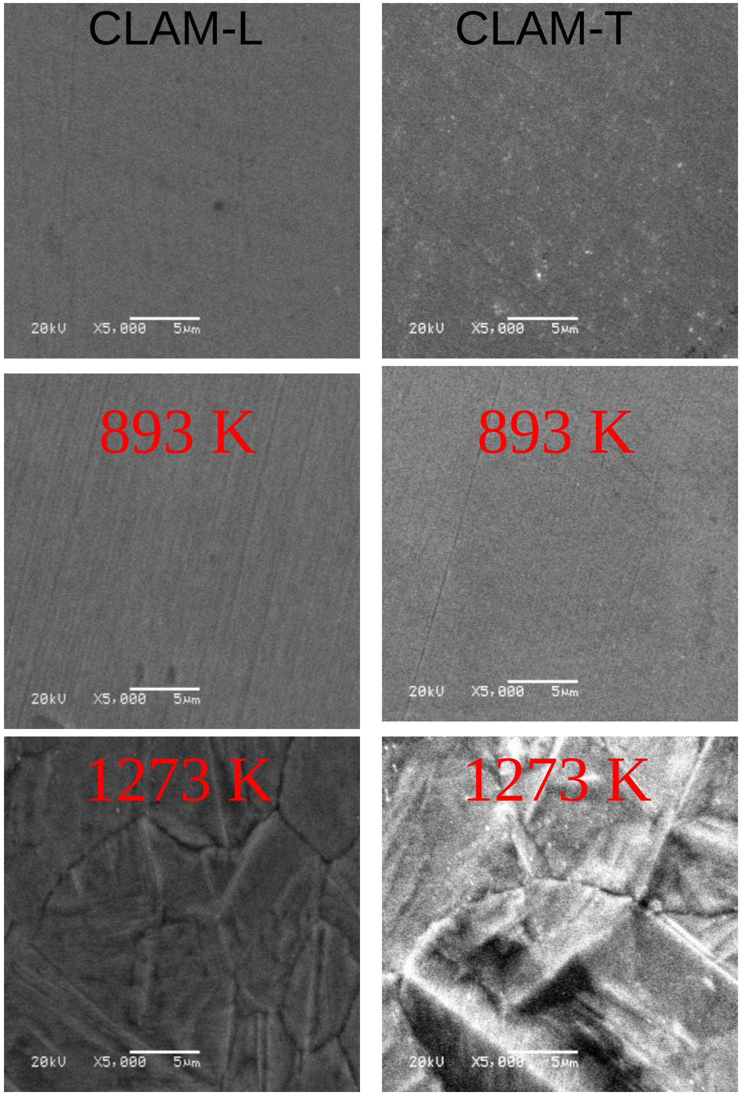


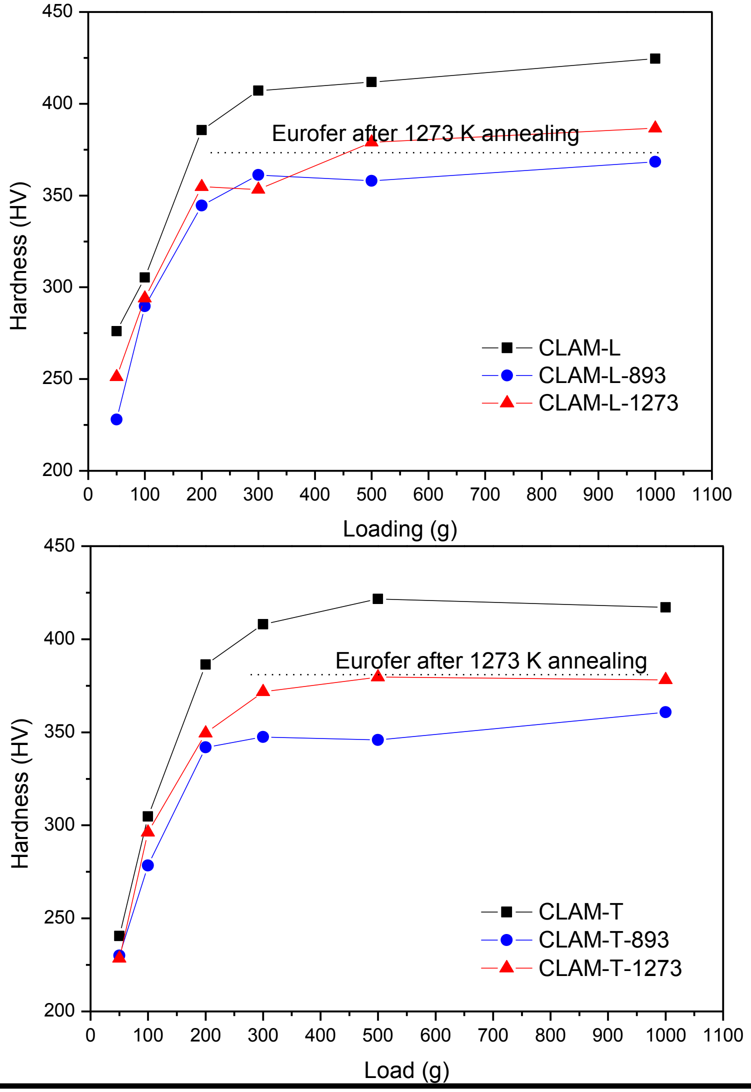
Sample preparation





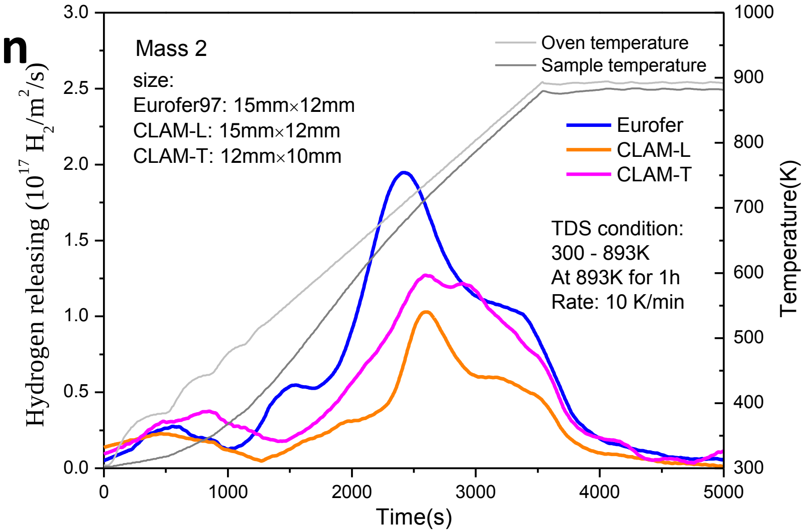
Sample preparation

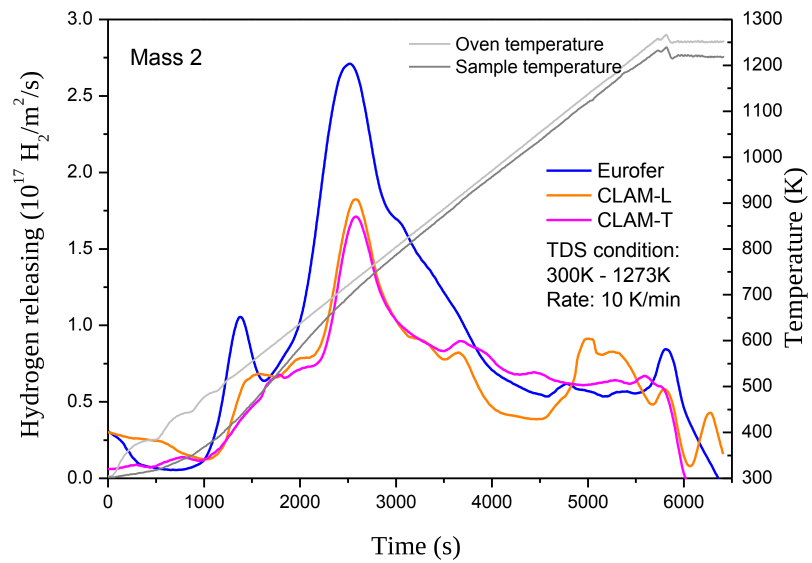




Native hydrogen releasing

Magnetron sputtering and Thermal desorption





L chamber: Magnetron sputtering with four targets

M chamber: 10^{-6}Pa base pressure with IR heating (RT-1100℃)

R chamber: 10^{-8} Pa base pressure with electron beam heating to 2000℃

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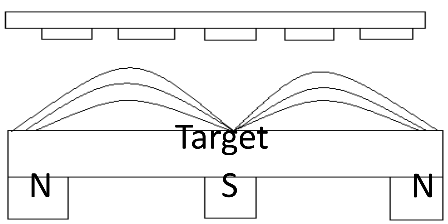
Deuterium retention in re-deposition layer

