3rd RAFM steel as first wall CRP meeting

Deuterium retention and erosion of CLF-1 and CLAM steels exposed to deuterium plasma

Peng Wang[1], Li Qiao[1], Hanwen Zhang[1], Ran He[1], Chuan Xu[2], Engang Fu[2]

1. Lanzhou Institute of Chemical Physics, Lanzhou, China

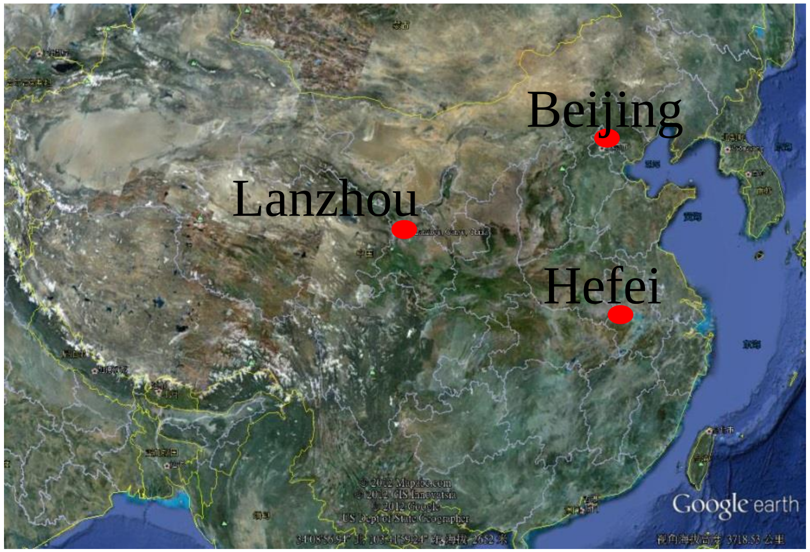
2. Department of Physics, Peking University, Beijing, China

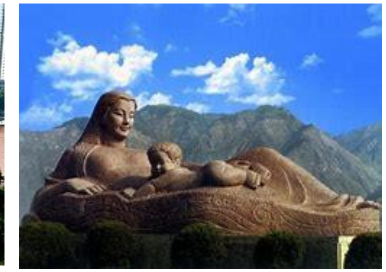
Outline

- Deuterium and helium depth profile determined by glow discharge optical emission spectroscopy
- Retention and erosion of RAFM steel exposed to deuterium plasma
- Summary

Experimental facilities & PSI research in LICP

Lanzhou institute of Chemical Physics, Chinese Academy of Sciences





Experimental facilities & PSI research in LICP

Lanzhou Institute of Chemical Physics

Research Divisions

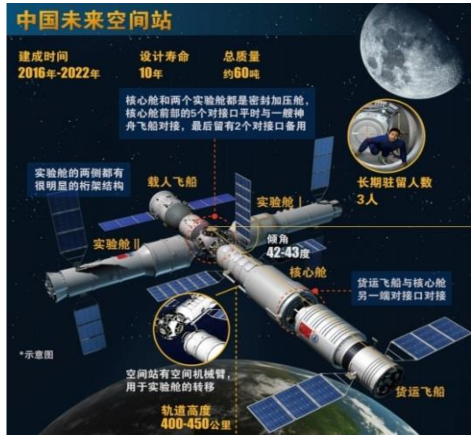
High-tech Research

- National Engineering Research Center of Fine Petrochemical Intermediates
- Key Laboratory of Chemistry of Northwestern Plant Resources, CAS
- R&D Center of Lubricating and Protecting Materials
- R&D Center for Green Chemistry and Catalysis
- R&D Center for Eco-material and Eco-chemistry

Applied Basic Research

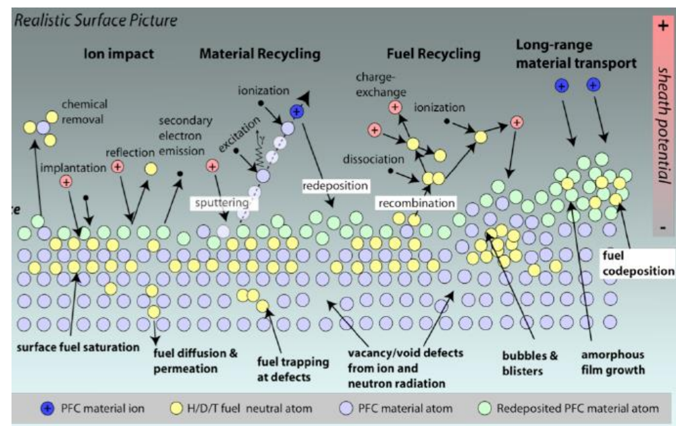
- State Key Laboratory of Oxo Synthesis and Selective Oxidation
- State Key Laboratory of Solid Lubrication

Experimental facilities & PSI research in LICP



Space & nuclear environments lubrication

- **Solid lubrication in space industry**
- **Irradiation & damage of lubricants in nuclear environment**

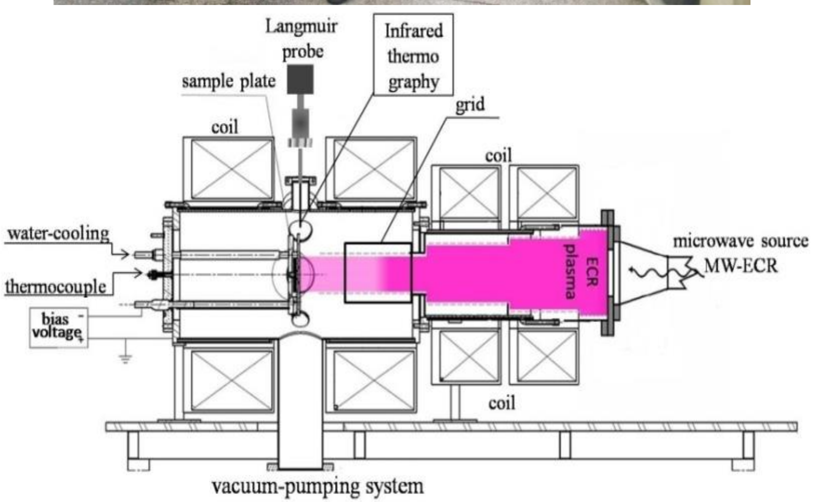


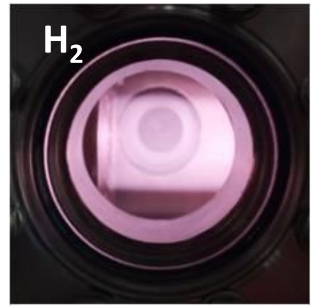
PMI research in laboratory

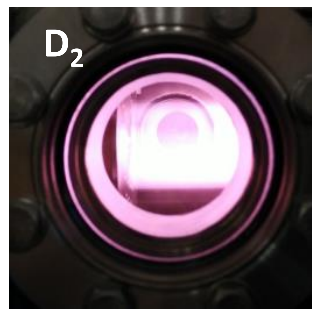
- **Hydrogen isotope retention**
- **Erosion of RAFM steel in fusion relevant plasma**

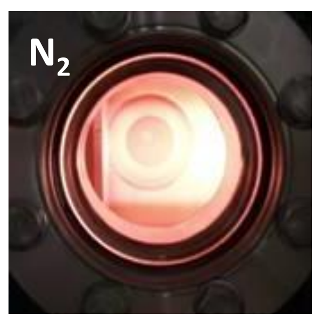
Experimental facilities & PSI research in LICP

Linear Experimental Plasma System (LEPS)



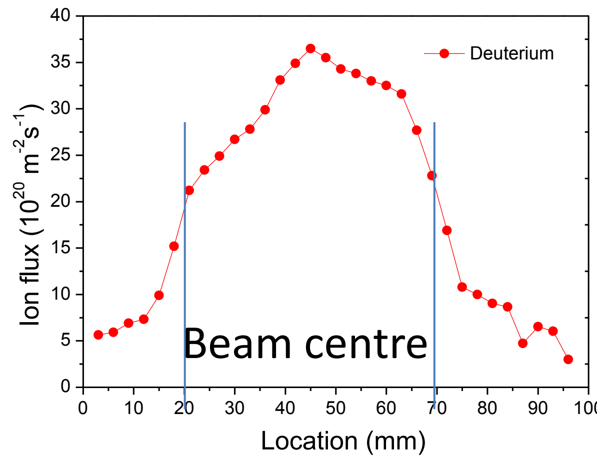






Parameters of LEPS plasma:

- Magnet field: 0.12-0.15 T
- Plasma beam diameter: 50 mm
- Ion flux: 2-5 $\times 10^{21}$ $m^{-2}s^{-1}$
- Ion composition: mainly D_3^+
- Electron density: 10^{16}--10^{18} m^{-3}
- Floating potential: -15 V
- Working pressure: 0.5-1.0 Pa



Deuterium plasma profile measured by LP

Experimental facilities & PSI research in LICP


Thermal desorption spectroscopy

Glow discharge optical emission spectroscopy

Preparation & Characterization

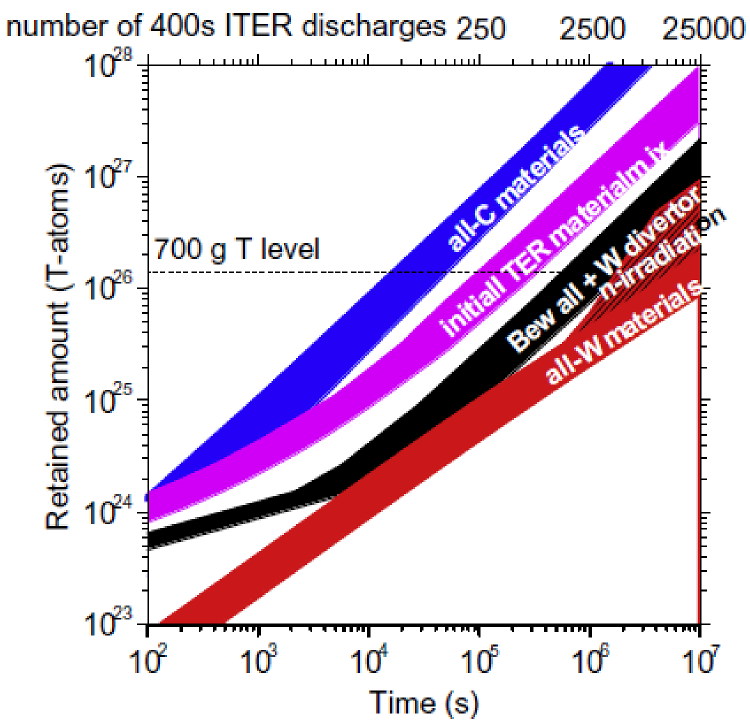

400 KV Implantation @ Xiamen University


2×1.7MV KV Accelerator @ Peking University


3MeV tandem accelerator @ IPP, Garching

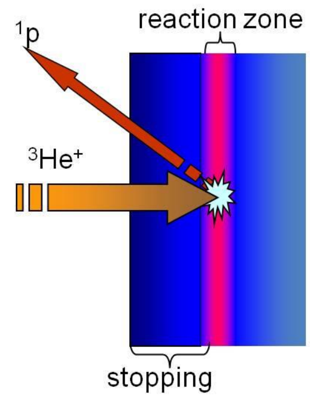
Deuterium/helium depth profile measured by GDOES

Retention limitation < 700 g

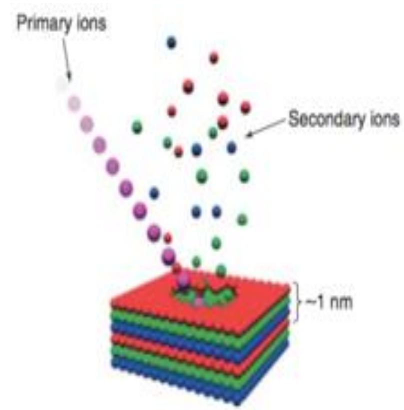


Hydrogen isotopes and helium retention in first wall materials is quite low (10^{-5}-10^{-1} at.fr)

