Surface modification by deuterium and helium bombardments in RAFM

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What kind of material "development" do we need to achieve for fusion reactor blanket system?

JAPAN DEMO

Safety

Basic strategy of safety assurance of fusion system
=> Basic principle for safety design/assessment and the technical criteria
=> **Fusion structural design criteria**

Structural design criteria of blanket

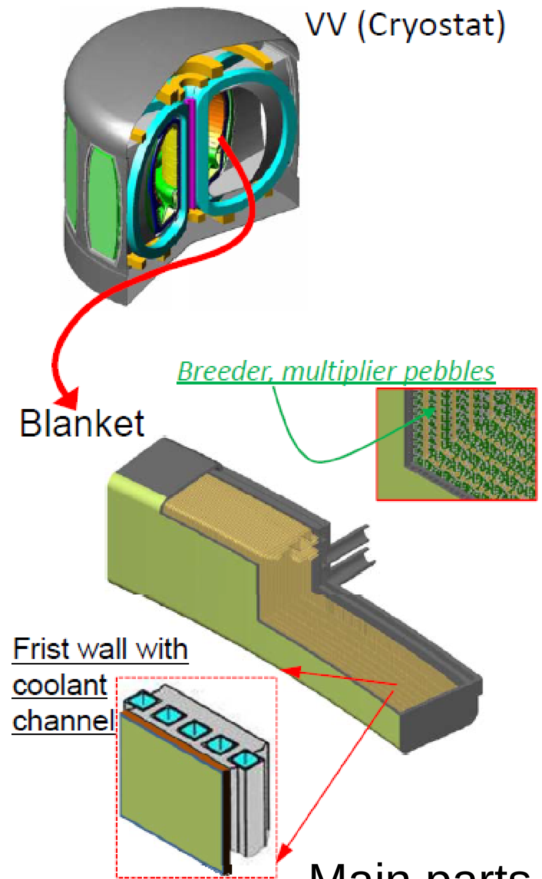
Function

The design have to assure
- ✓ Neutron shield
- ✓ Tritium breeding
- ✓ Heat generation

Material specification

The criteria and requirement define the requested specification of blanket structural material

Assure the requested specification
= Define a material standard



Main parts of F82H; FW, cooling pipe, back plate of BM (partially)

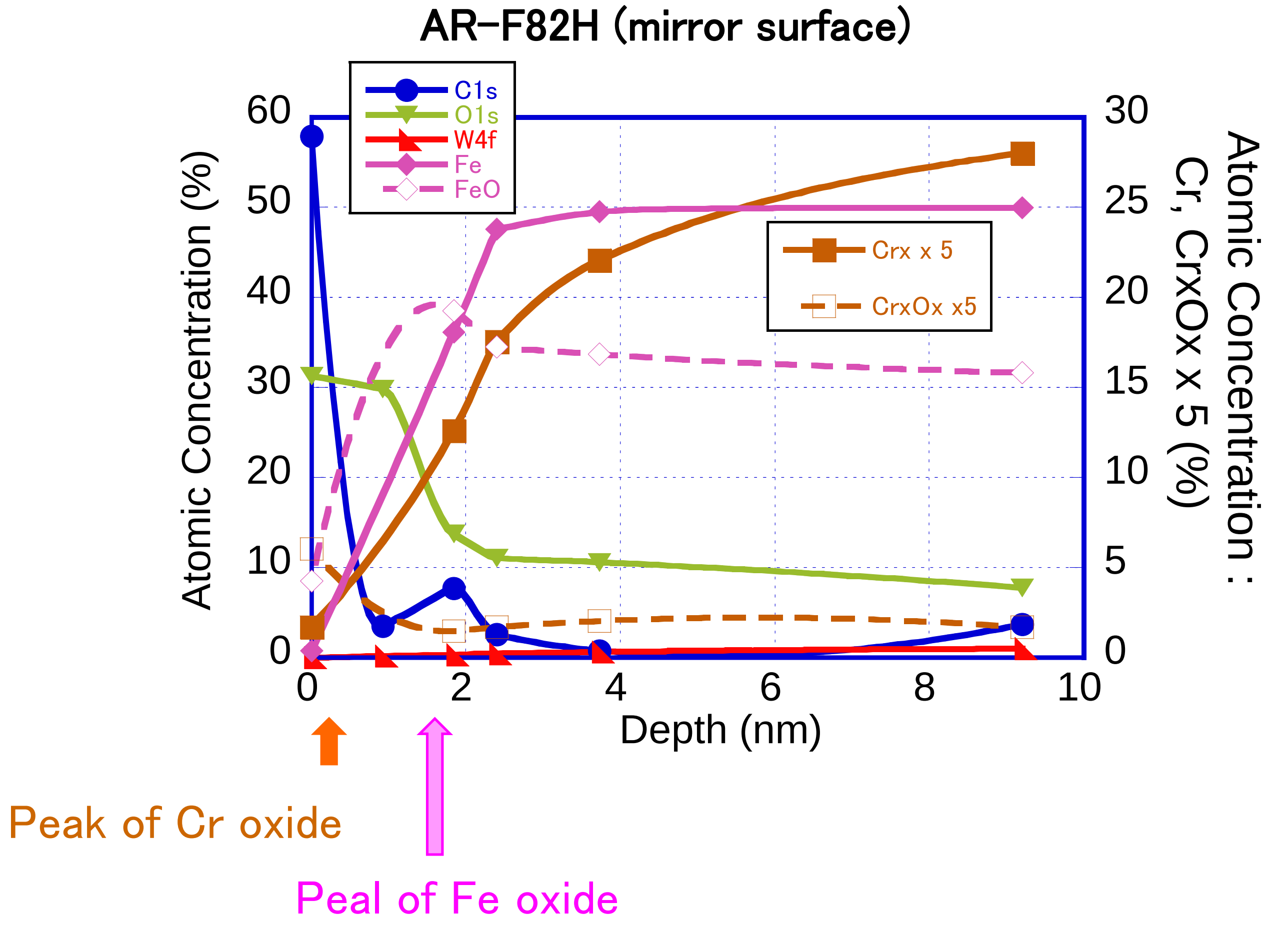
H. Tanigawa, 3rd IAEA DEMO programme WS, China (2015)