Magnetron sputtering



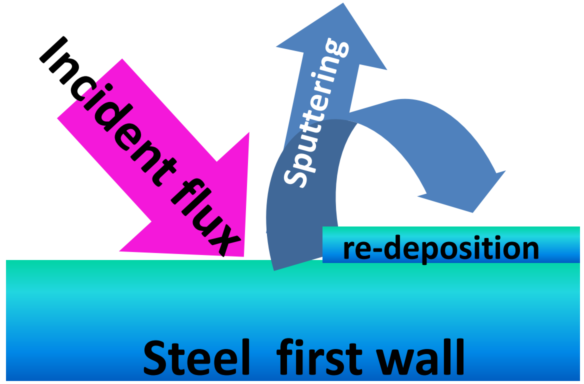
Re-deposition layer preparation

Atmosphere: Ar & D_2

Pressure：0.75 Pa

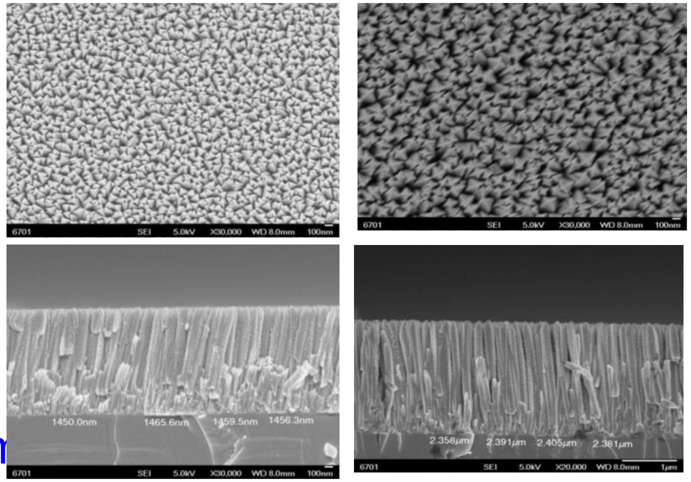
Target: iron and chromium

Influence of PWI process



- ✓ Steel used as first wall material will inevitably be sputtered and re-deposited on wall
- ✓ Fe & Cr layers deposited by magnetron sputtering were used as a model system to study the D retention and releasing behaviors of re-deposited layer

Fe & D　　Cr & D



Deuterium implantation

CCP plasma:

Pressure: 1.0 Pa

Bias: -200 V

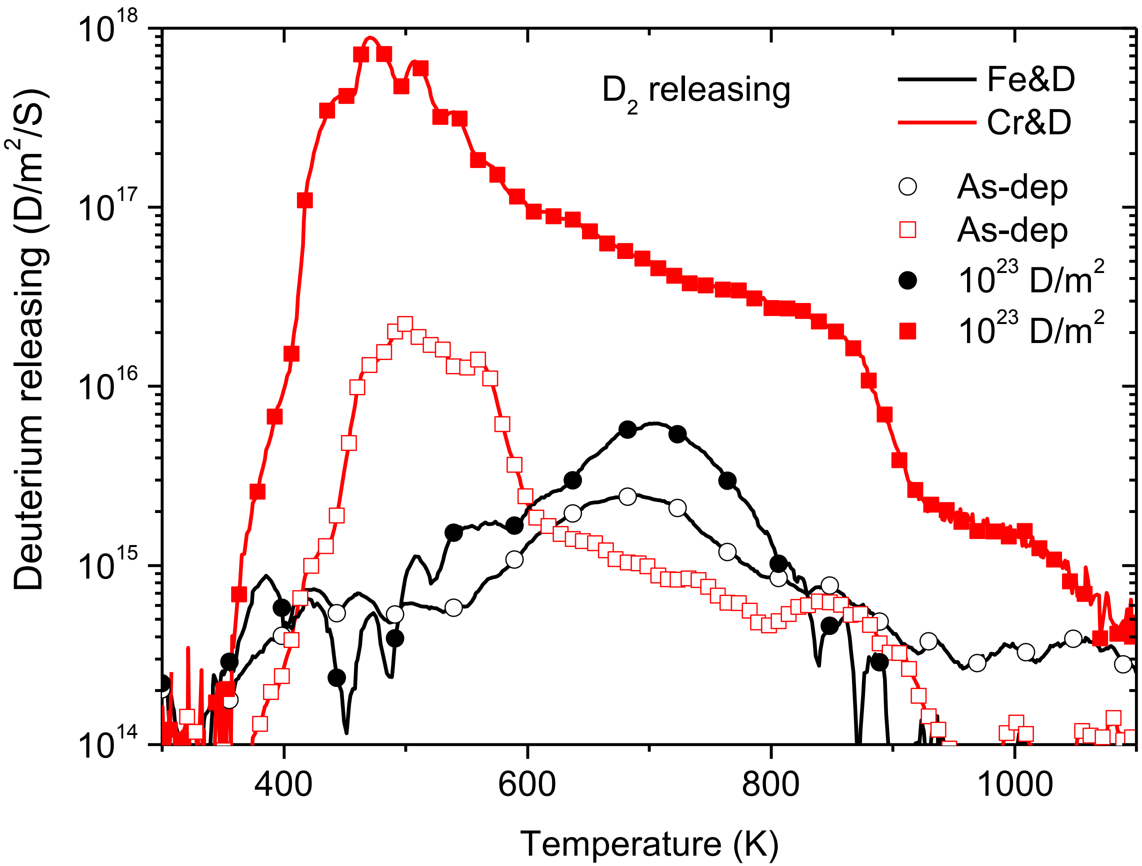
Substrate T: ~400 K

Flux: 2×10^{18} D s^{-1} m^{-2}

Fluence: 1.4×10^{23} D m^{-2}

Deuterium retention in re-deposition layer

Deuterium releasing from Fe, Cr layers before and after deuterium implantation



D releasing from co-deposition layer:

Fe-D: 700 K

Cr-D: 500 K

After implantation:

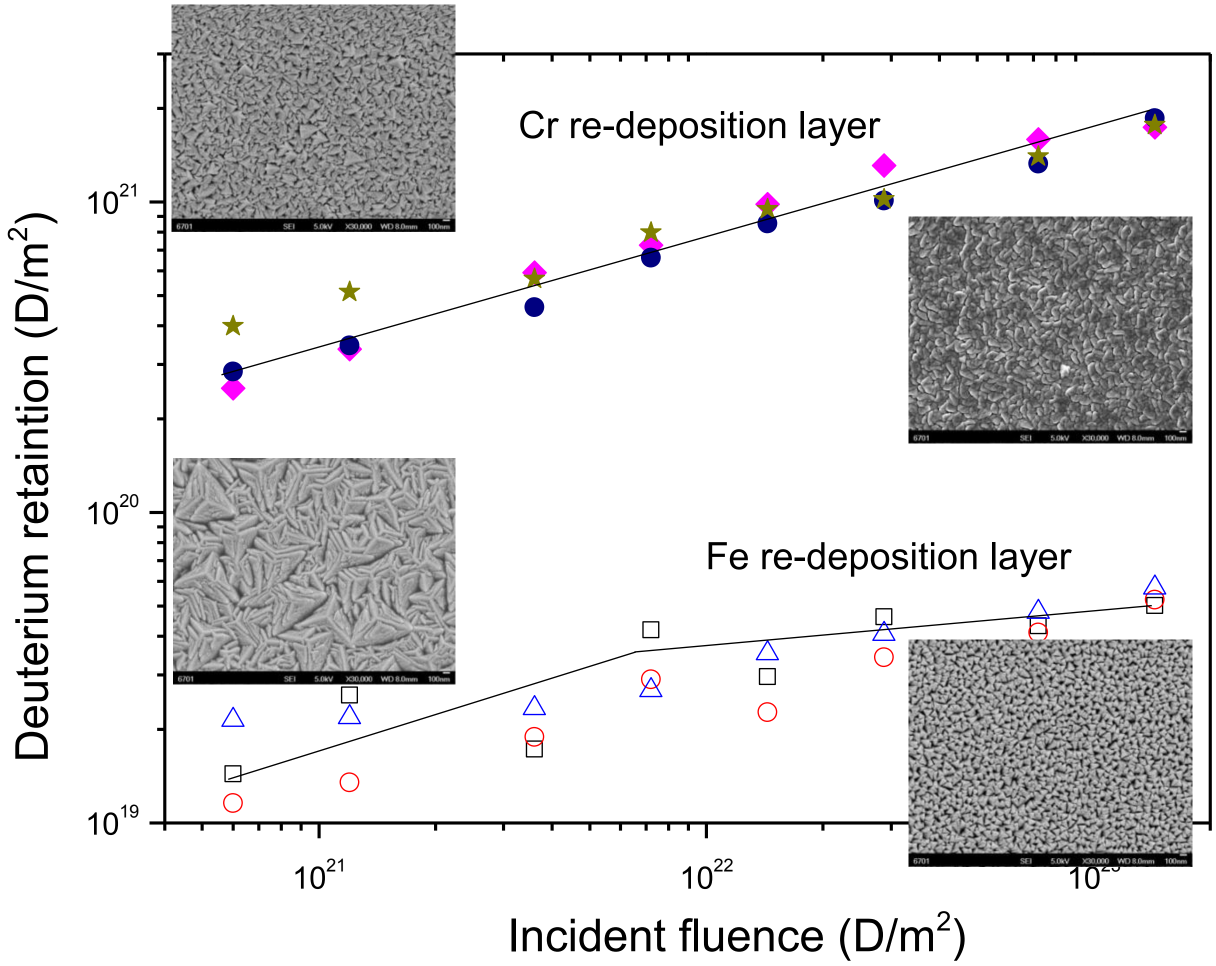
Fe-D: 700 K

Cr-D: 500 K

600 to 900K

Deuterium retention in re-deposition layer

Total deuterium retention as a function of incident fluence



No saturation of D retention in Cr re-deposition layer

D retention in Fe re-deposition layer saturated at a fluence of 10^{22} D/m^2

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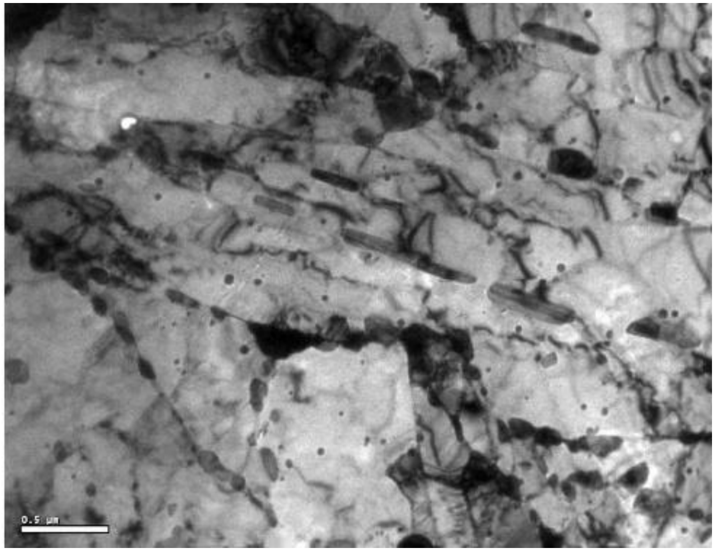
Experimental procedure

Alloy element	Cr	C	W	Ta	Mn	V	N	
Content control	8.5±0.3	0.11±0.015	1.5±0.2	0.10±0.03	0.5±0.2	0.3±0.1	0.02-0.035	
Impurity	S	P	Ti	B	Nb	O	Ni	Mo
Content control	<0.005	<0.005	<0.01	<0.005	<0.01	<0.005	<0.01	<0.01
Impurity	Cu	Al	Si	Co	As	Sn	Sb	Zr
Content control	<0.01	<0.03	<0.05	<0.01	As+Sn+Sb+Zr<0.05			

Chemical composition of CLF-1 steels



Reference: P H Wang , report at Chendu, 2013

- **He ions implantation**

  Energy: 3.5 MeV

  Flux: 5×10^{11} ions/(cm^2 s)

  Temperature: R.T

- **GDP (gas driven permeation)**

  Sample held by VCR couplings.