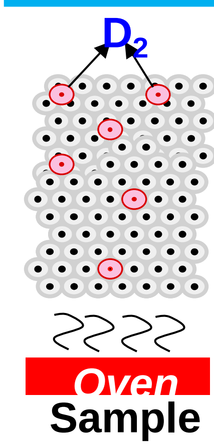
IBA



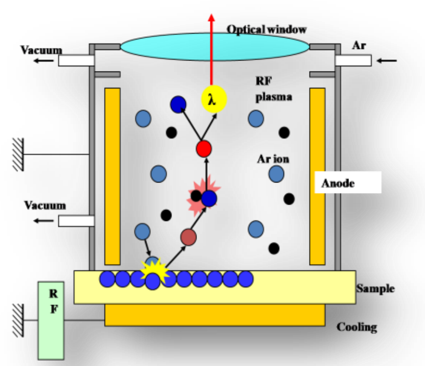
SIMS



TDS

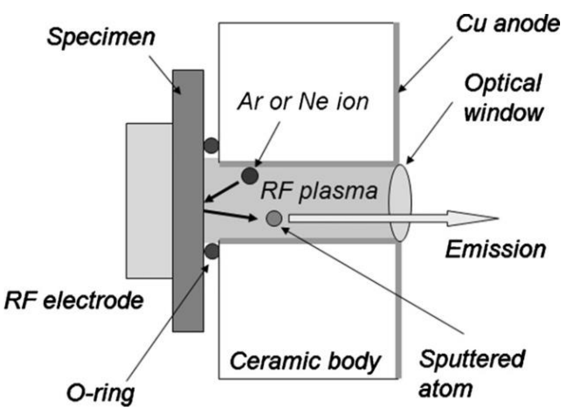


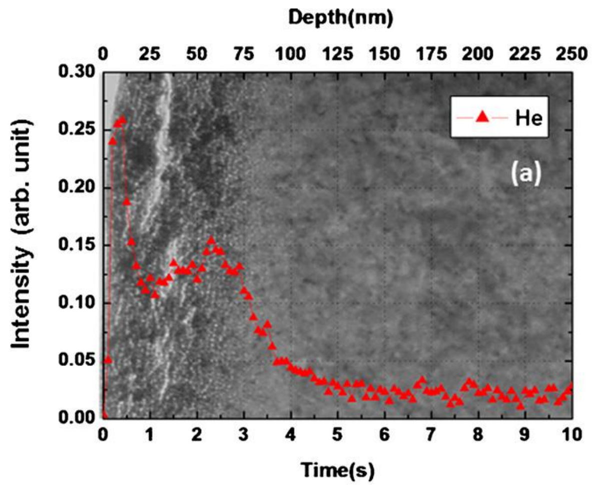
GDOES

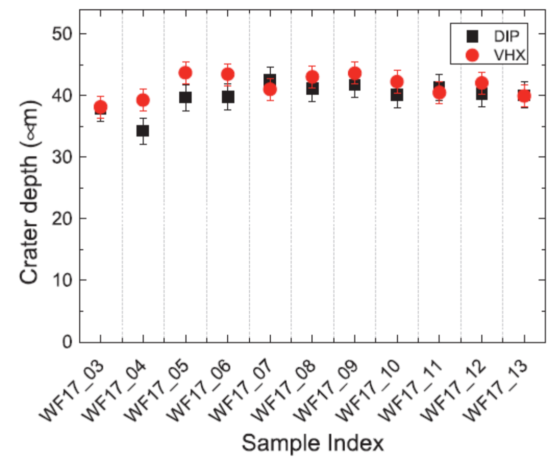


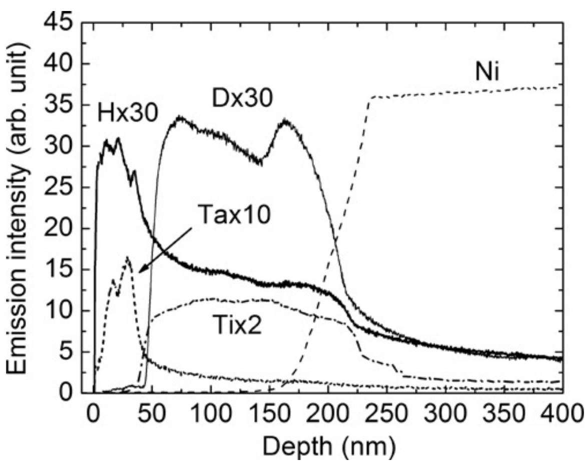
Deuterium/helium depth profile measured by GDOES

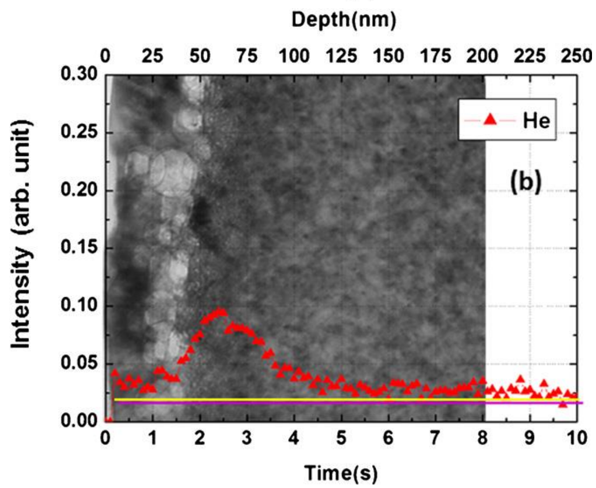
Deuterium/helium retention measured by glow discharge optical emission

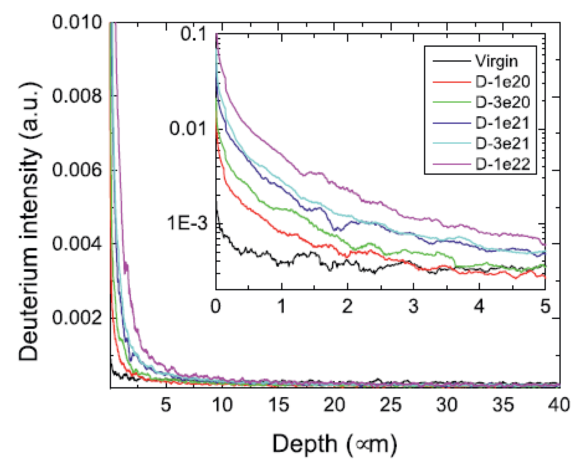












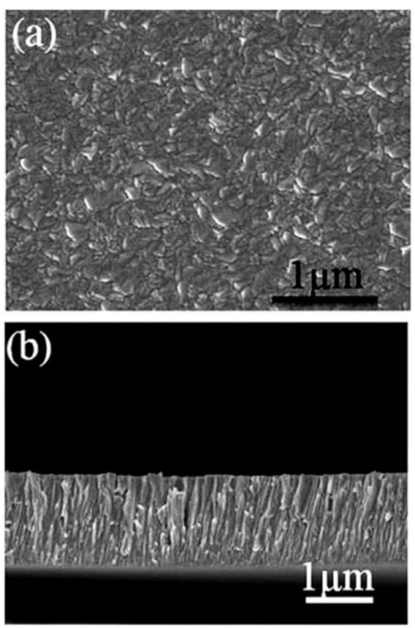
Yuji Hatano, Fus. Eng. Des, 2012

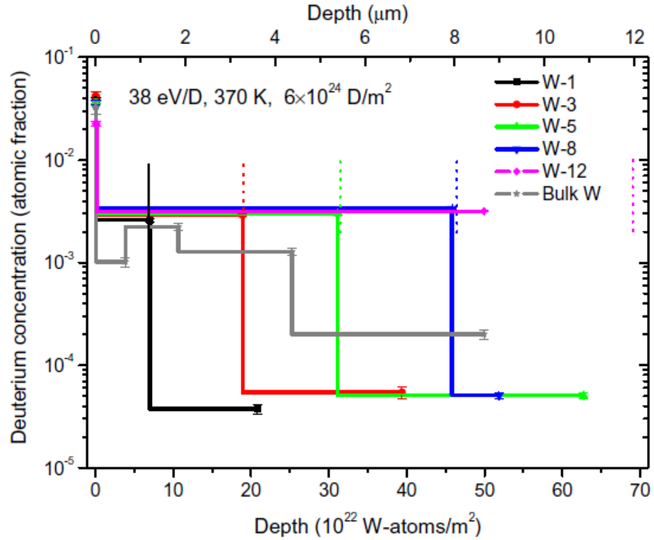
Chase N. Taylor, Nucl. Mater. Eng, 2018

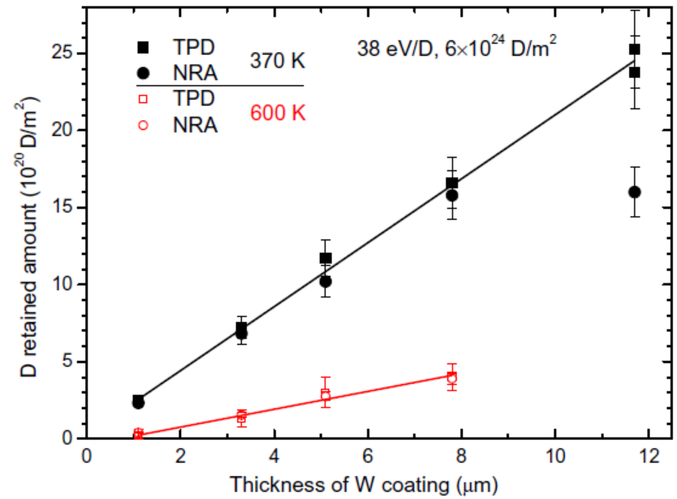
Deuterium/helium depth profile measured by GDOES

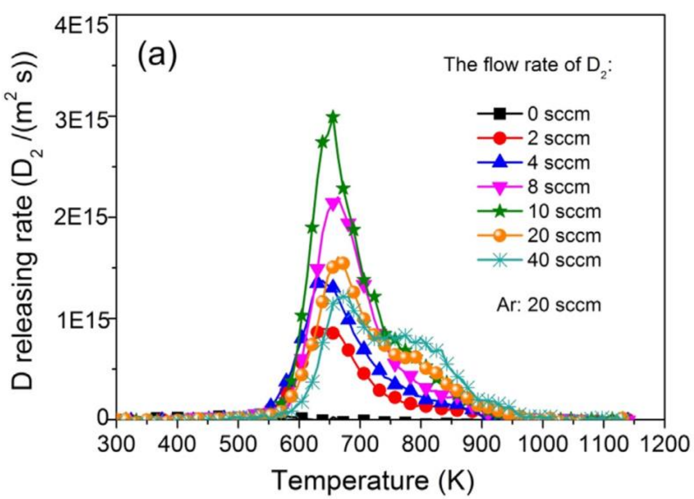
Deuterium retention measured by GDOES using metal/D coating

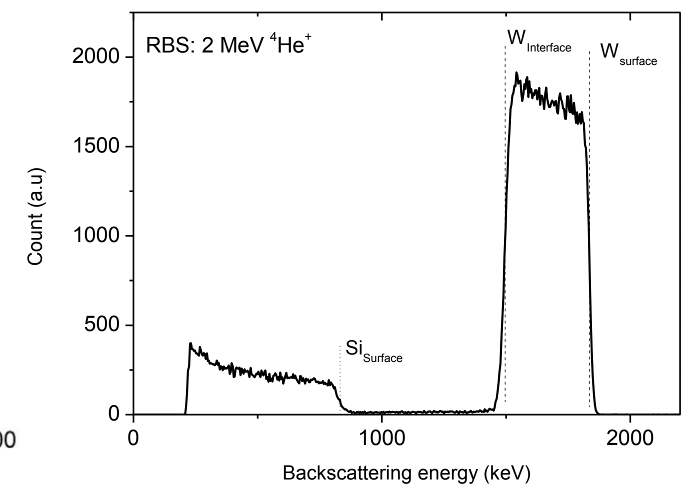
Metal/D coating





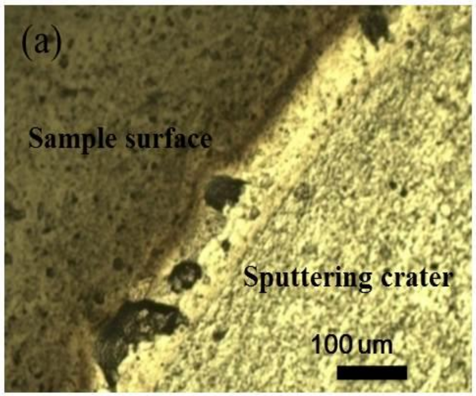


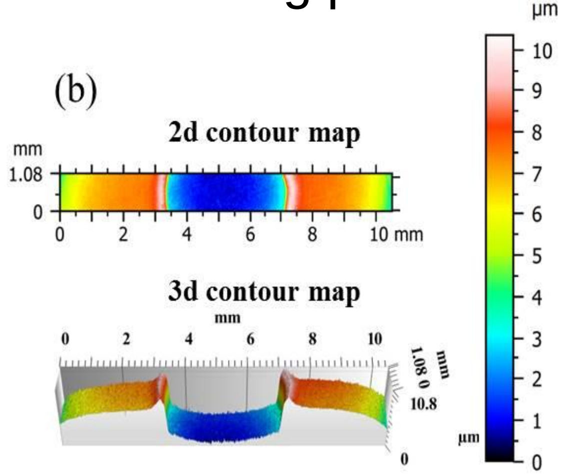


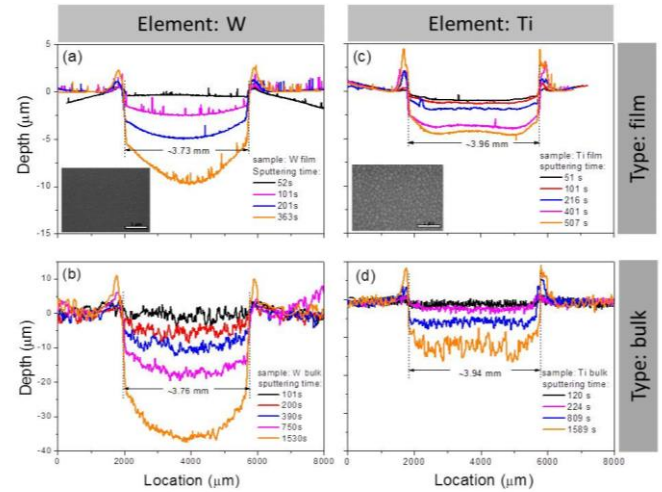


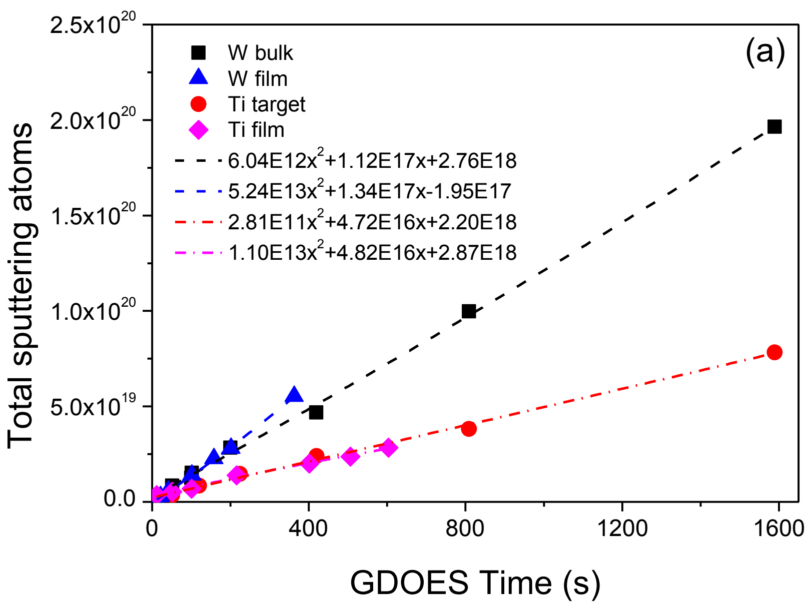
Deuterium/helium depth profile measured by GDOES