F82H for structural material : ~550°C, F82H / ODS steel : ~700°C
V alloy : ~700°C, V alloy / ODS : ~900°C, SiC/SiC : ~1000°C

Motivation

- Reduced Activation Ferritic/Martensitic (RAFM) steels are candidate materials for fusion DEMO reactors .
- Helium ash produced by D-T fusion reactions and hydrogen isotopes mix with each other in the vacuum vessel of DEMO reactors. To understand bulk fueling retention and tritium inventories of plasma facing materials in DEMO reactors, analysis of samples exposed to plasmas of both hydrogen and helium is essential.
- However, investigations of bulk retention after exposures to plasmas of the two elements are still limited for RAFM steels.
- In this study, RAFM steel, F82H and EUROFER alloys, samples are exposed to helium plasmas and the effects of helium bombardment is elucidated.

AR-F82H specimen with mirror polish



Oxide layer of 2 nm from the top surface including Cr– and Fe are observed by sputtered XPS (Ar, 4keV).

D retention in F82H and Eurofer (Fluence dependence)

Plasma exposure was done in Pla-Q

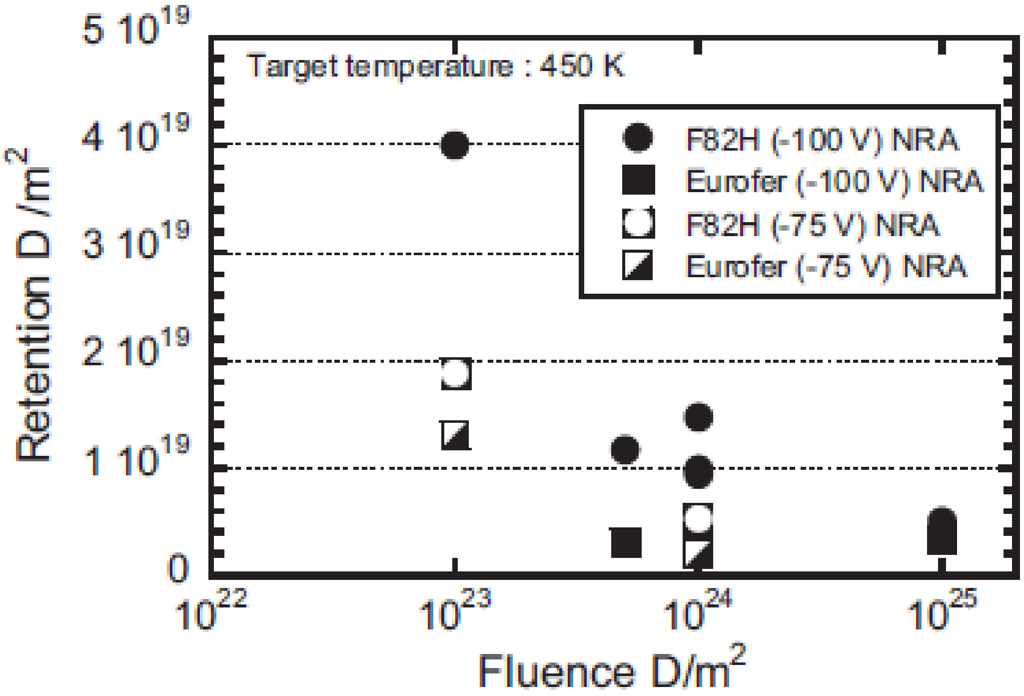
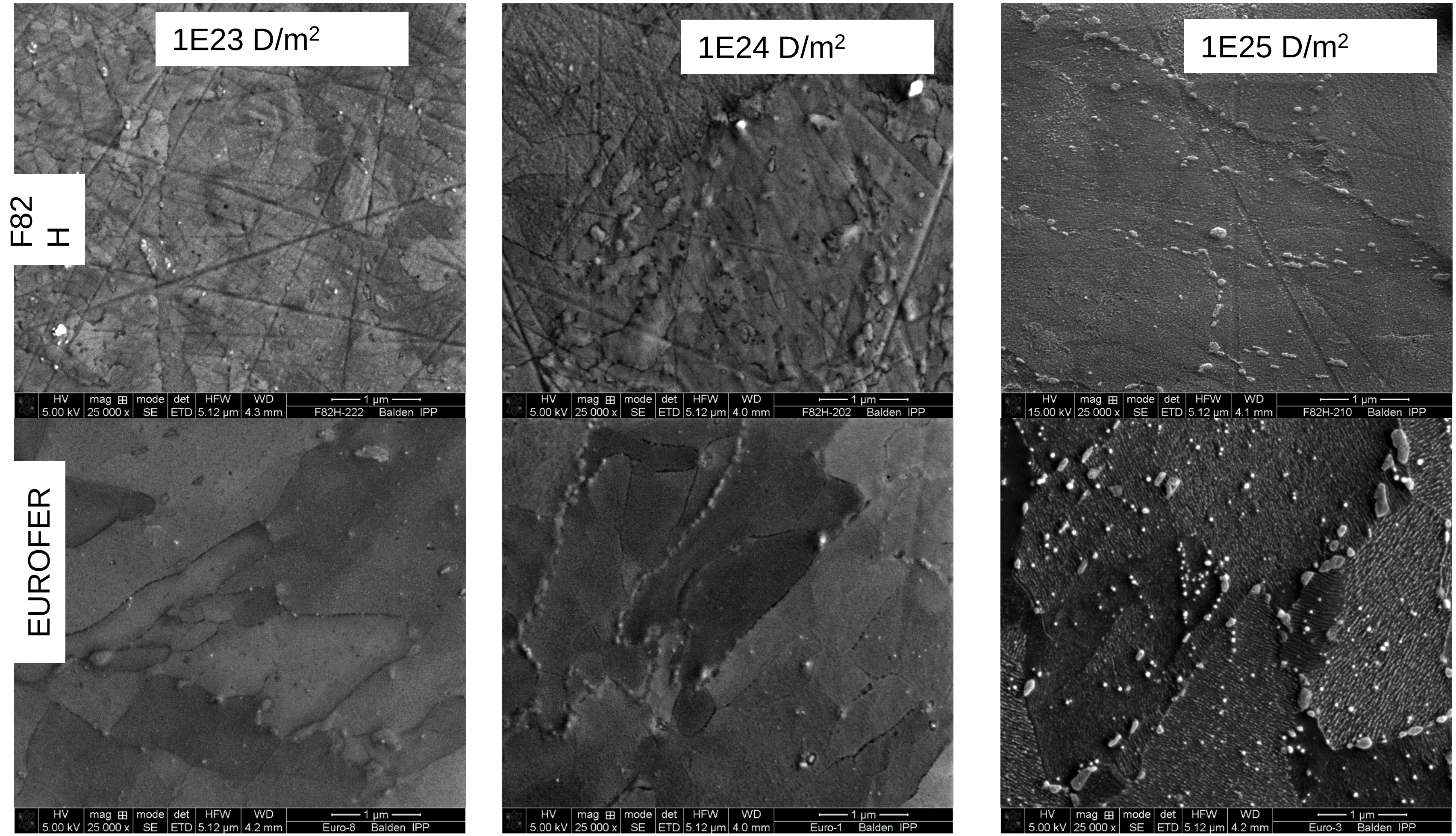