  Temperature: 350-550 °C

  Driving pressure: 10^3 Pa-10^5 Pa

- **D_2 exposure and TDS**

  Exposure temperature: 350 °C

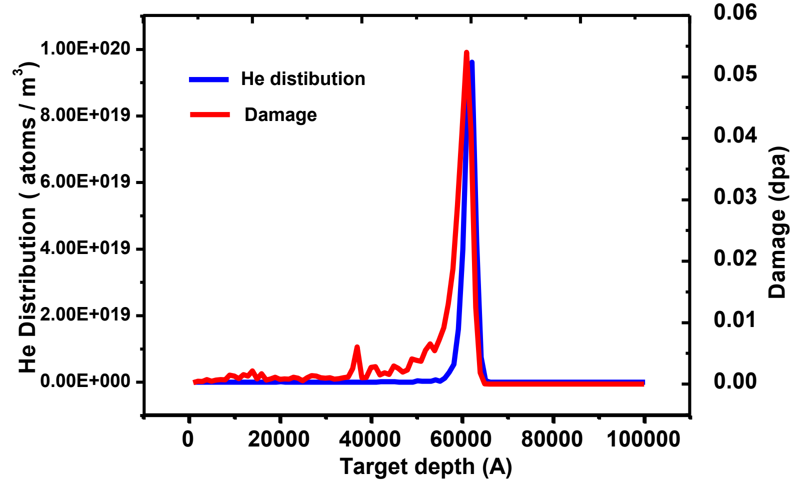
  Exposure pressure: 8×10^4 Pa

  TDS temperature rate: 1 °C/s

  TDS temperature range: R.T – 1000 °C

He ions irradiation

4.5 MV electrostatic accelerator in Peking University

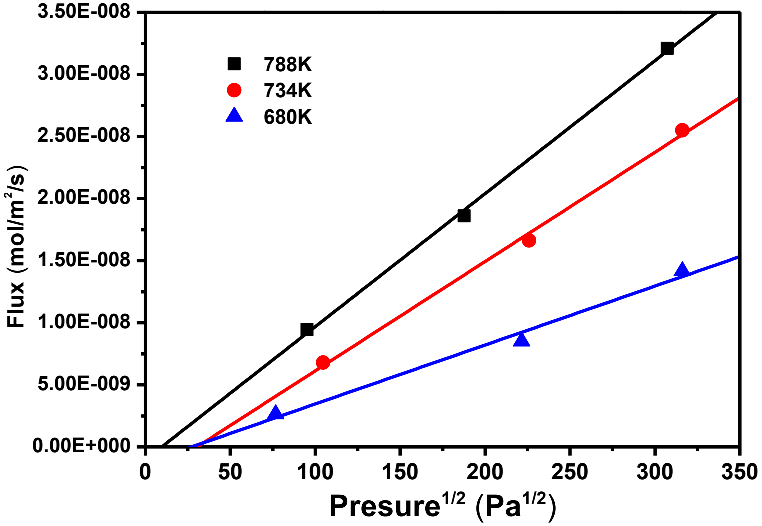


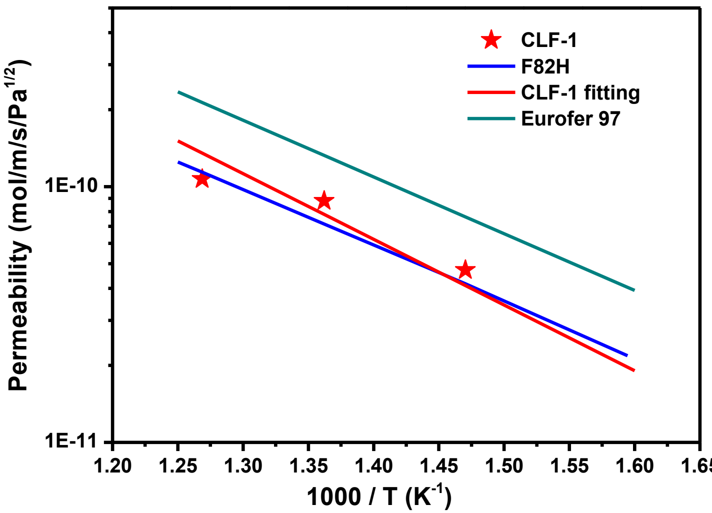
SRIM caculation