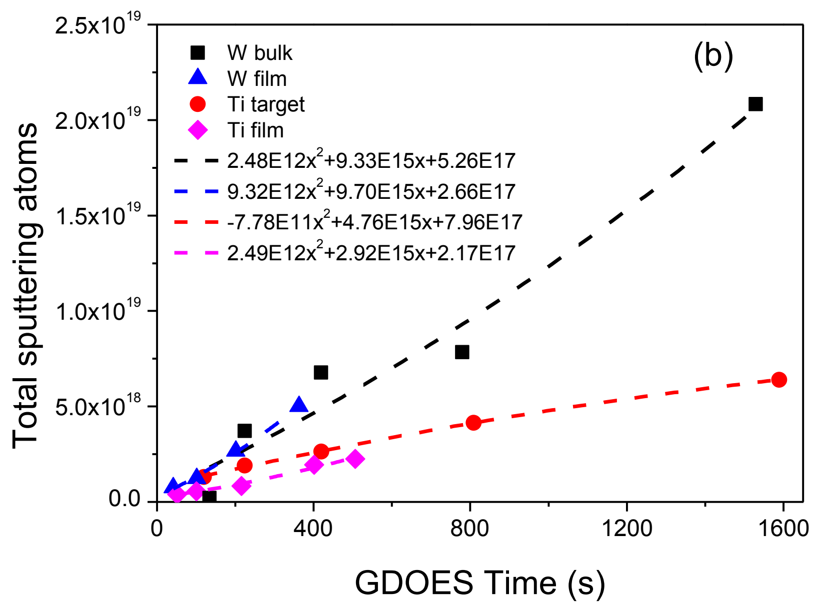
Sputtering depth calibration using profile meter





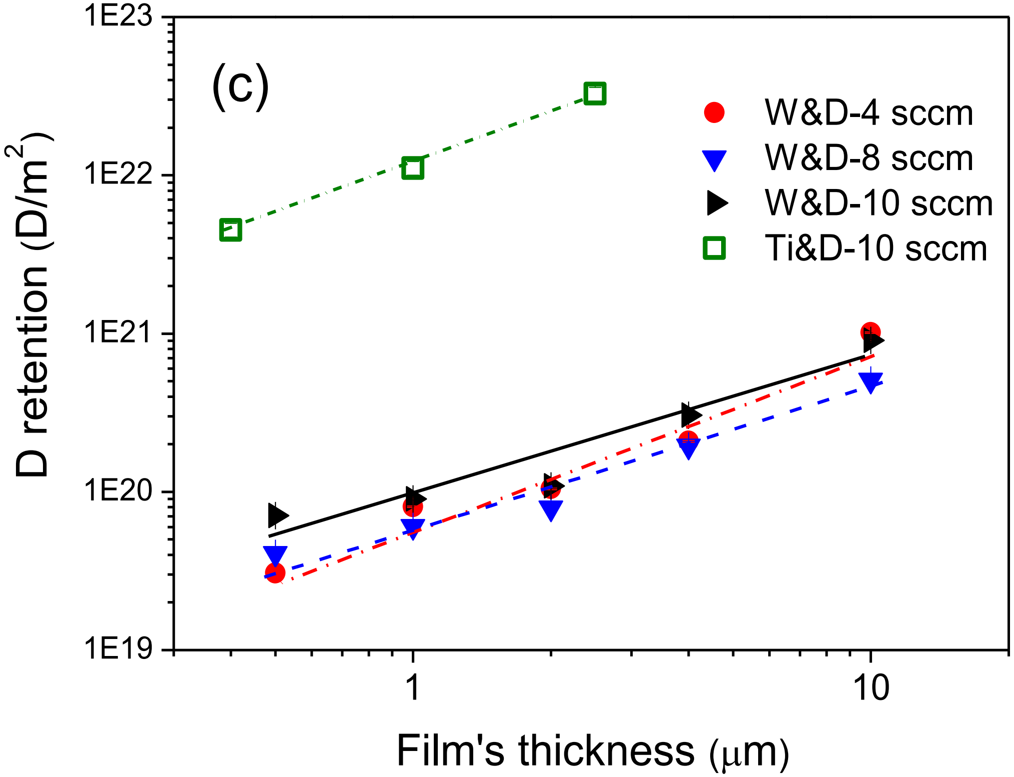


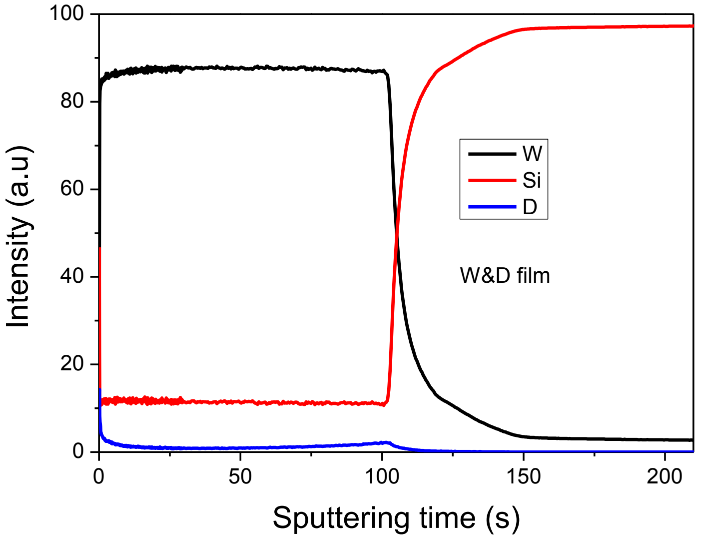


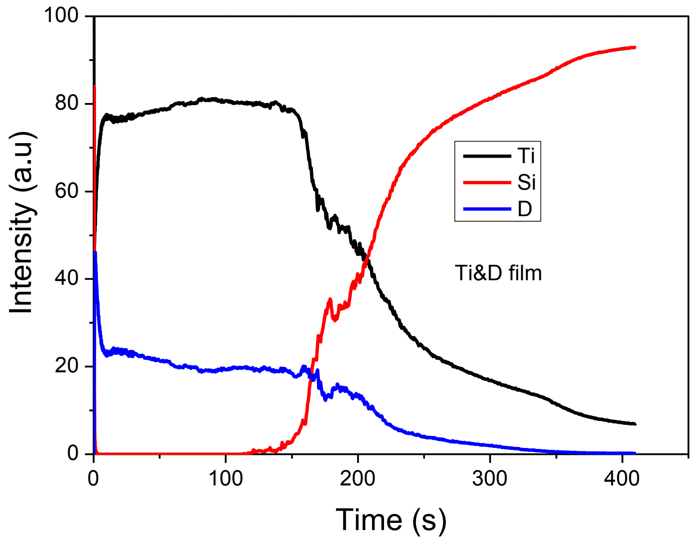


Deuterium/helium depth profile measured by GDOES

Metal/D coatings (TiD,W/D) were used as calibration samples







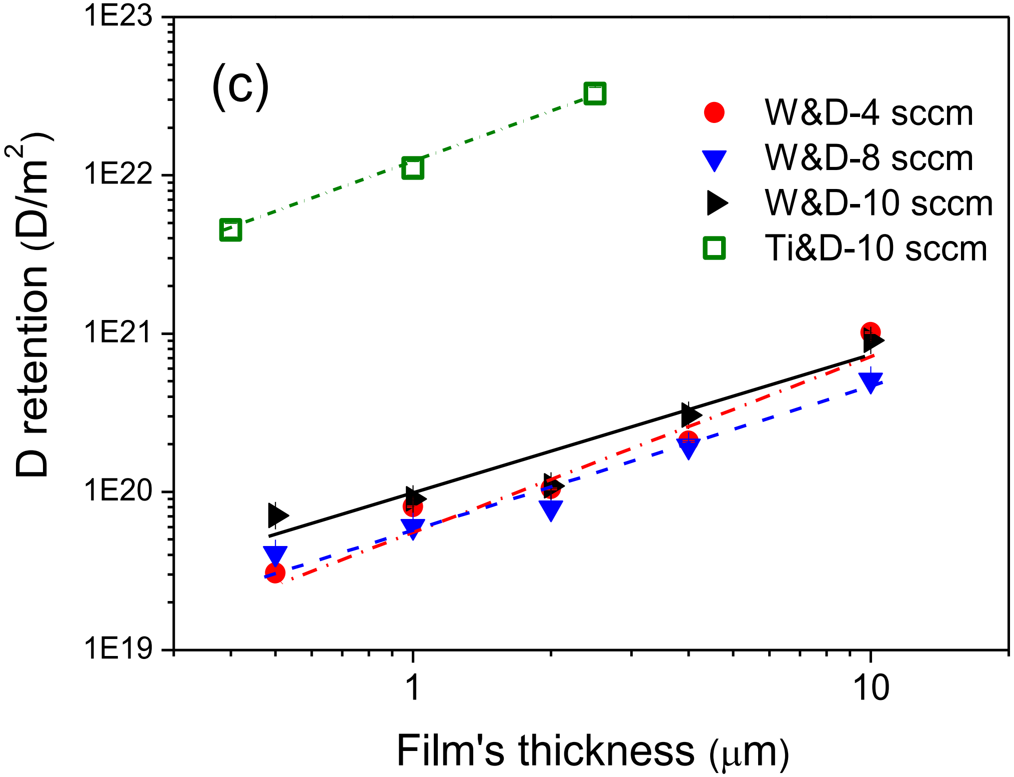
Coatings with different deuterium concentration

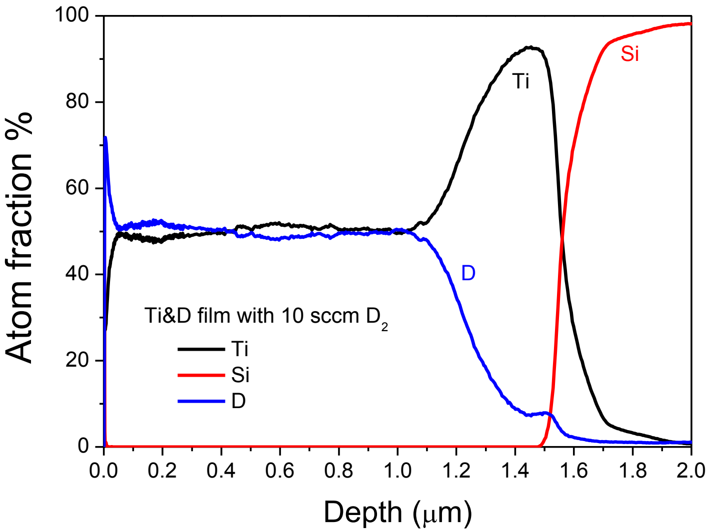
were produced by magnetron sputtering:

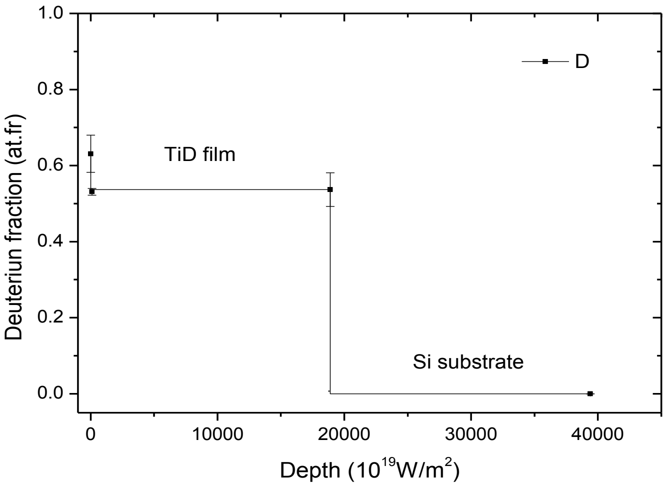
TiD films: 0.3-0.5 at.fr W/D films: ~10^{-3} at.fr

Deuterium/helium depth profile measured by GDOES

Metal/D coatings (TiD,W/D) were used as calibration samples







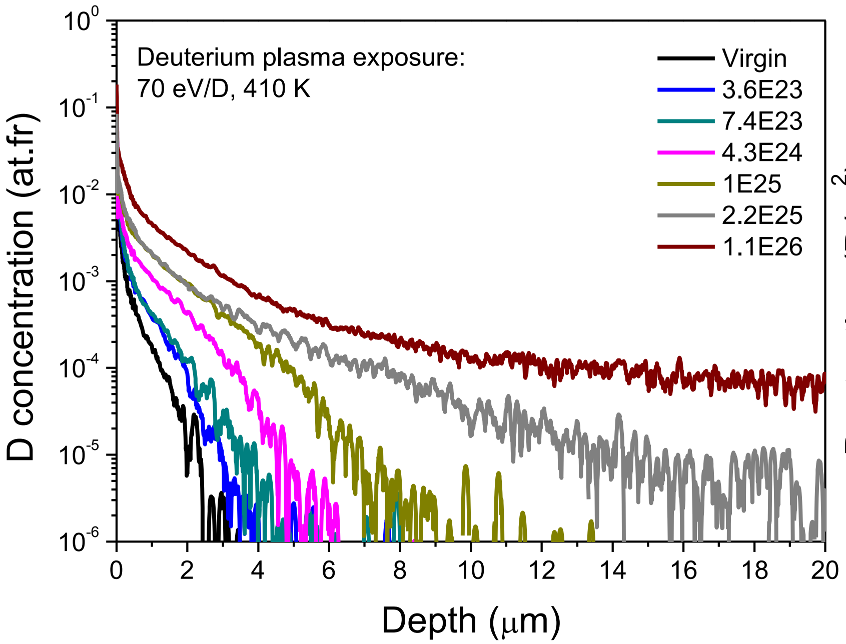
Coatings with different deuterium concentration