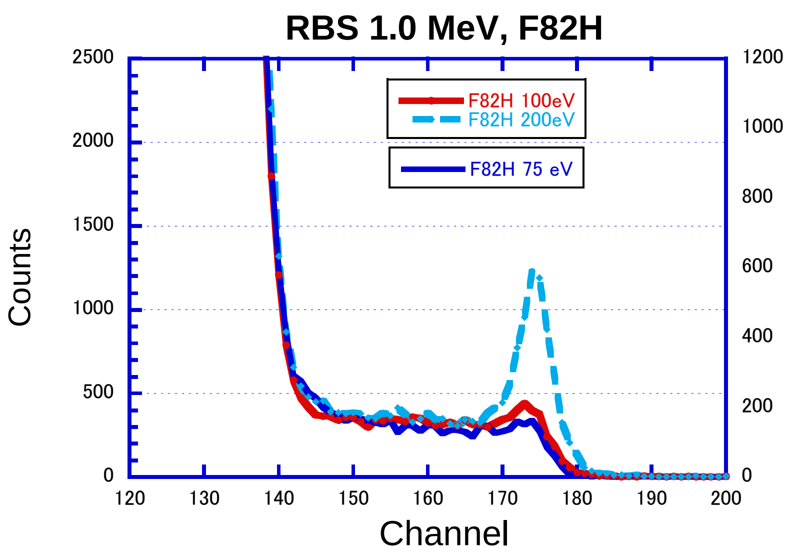
Fig. 3. Fluence dependence of deuterium retention after deuterium plasma bombardment. Retention is measured by NRA using $^3He^+$ beam of 690 keV.

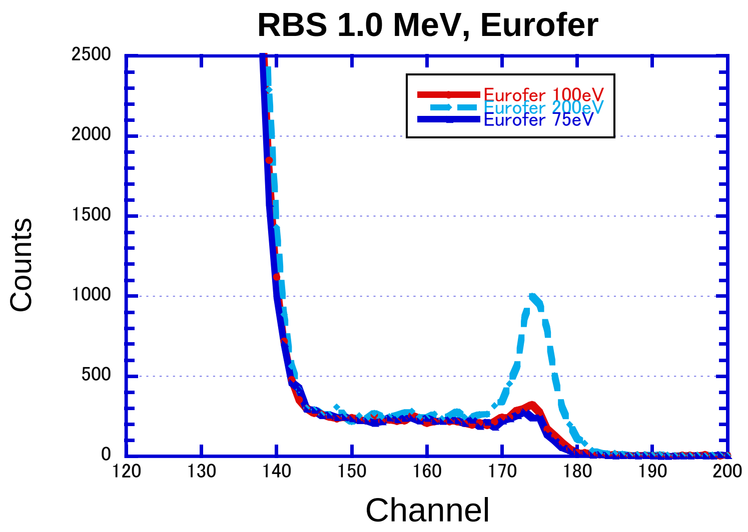
N. Ashikawa, FED(2016)

Surface morphologies、450K （Deuterium plasma)