Three groups of irradiated CLF-1 steel samples were got with one sample for permeation experiment and one for D_2 exposure and TDS in one group.

No.	DPA Peak value	He implantation ions/m^2
1	0.001	6×10^{17}
2	0.01	6×10^{18}
3	0.05	3×10^{19}

GDP results of virgin CLF-1 steel



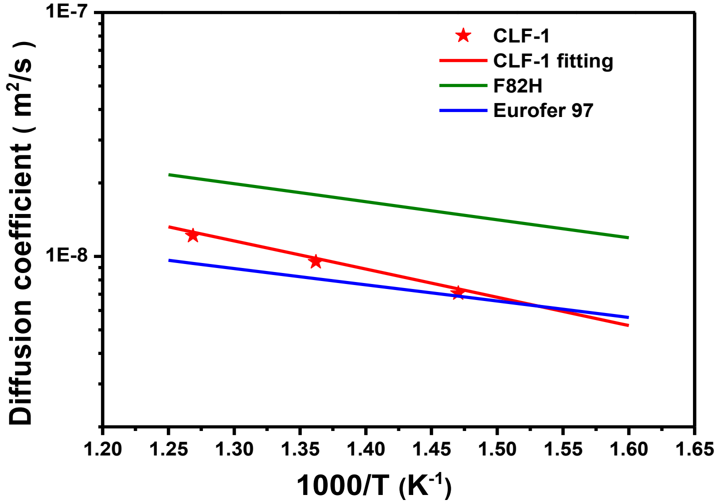


The permeability ($mol \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1/2}$) of the virgin CLF-1 sample can be described by :

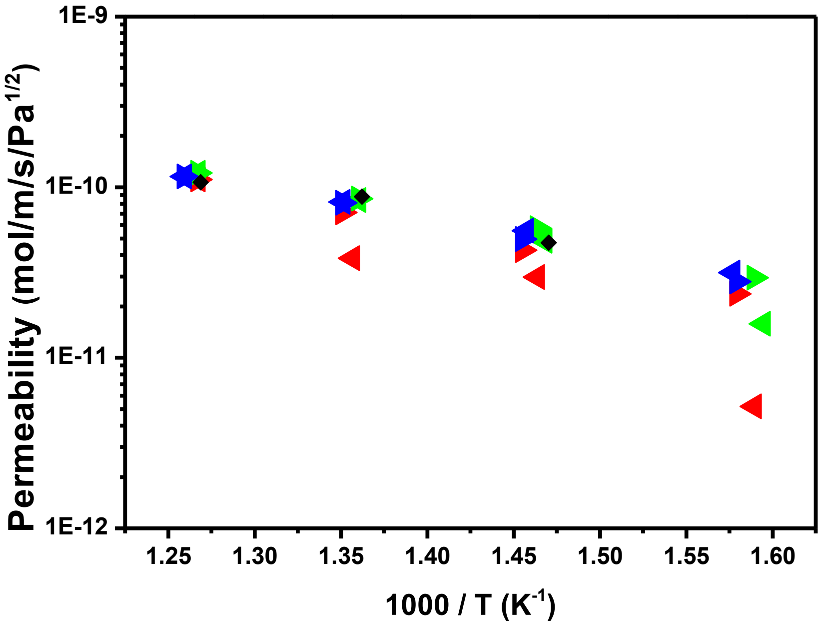
$$P_{clf\text{-}1}=6.36\times10^{-8}\exp\left(\frac{-0.43[eV]}{kt}\right);$$