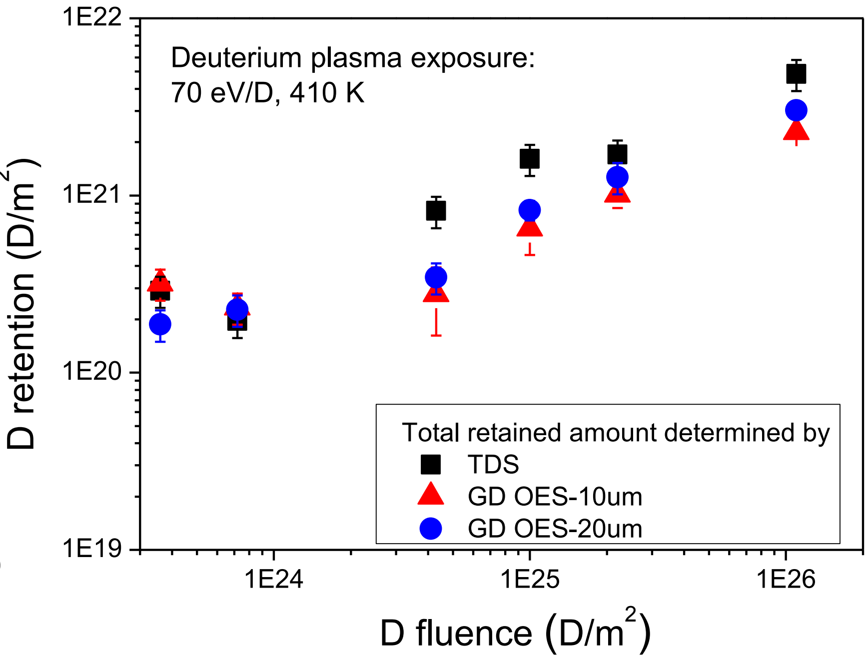
were produced by magnetron sputtering:

TiD films: 0.3-0.5 at.fr   W/D films: ~10^{-3} at.fr

Deuterium/helium depth profile measured by GDOES

Deuterium depth profile of **tungsten** samples exposed to deuterium plasma up to a fluence of 10^{26} D/m^2.

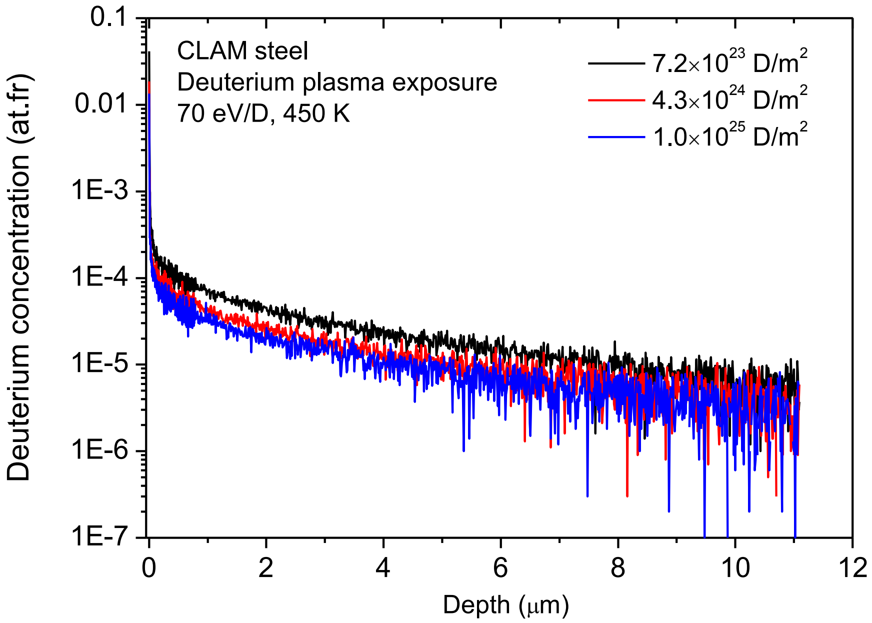


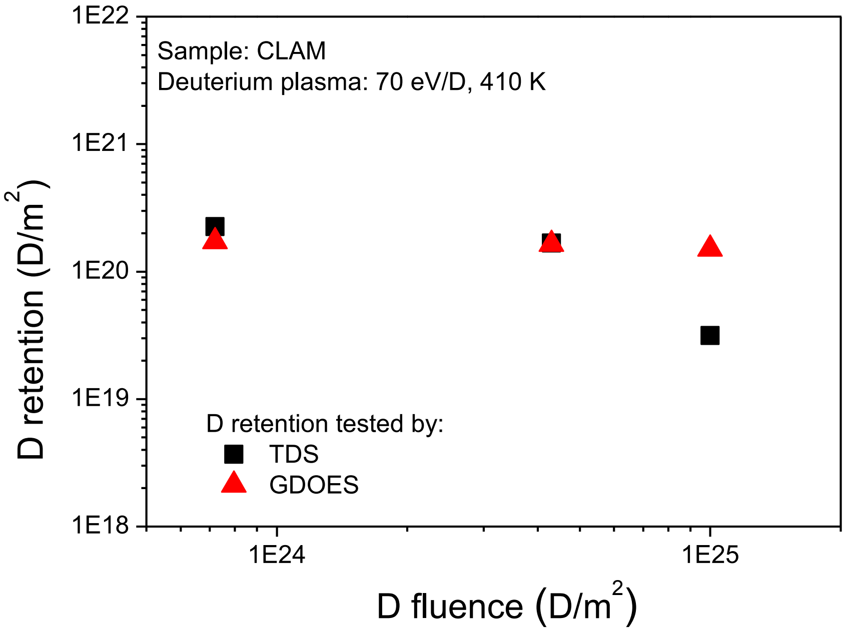


- A clear diffusion trend with respect to the implantation fluence
- Total D amount measured by two methods shows similar increase tendency
- GDOES can be used to evaluate the deuterium depth profile up to 20 μm

Deuterium/helium depth profile measured by GDOES

Deuterium depth profile of **CLAM steel** samples exposed to deuterium plasma up to a fluence of 10^{26} D/m^2.



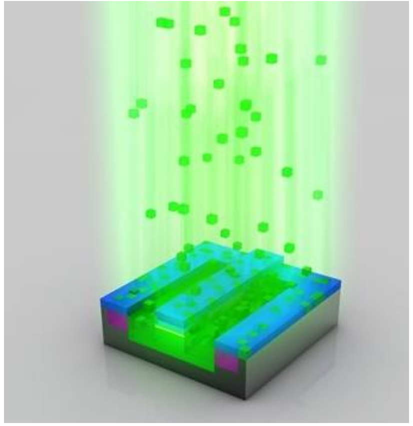


- No diffusion process similar with tungsten was found in steel, deuterium concentration decrease slightly with increasing incident fluence
- GDOES shows mismatch with TDS at higher fluence, due to low D concentration in steel

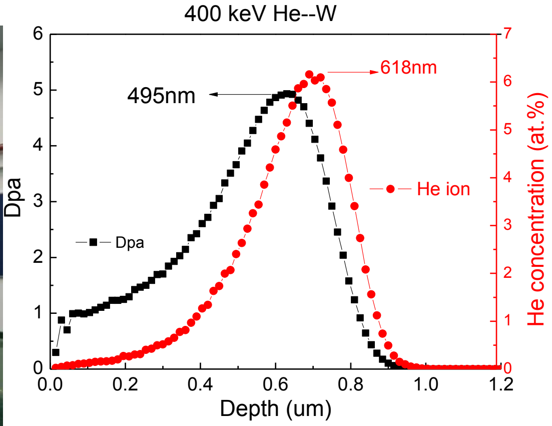
Deuterium/helium depth profile measured by GDOES

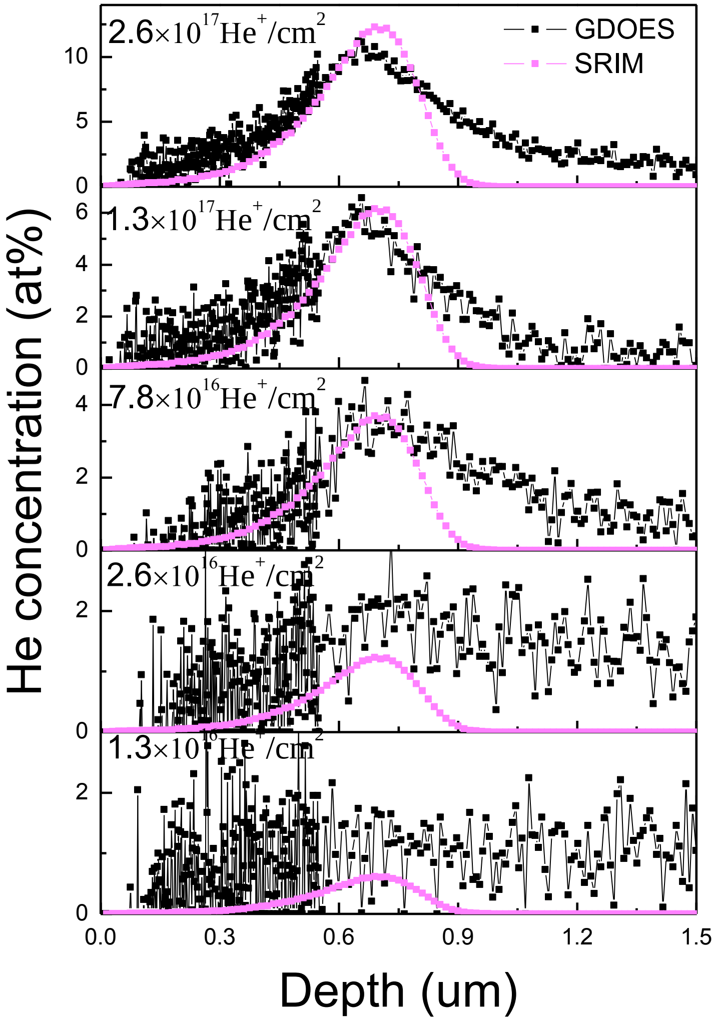
Helium retention measured by GDOES using implanted sample

Sample preparation



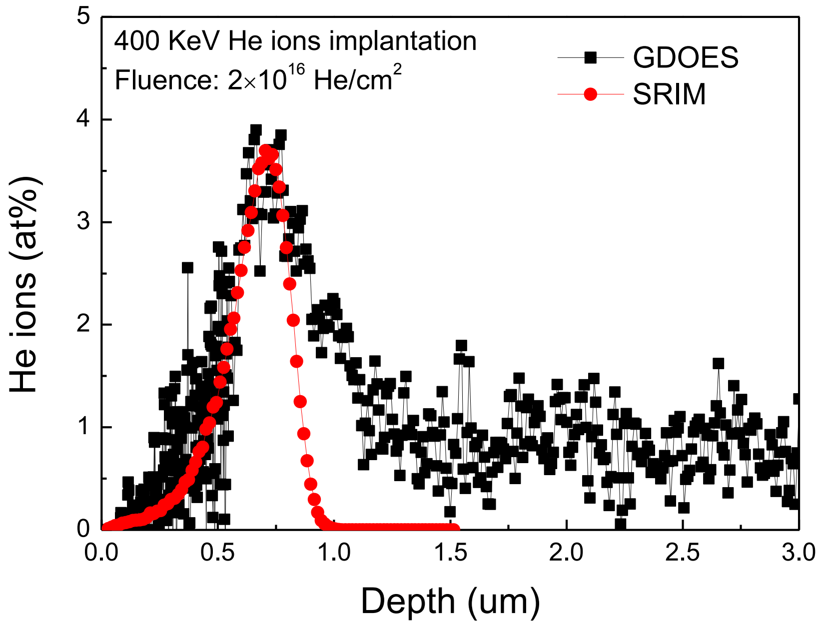
Implantation parameters	
Ions	Helium
Energy	100-400 KeV
Fluence	10^{15}-10^{18} ions/cm^2
Temp	RT-350 K