Tungsten enrichment ; Energy dependence, D plasma

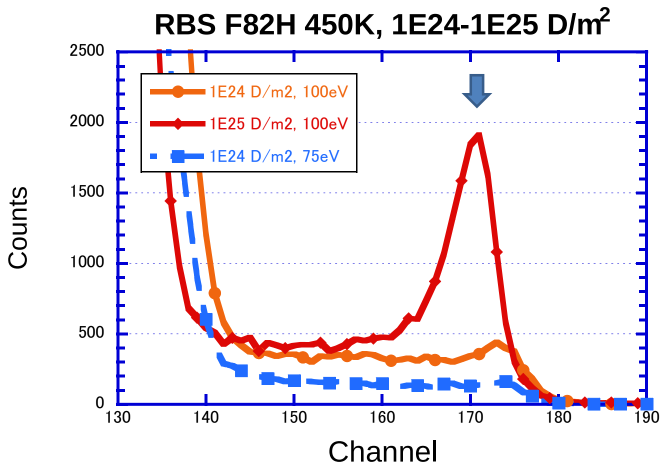


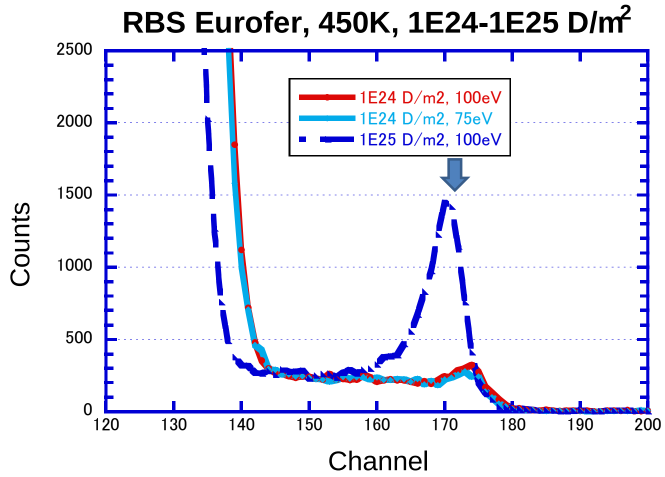


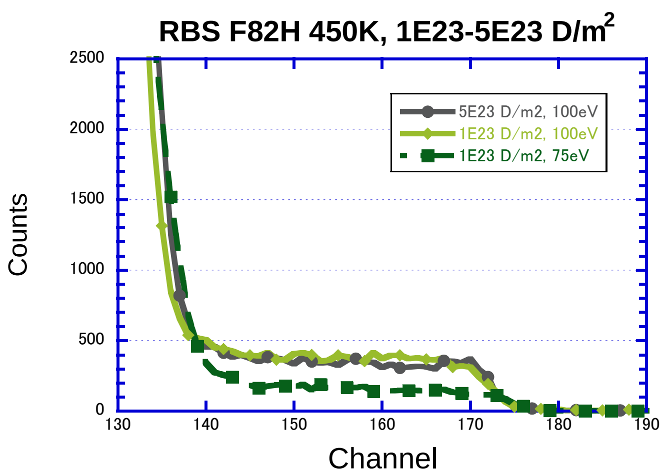
450K, 1E24 D/m^2

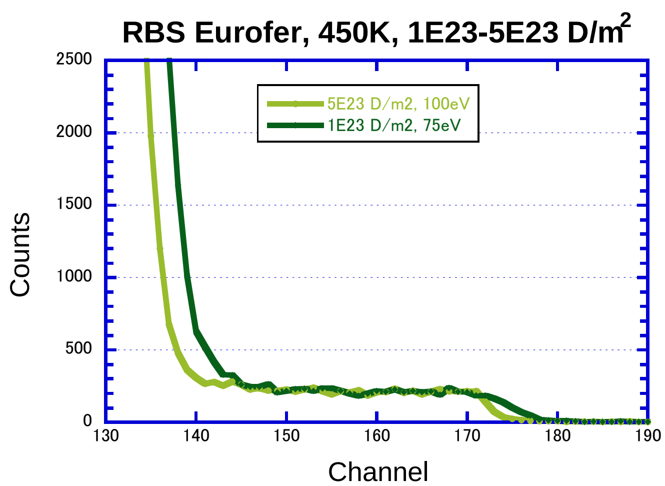
450K, 1E24 D/m^2