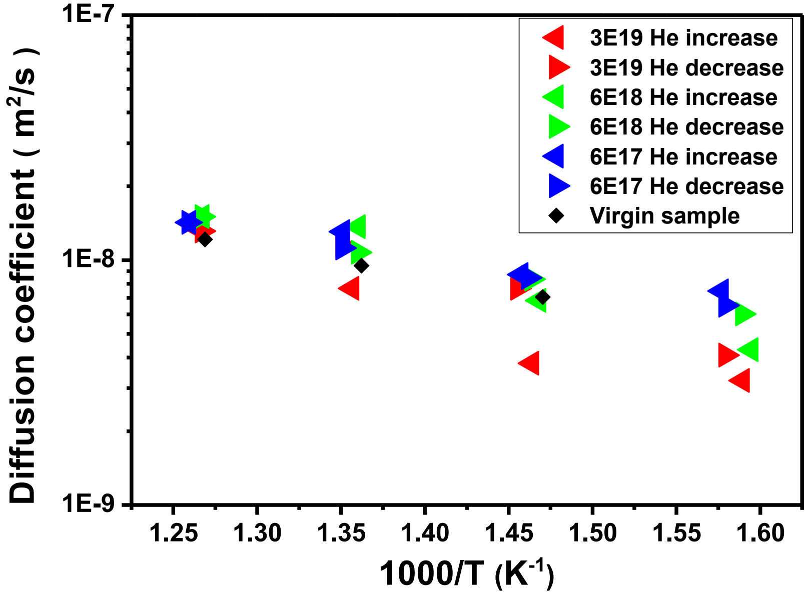
The diffusion coefficient ($m^2 \cdot s^{-1}$) :