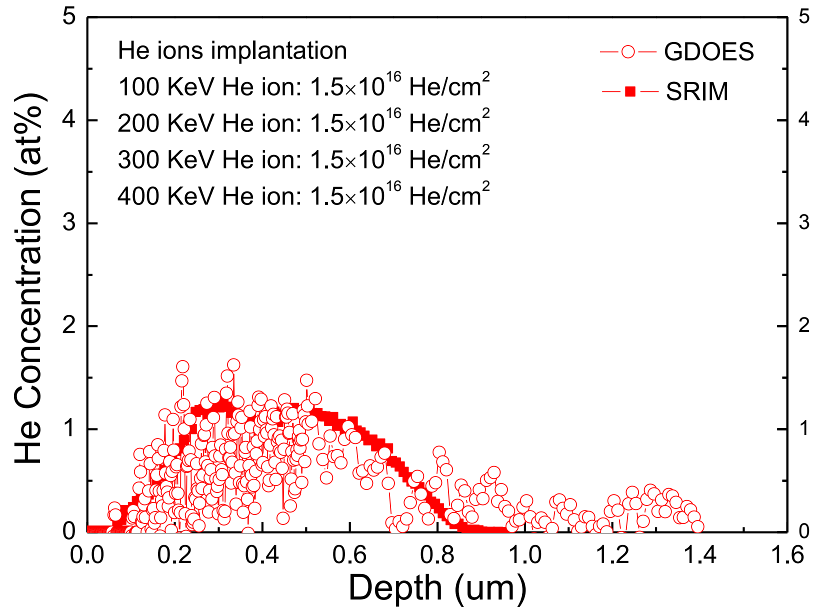




Deuterium/helium depth profile measured by GDOES

Helium depth profile and retention measured by GDOES

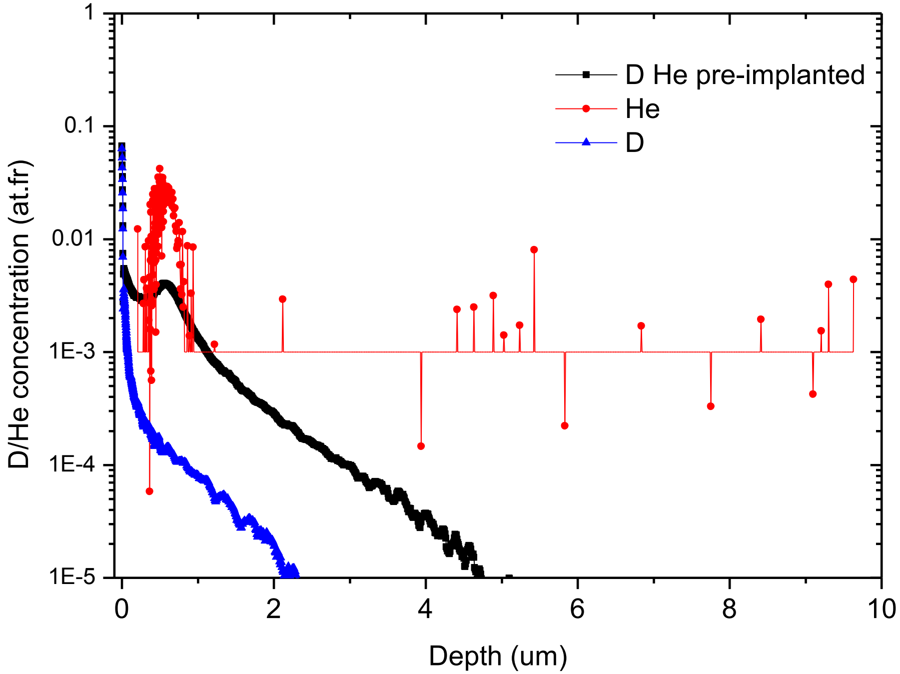


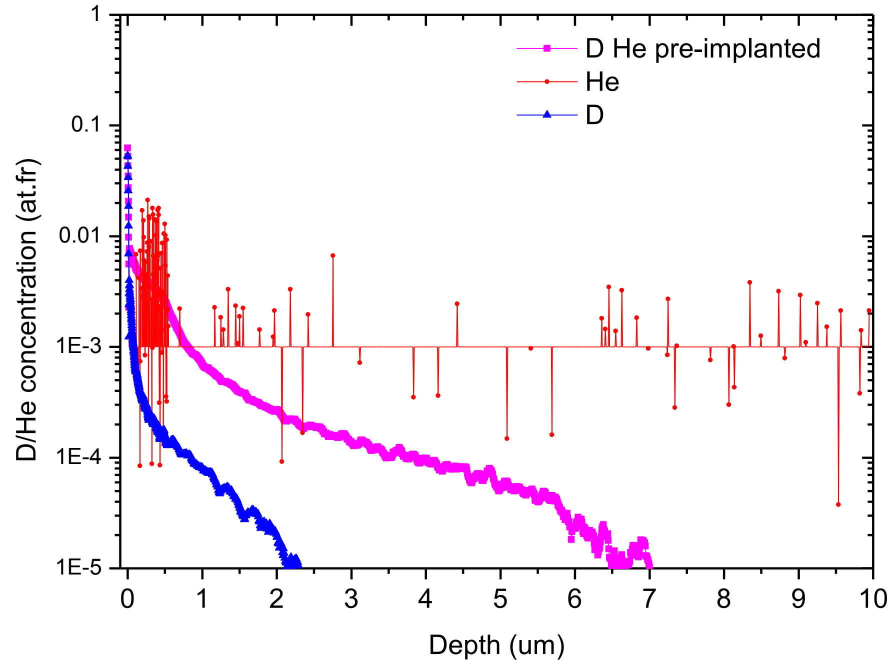


- Helium ions implanted tungsten was used to as calibration samples
- GDOES can be used to evaluate the helium depth profile
- the measurement low limitation up to 10^{-3} at.fr

Deuterium/helium depth profile measured by GDOES

Influence of helium pre-implantation on deuterium retention





	He ions implantation	D plasma exposure
1st sample	400KeV	38eV/D, 400 K, 1×10^{25}D/m^2
2nd sample	100KeV, 200KeV, 300KeV, 400KeV	38eV/D, 400 K, 1×10^{25}D/m^2
3rd sample	/	38eV/D, 400 K, 1×10^{25}D/m^2

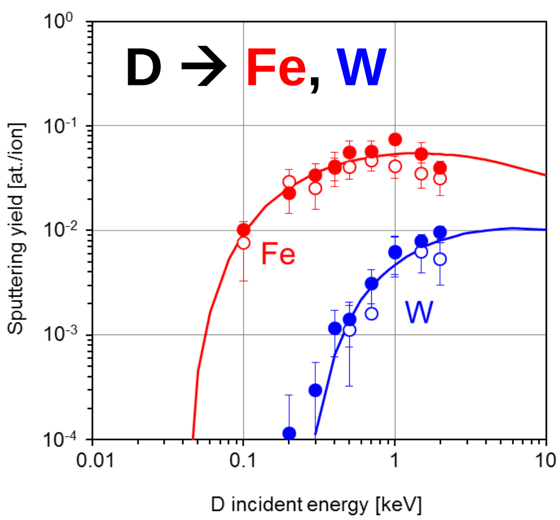
Outline

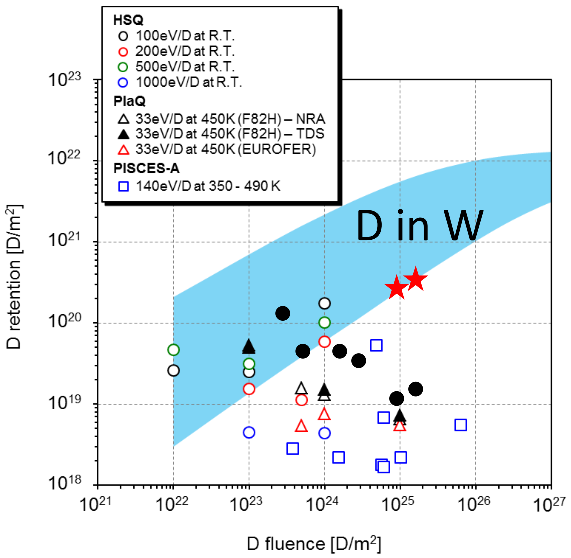
- Deuterium and helium depth profile determined by glow discharge optical emission spectroscopy
- Retention and erosion of RAFM steel exposed to deuterium plasma
- Summary

Retention and erosion of RAFM steel exposed to deuterium plasma

● Reduced activation ferritic martensitic (RAFM) steel has been proposed to use as plasma-facing material in remote regions of the first wall.

- Blanket modules blankets are made of RAFM steel
- Technologically it would be much easier and less expensive
- H retention in RAFM steels is low, even lower than in W

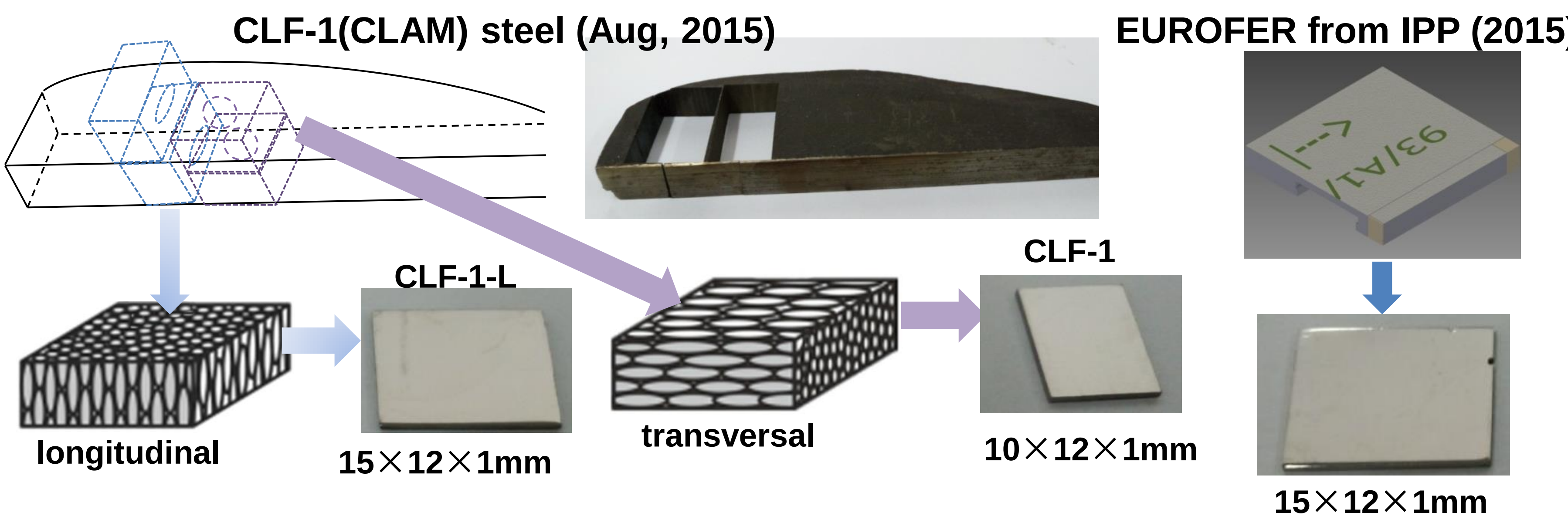




Retention and erosion of RAFM steel exposed to deuterium plasma

Composition of various RAFM steel grades (in wt.%)

RAFM steel	Cr	W	Mn	V	Ta	C	N	P	S	Fe
CLF-1	8.5	1.55	0.6	0.3	0.1	0.12	0.02	0.003	--	Bal.
CLAM	9.11	1.52	0.41	0.19	0.2	0.12	0.002	0.003	0.003	Bal.

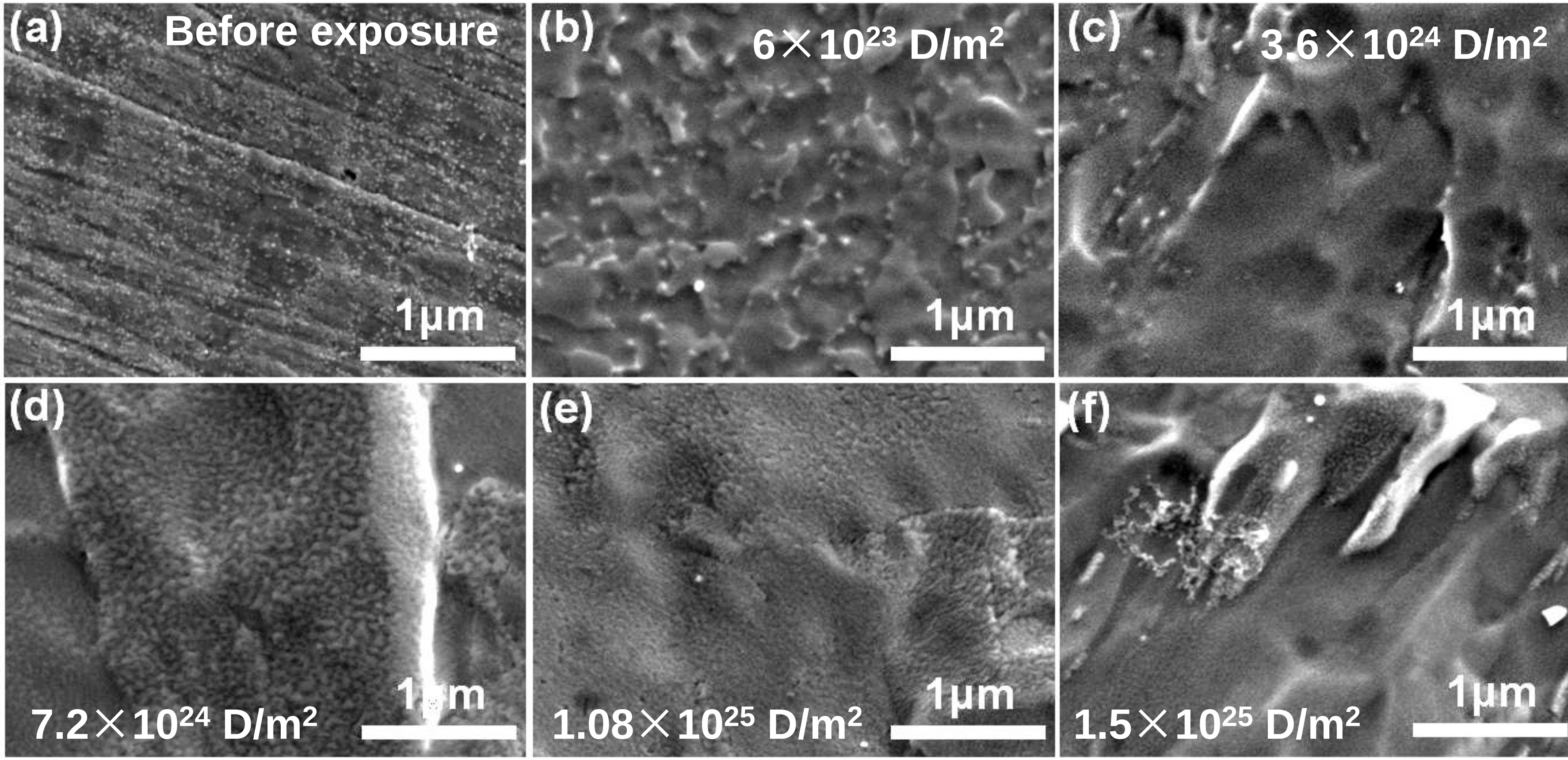


Sample treatment:

1st: Polishing with increasingly fine-grained SiC grinding paper, **2nd:** Polishing with diamond suspension and water on the nap cloth, **3rd:** heating in vacuum at 800 K for 1 hour

Retention and erosion of RAFM steel exposed to deuterium plasma

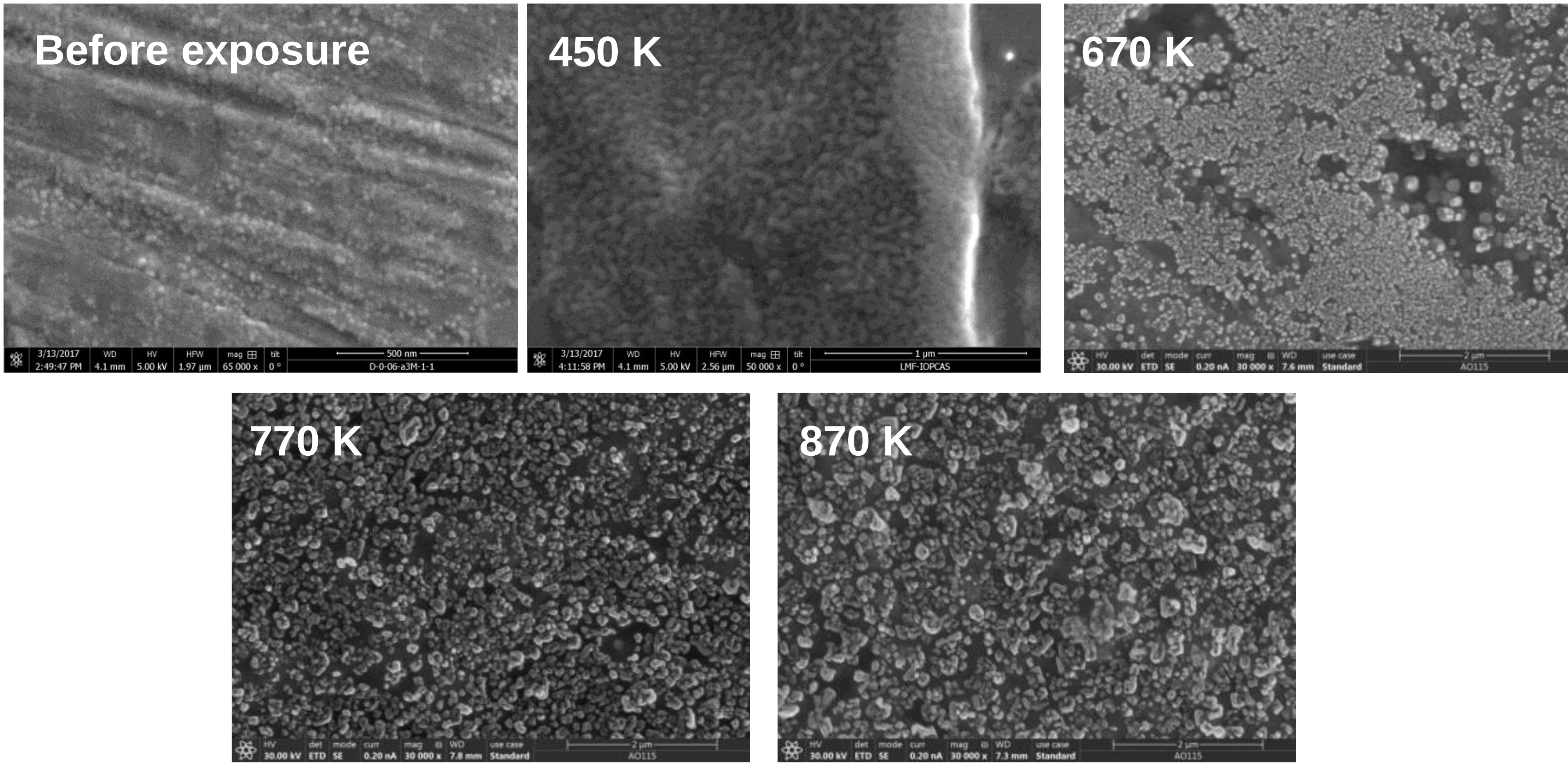
Morphology changes- fluence dependence



Deuterium plasma exposure: Energy: 150 eV/D, temperature: 450 K

Retention and erosion of RAFM steel exposed to deuterium plasma

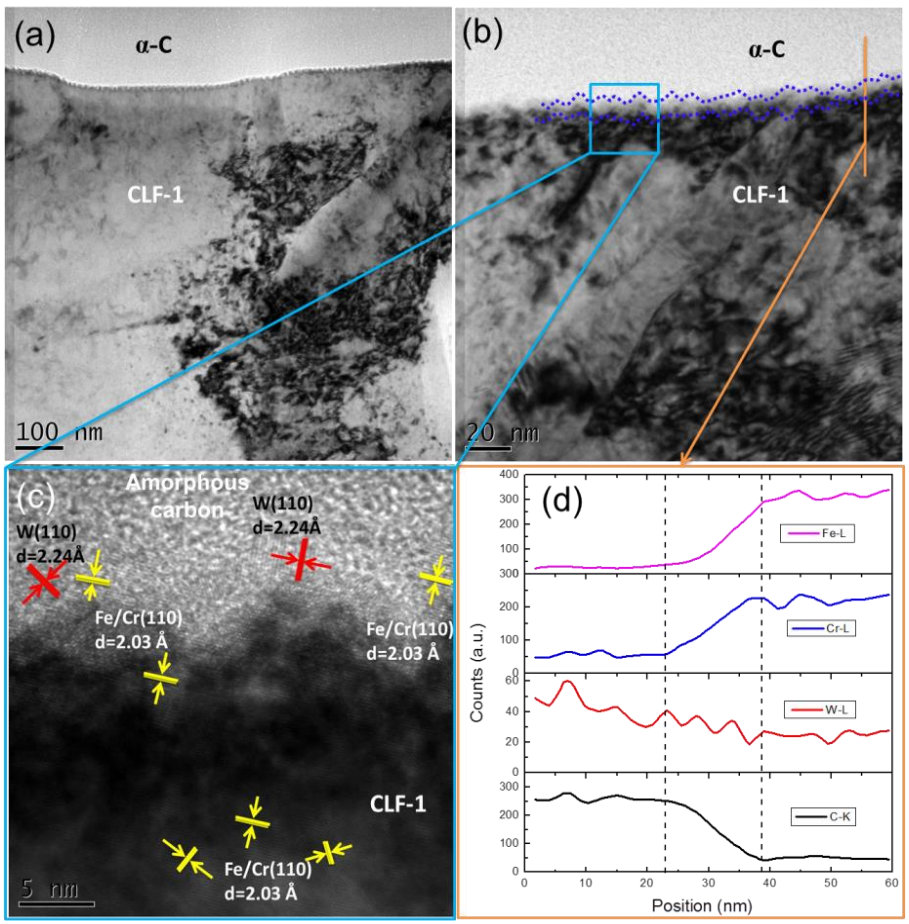
Morphology changes- temperature dependence

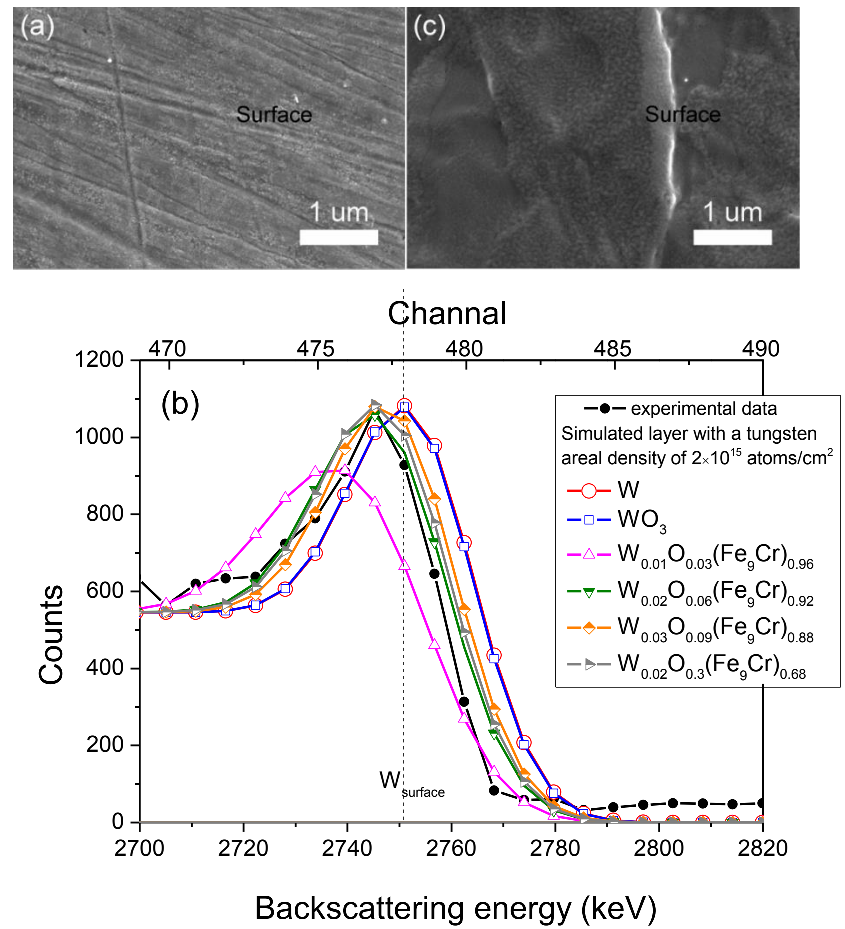


- CLF-1 exposed to deuterium plasma: Development of surface topography is strongly affected by the exposure temperature.

Retention and erosion of RAFM steel exposed to deuterium plasma

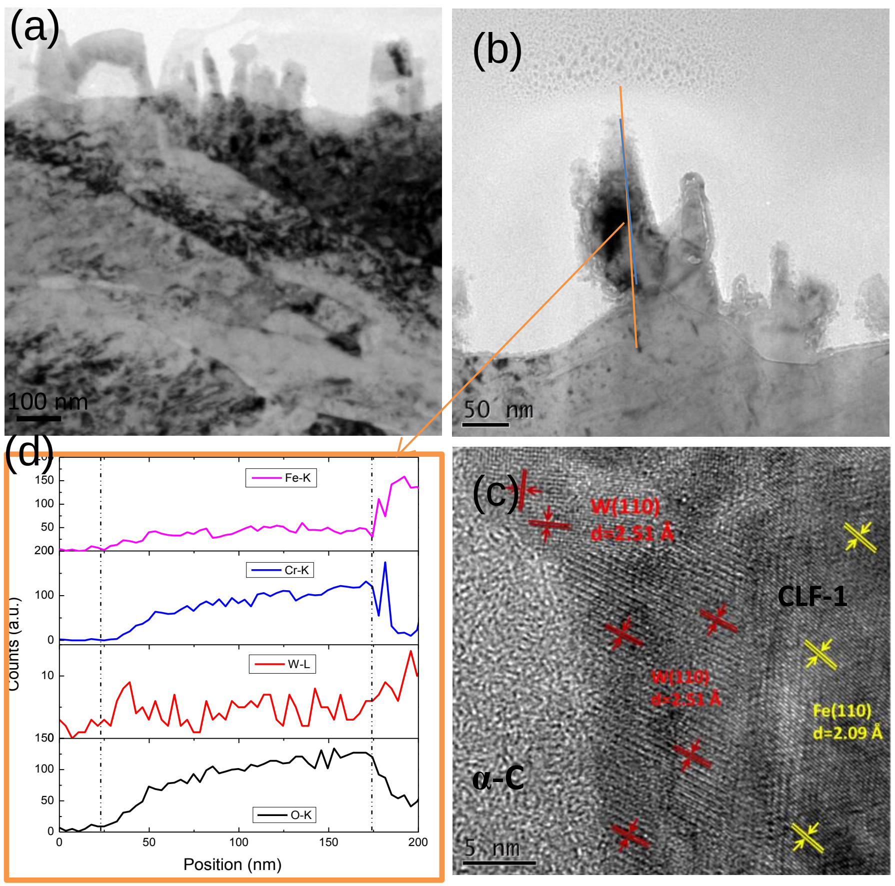
- W concentration increased after deuterium plasma exposure but no continuous film formed at the surface, the thickness of the enrichment layer is less than 5 nm, in which W concentration is 4-5 times higher than bulk.