Tungsten enrichment ; Fluence dependence, D plasma

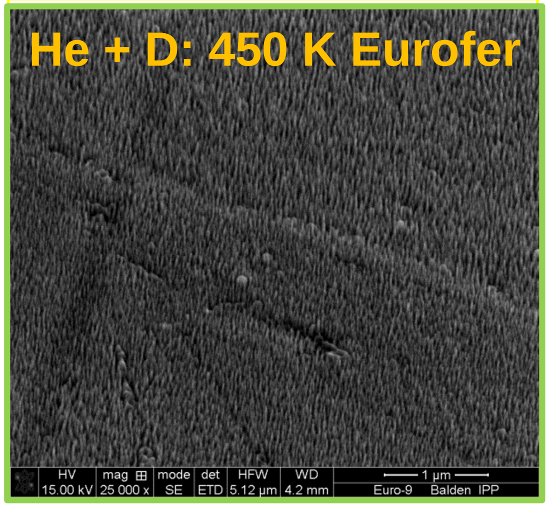


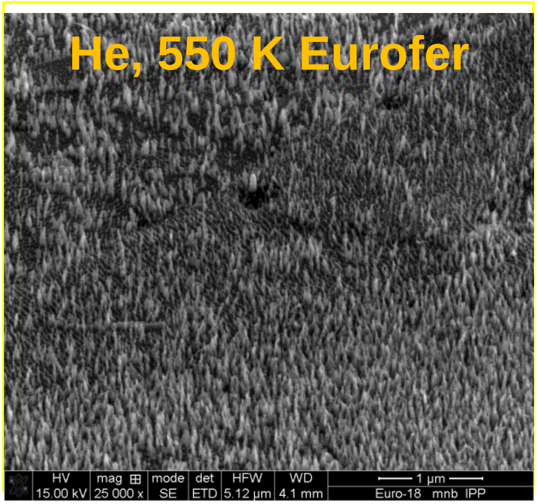


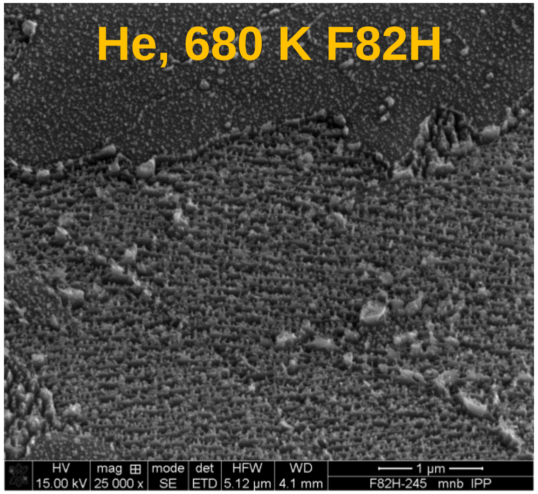


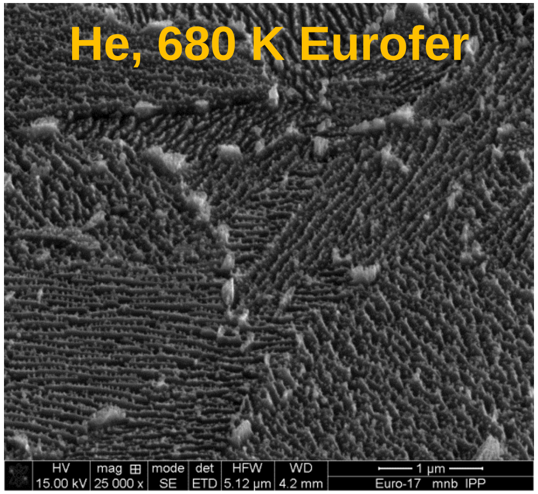


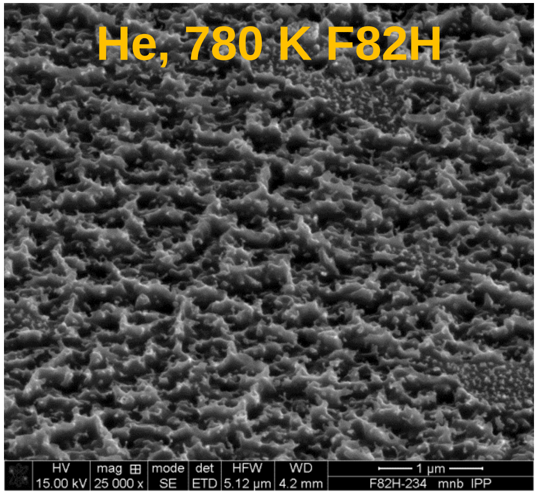