$$D_{clf\text{-}1}=3.71\times10^{-7}\exp\left(\frac{-0.23[eV]}{kt}\right);$$



GDP results of irradiated CLF-1 steel

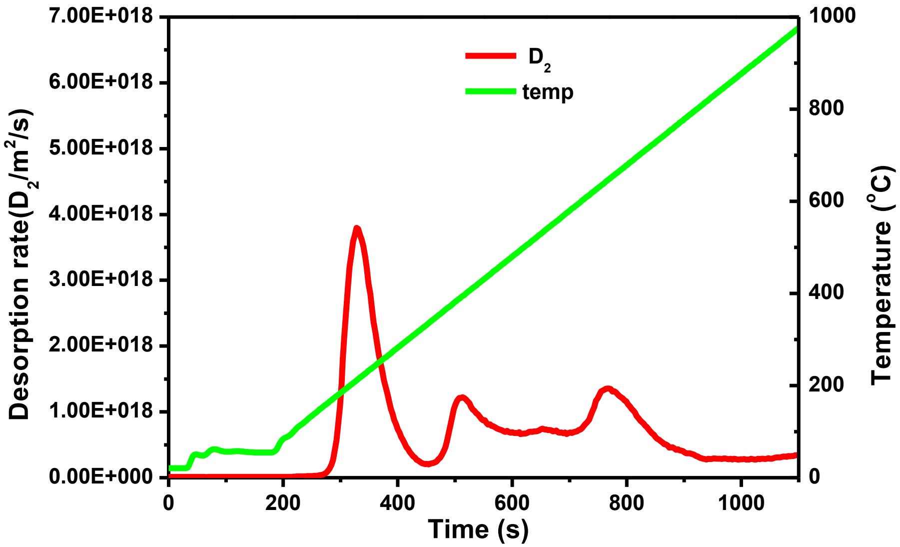




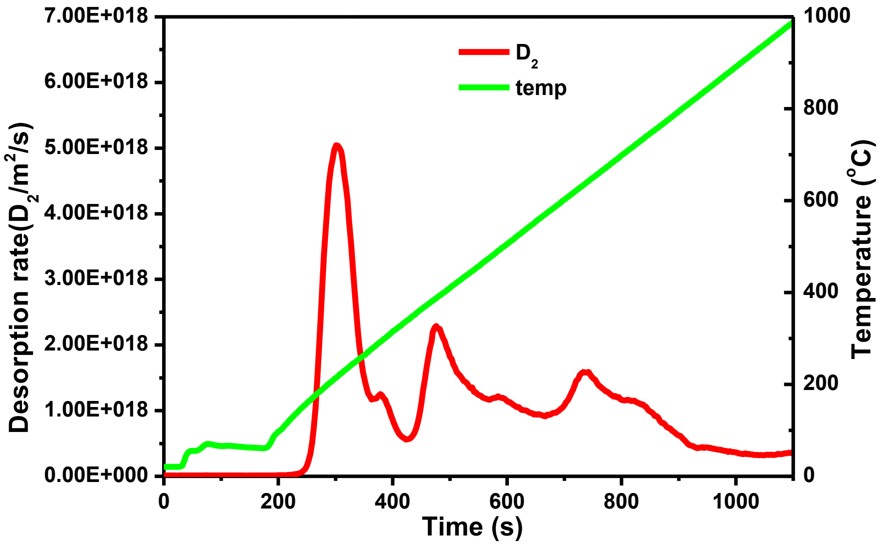
For each irradiated sample, the GDP experiments were performed from low temperature to high temperature and back to low temperature again.

Influence on Deuterium Retention

Virgin sample



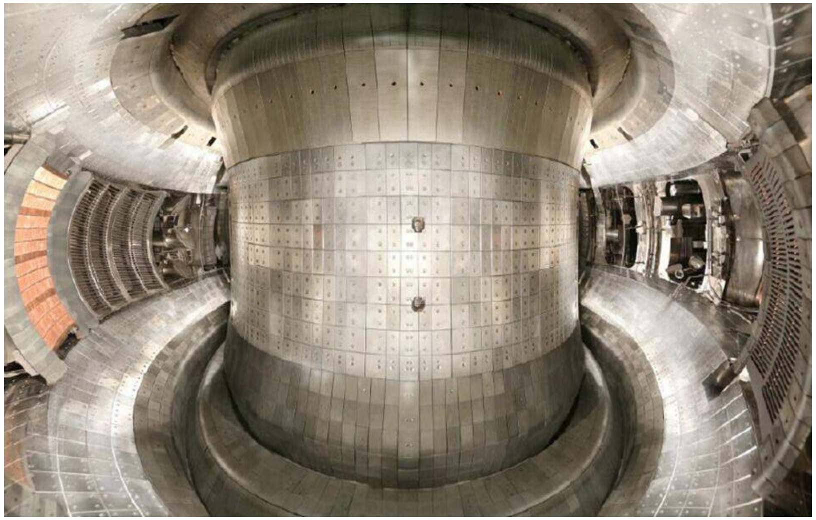
After 3×10^19 He/m^2 irradiation

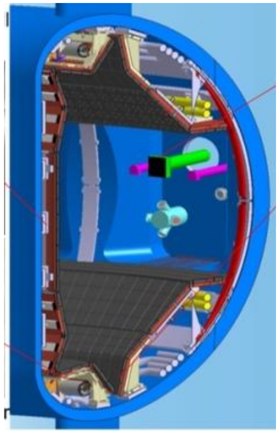


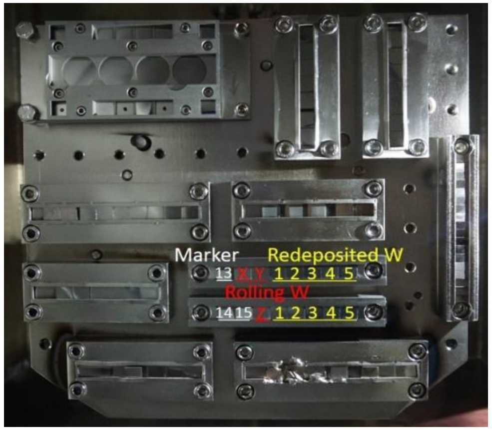
- **As the amount of helium implantation is too small, the mess 4 signal in the TDS is only from D_2 gas.**
- **Both the samples show three main peaks, 210 ^oC, 380 ^oC, 645 ^oC.**
- **The irradiated sample shows larger retention than that of virgin sample after exposure to deuterium gas at the same condition**

More work on RAFMs

- **Heavy ions irradiation effect on the microstructure and the hydrogen isotope permeation and retention behavior (Ongoing).**
- **Evaluation of RAFMs as the plasma-facing material by the material and plasma evaluation system (MAPES) in the EAST tokamak (Ongoing).**
- **Explore the technique to obtain α-Al_2O_3 at low temperature on RAFMs as tritium permeation barrier (Planning)**







MAPES on EAST

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Summary

What we have done:

1. Prepare CLAM and Eurofer samples for laboratory plasma exposure
2. Investigate the deuterium retention in steel related re-deposition layer
3. Study the influence of He ions irradiation on deuterium retention and permeation

What we plan to do:

1. Study the erosion and deuterium retention of steel under the laboratory plasma
2. Investigate the performance of different RAFM steel in EAST plasma condition
3. Simulation the D retention behavior in steel/iron

Thank you
for your attention!