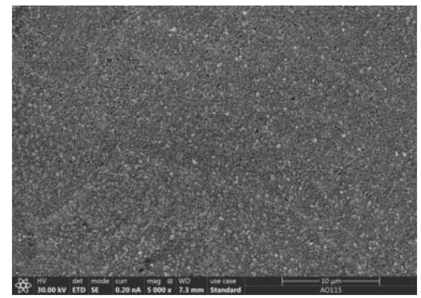


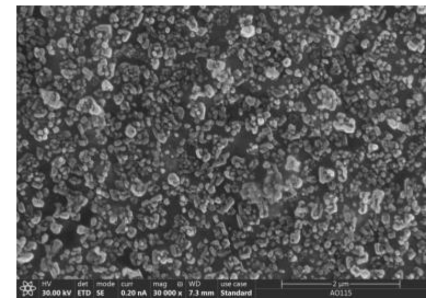


Retention and erosion of RAFM steel exposed to deuterium plasma

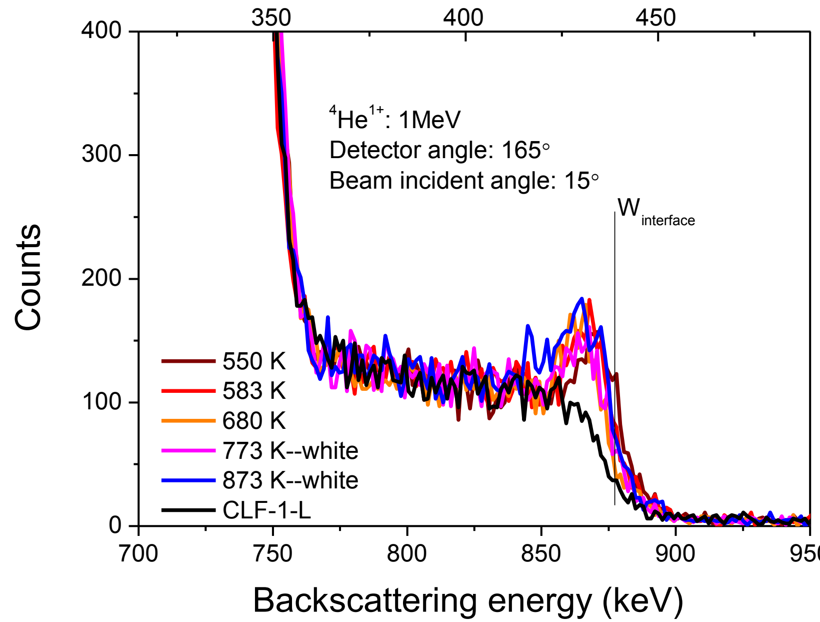
- W concentration increased after deuterium plasma exposure, the thickness of the enrichment layer is about 5-10 nm, in which W concentration is 8-10 times higher than bulk.





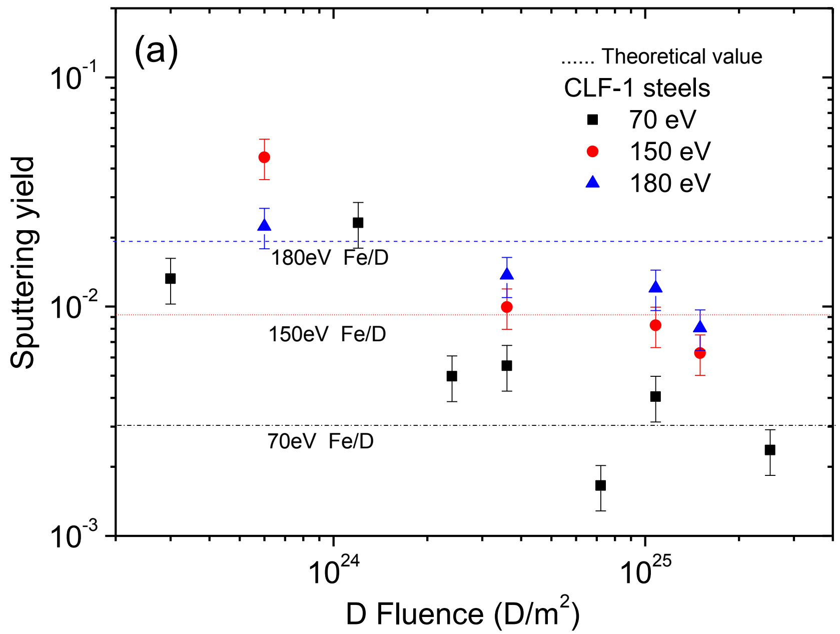


Channel

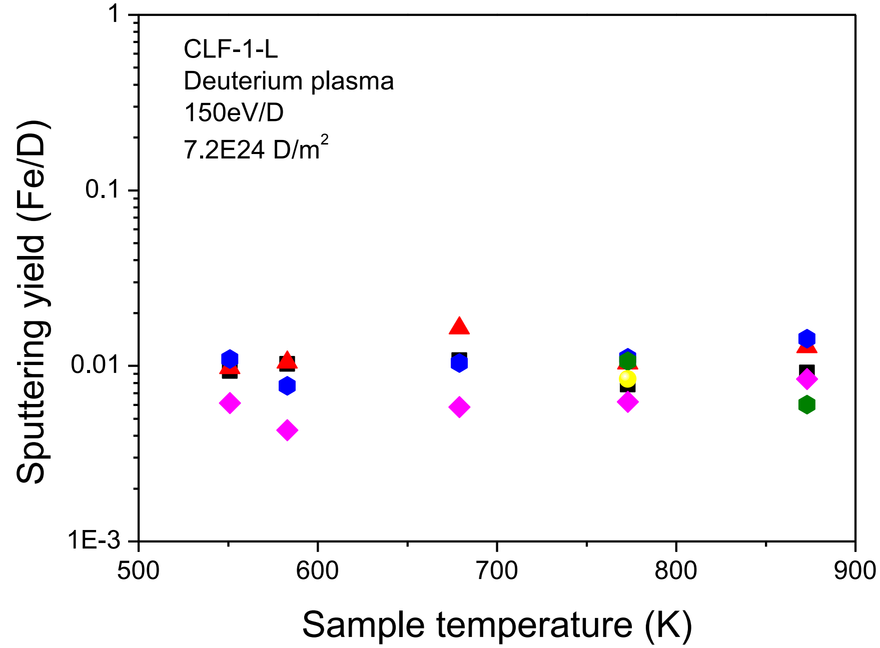


Retention and erosion of RAFM steel exposed to deuterium plasma

Fluence dependence of sputtering yield of CLF-1 steel



Temperature dependence of sputtering yield of CLF-1 steels

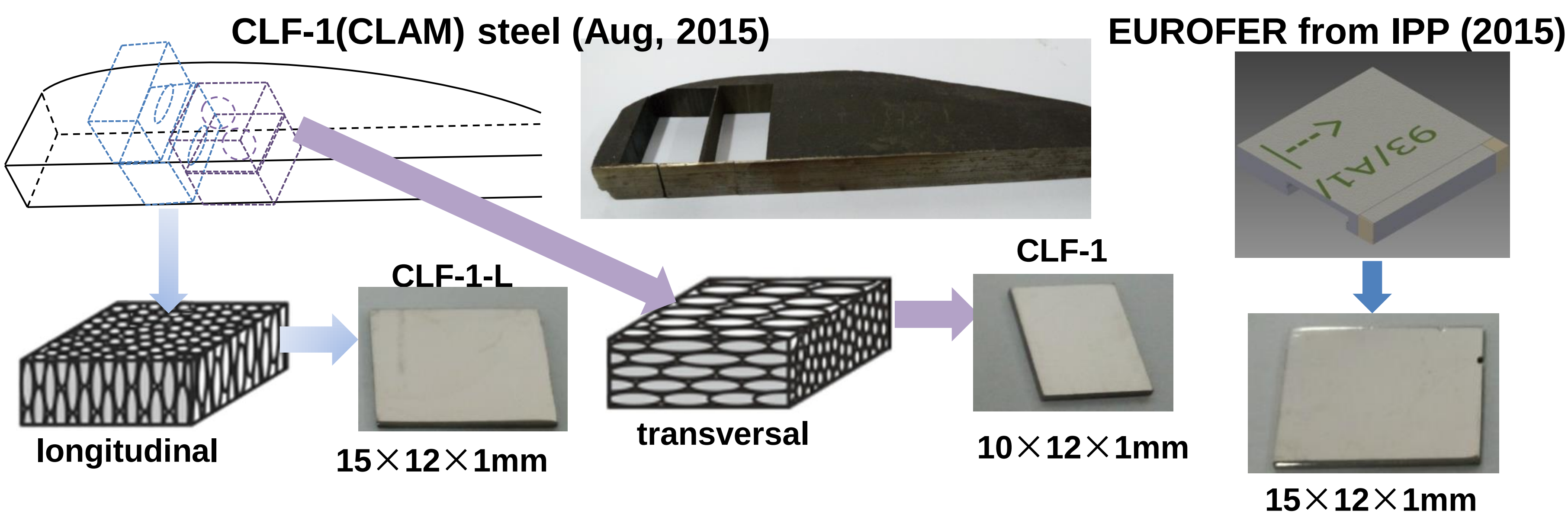


Sputtering yield of CLF-1 decreases with increasing of incident fluence, no clear saturation of yield at fluence of 10^{25} D/m^2. No obvious change of sputtering yield with increase of temperature to 900 K.

Retention and erosion of RAFM steel exposed to deuterium plasma

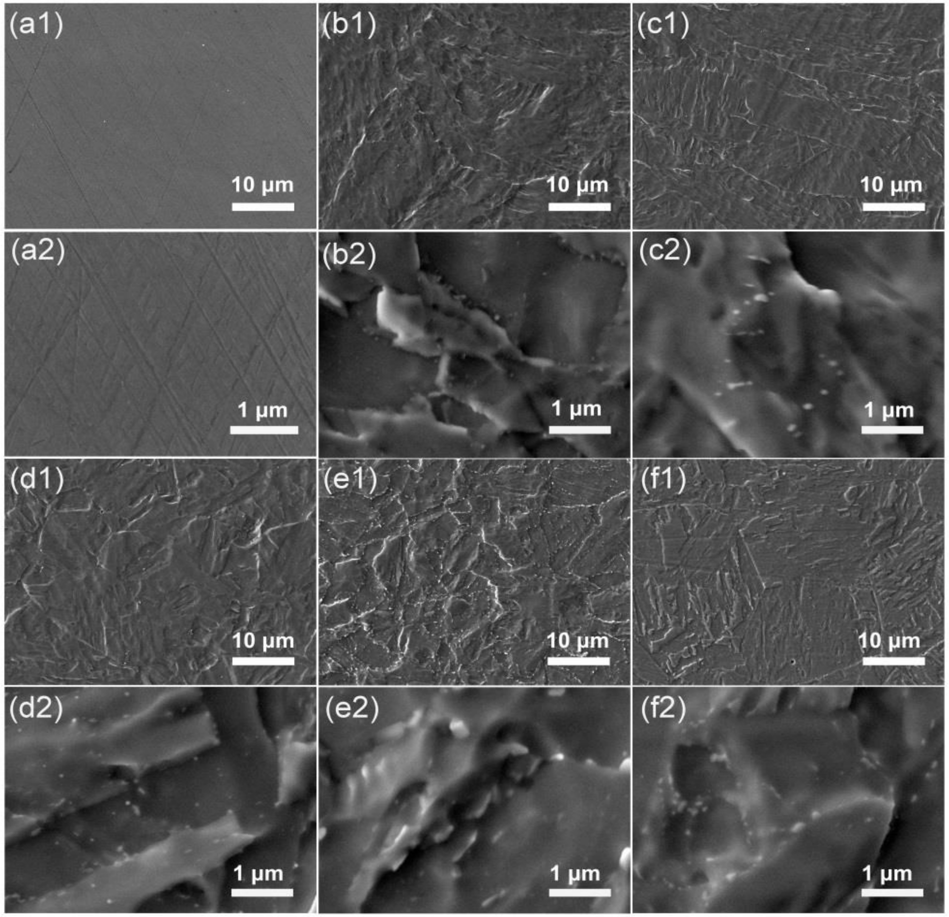
Composition of various RAFM steel grades (in wt.%)

RAFM steel	Cr	W	Mn	V	Ta	C	N	P	S	Fe
CLF-1	8.5	1.55	0.6	0.3	0.1	0.12	0.02	0.003	--	Bal.
CLAM	9.11	1.52	0.41	0.19	0.2	0.12	0.002	0.003	0.003	Bal.
EUROFER	9.0	1.1	0.40	0.20	0.12	0.11	0.03	0.004	0.003	Bal.
RUSFER	11.17	1.15	0.76	0.32	0.11	0.15	0.055	0.001	0.006	Bal.