Helium Damages : Surface morphologies





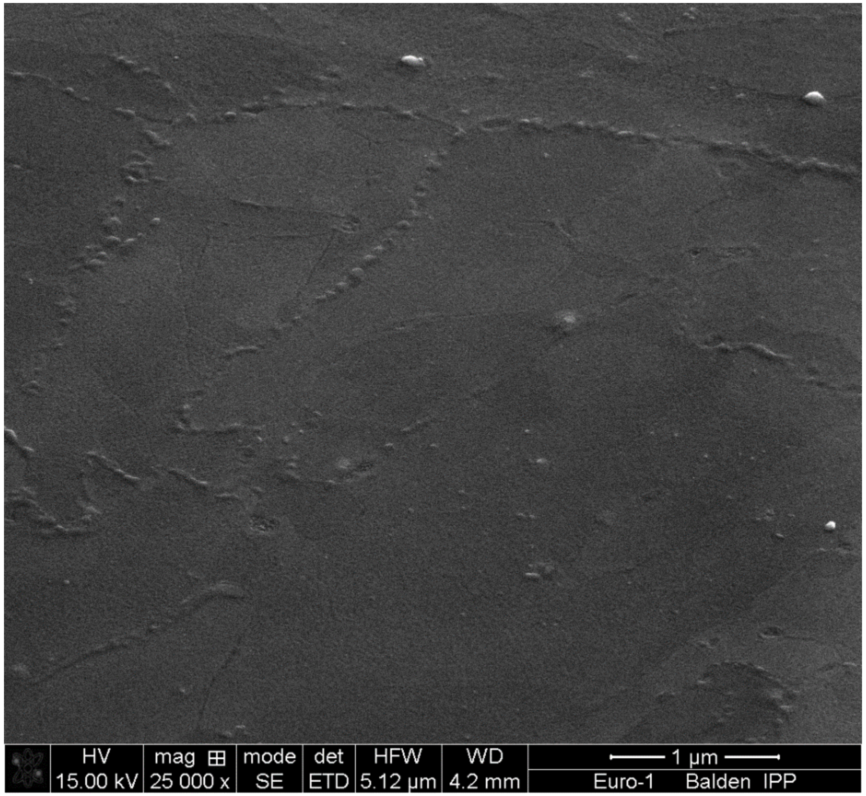




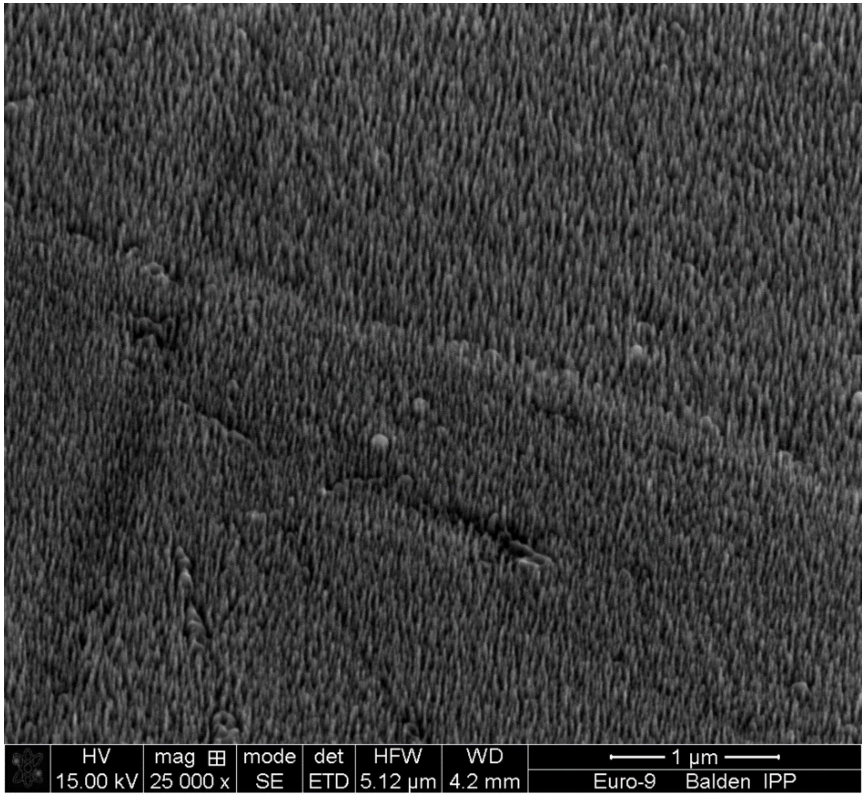


Helium Damages : Surface morphologies (Eurofer, 450K)

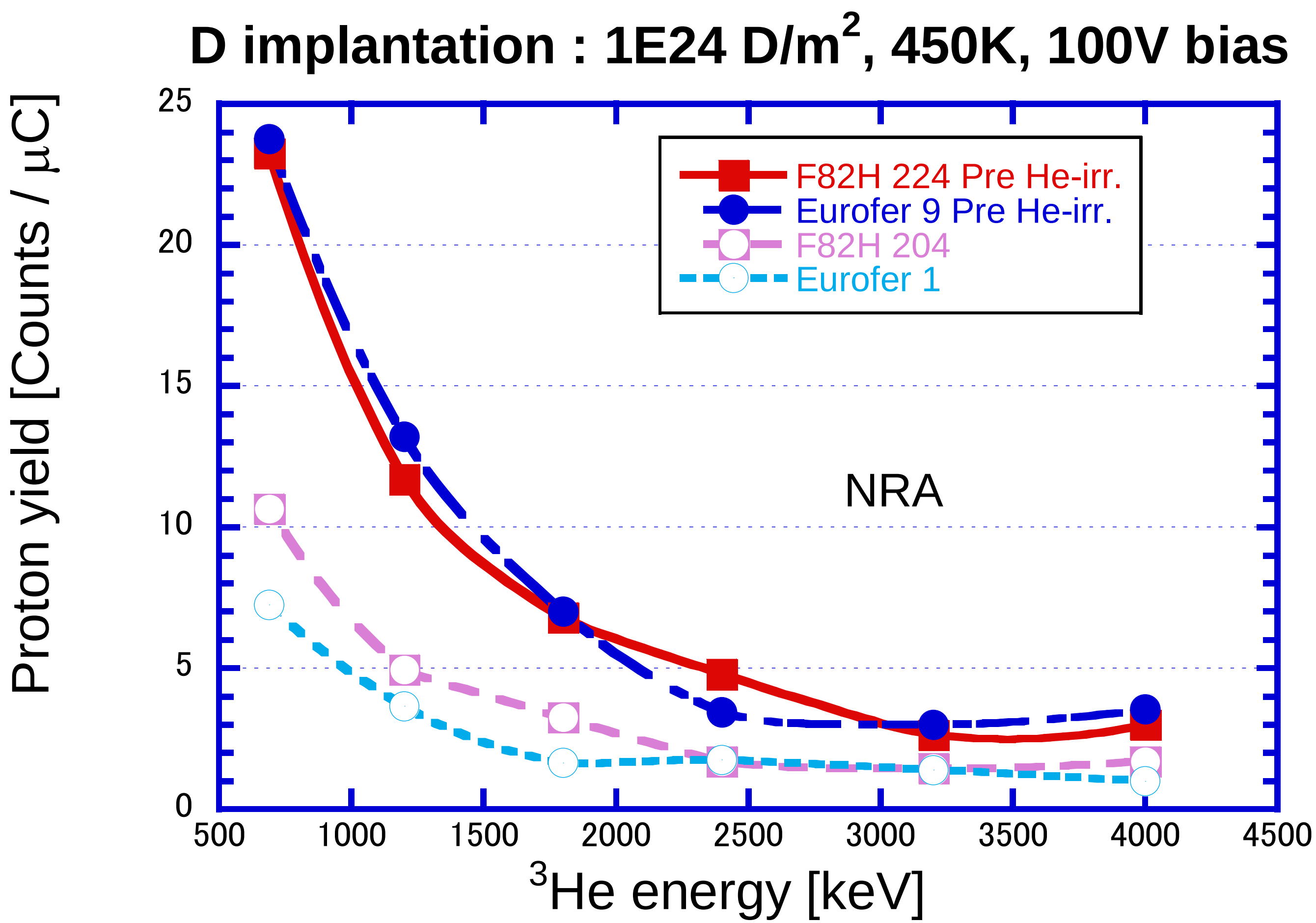
D plasma (100V)



He irr.(200V) =>D plasma (100V)



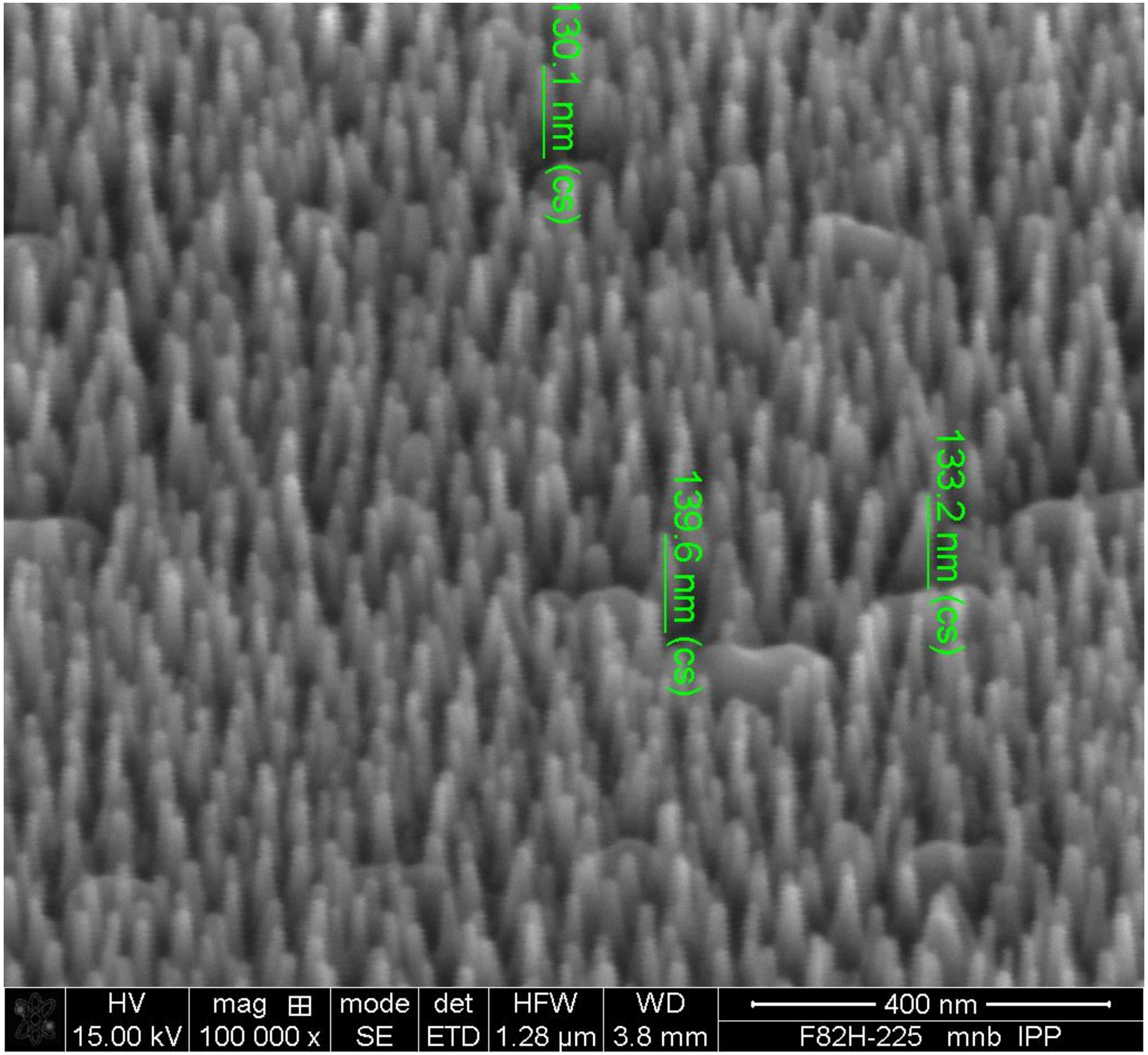
Helium Damages : D retention



In this plasma condition, D retention of specimens with He pre irradiation .is higher than that without He pre irradiation

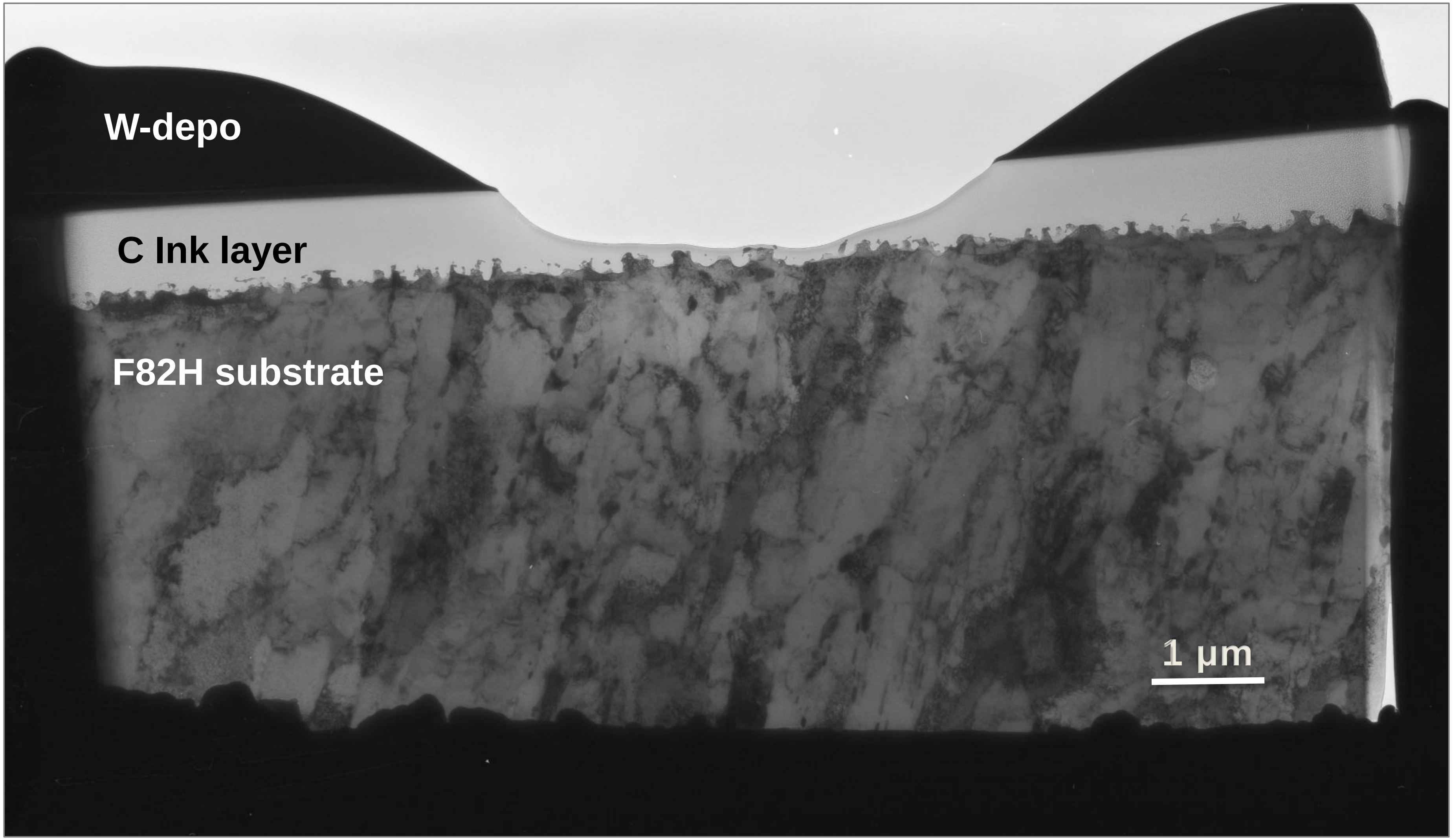
Helium Damages : Surface morphologies (F82H, 450K)