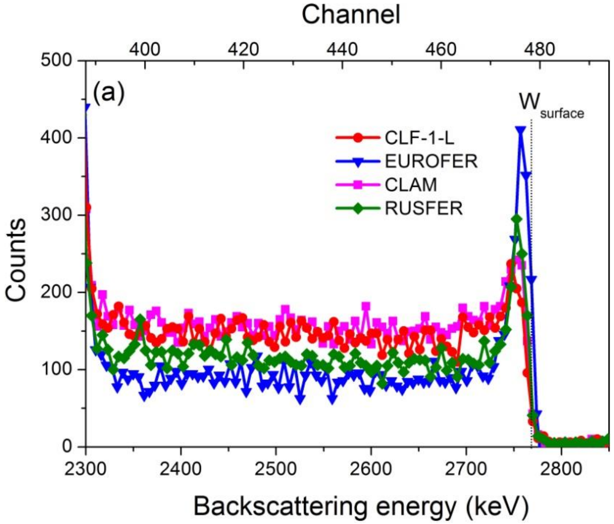


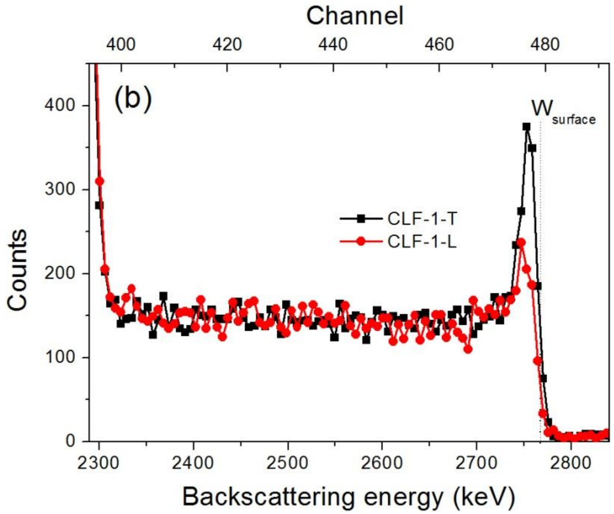
Retention and erosion of RAFM steel exposed to deuterium plasma

Morphology and tungsten enrichment after deuterium plasma exposure



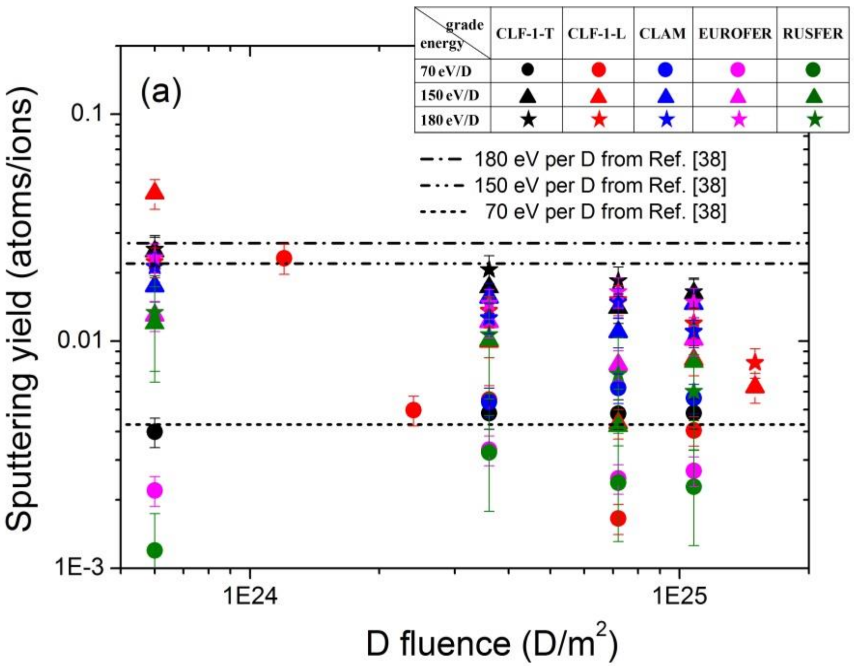
Different RAFM steel grades



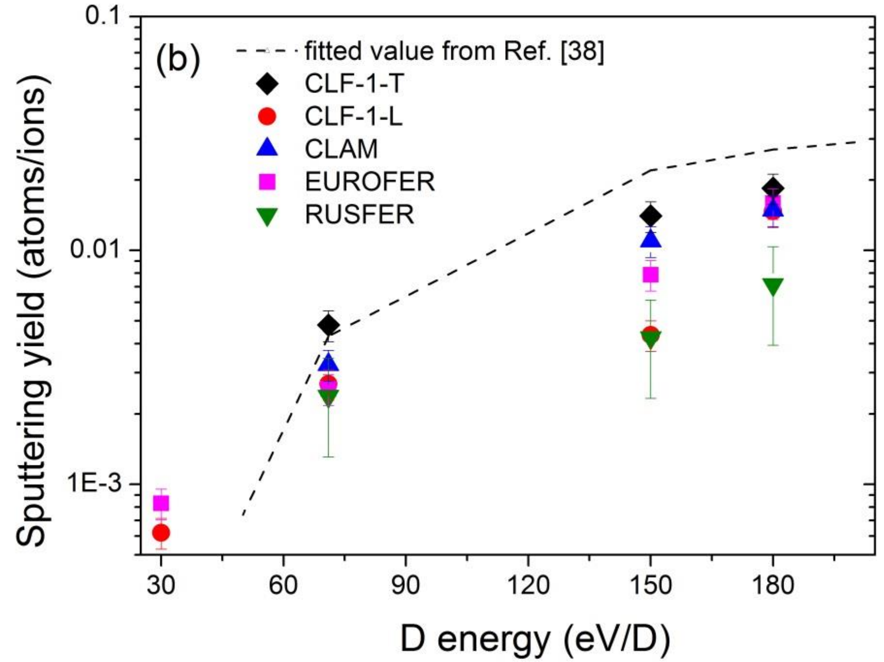


Retention and erosion of RAFM steel exposed to deuterium plasma

Sputtering yield as function of fluence



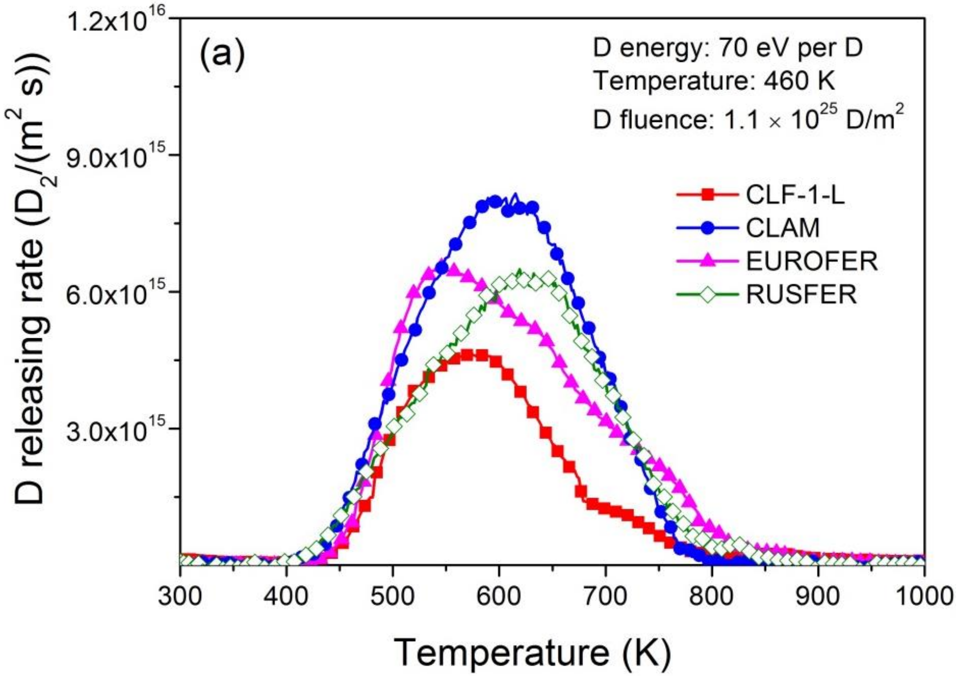
Sputtering yield as function of energy



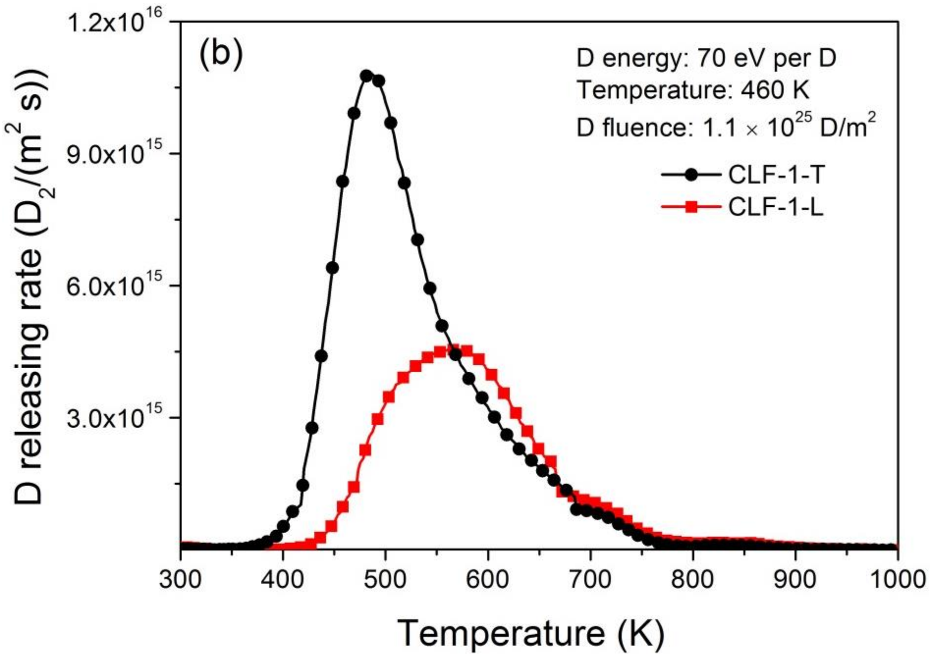
Sputtering yield of CLF-1 and EUROPER steels is lower than pure Fe, clear decreases of yield of CLF-1 steels with increasing of incident fluence. No clear saturation of yield at fluence of 10^{25} D/m^2.

Retention and erosion of RAFM steel exposed to deuterium plasma

Deuterium releasing of different RAFM steel grades measured by TDS



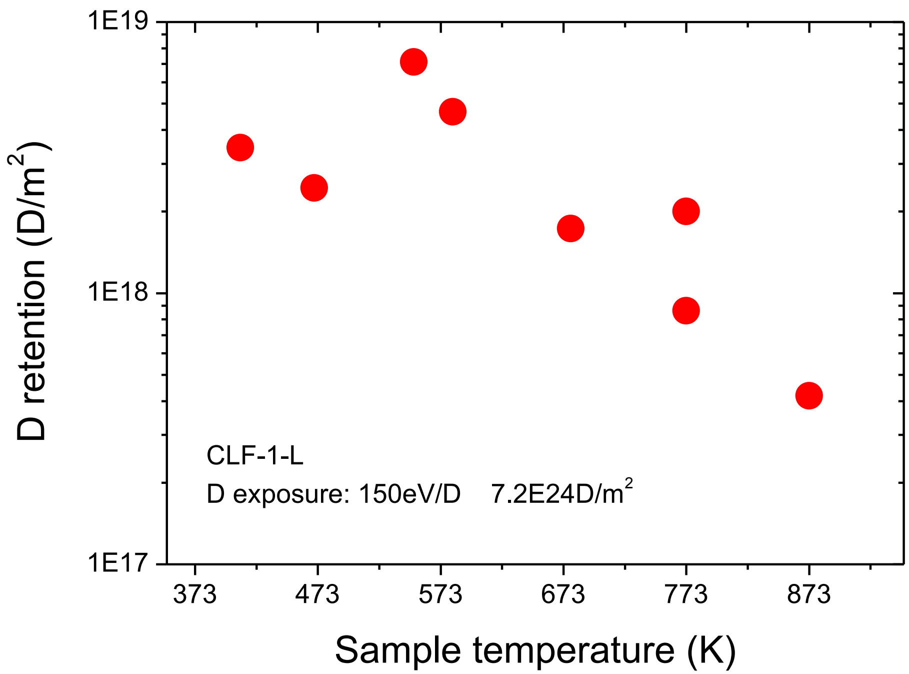
Deuterium releasing of CLF-1 with different cut direction



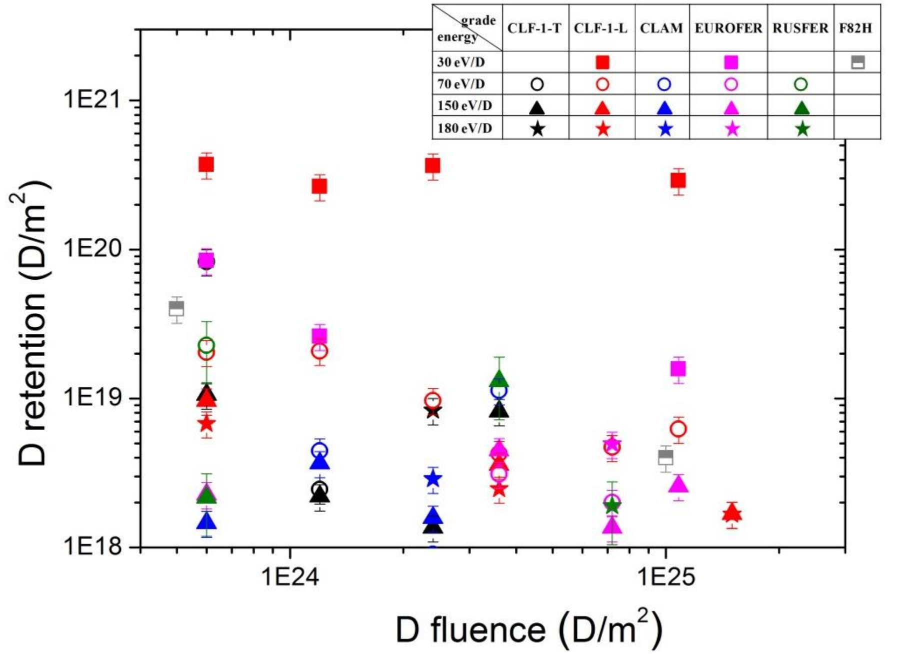
Deuterium releasing from 400 to 800 K. Unusual deuterium thermal releasing from same kind of steel sample.

Retention and erosion of RAFM steel exposed to deuterium plasma

Deuterium retention of CLF-1 exposed at different temperature



Deuterium retention in different RAFM steel as function of fluence



Total deuterium retention decrease in CLF-1 with the increasing temperature

Total deuterium retention in different RAFM steel exposed to the same batch show a clear decrease trend

Summary

- A deuterium and helium depth profile measurement method was developed on GDOES based on co-deposited and implanted samples
- He pre-implanted clear increases the deuterium retention by increasing defects and promoting diffusion
- Surface enrichment of W and reduction of sputter yield were experimentally proven, but the reduction possibly strongly influenced by surface morphology development
- Total deuterium retention in different RAFM steel exposed to the same batch show a clear decrease trend

Thanks for your attention!