He irr.(200V) =>D plasma (100V)



Overview of cross-section image (FIB), F82H

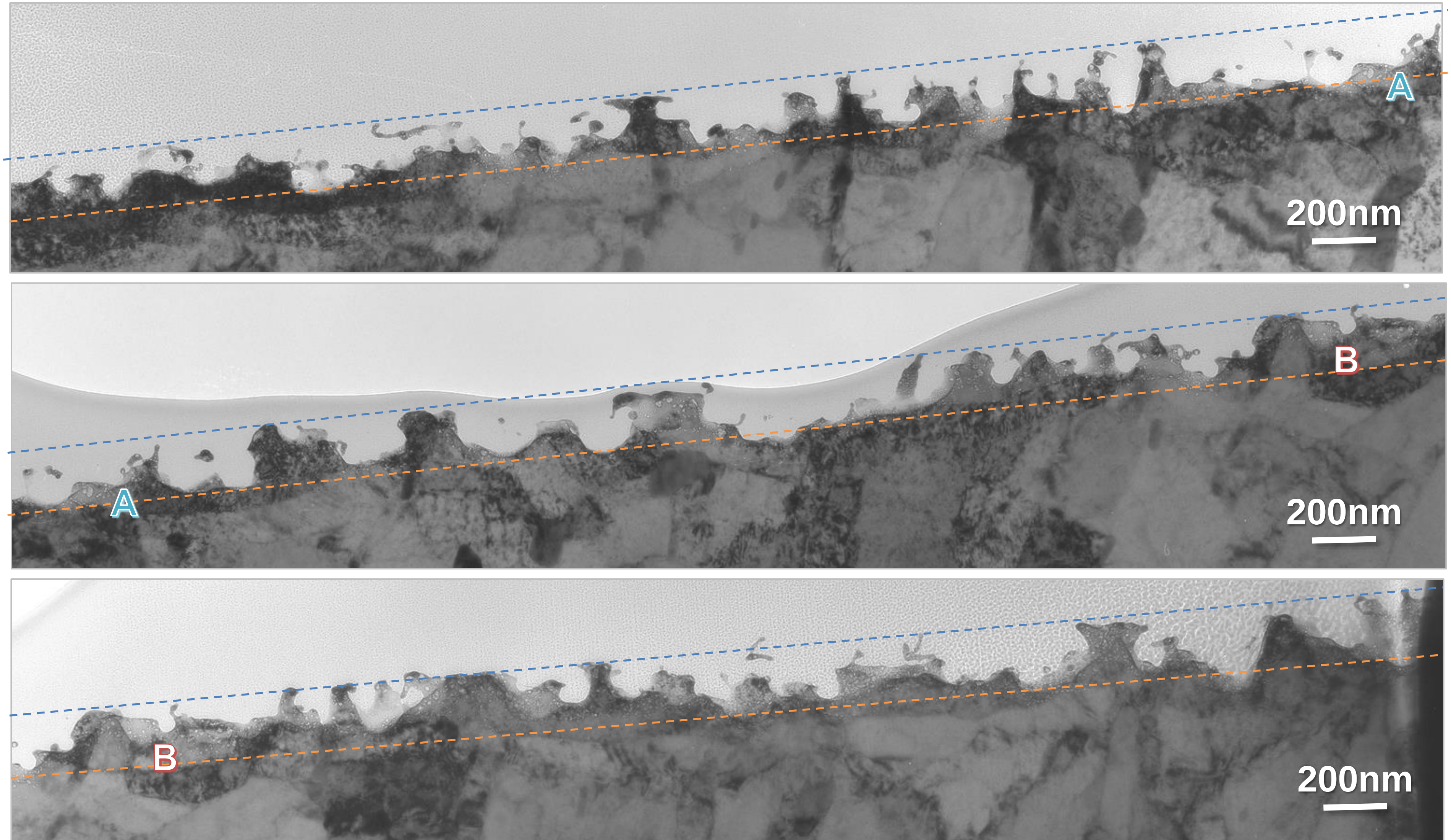
He irr.(200V) =>D plasma (100V)



Overview of cross-section image (FIB), F82H, 450K

- Maximum length of structures on the surface about 200nm

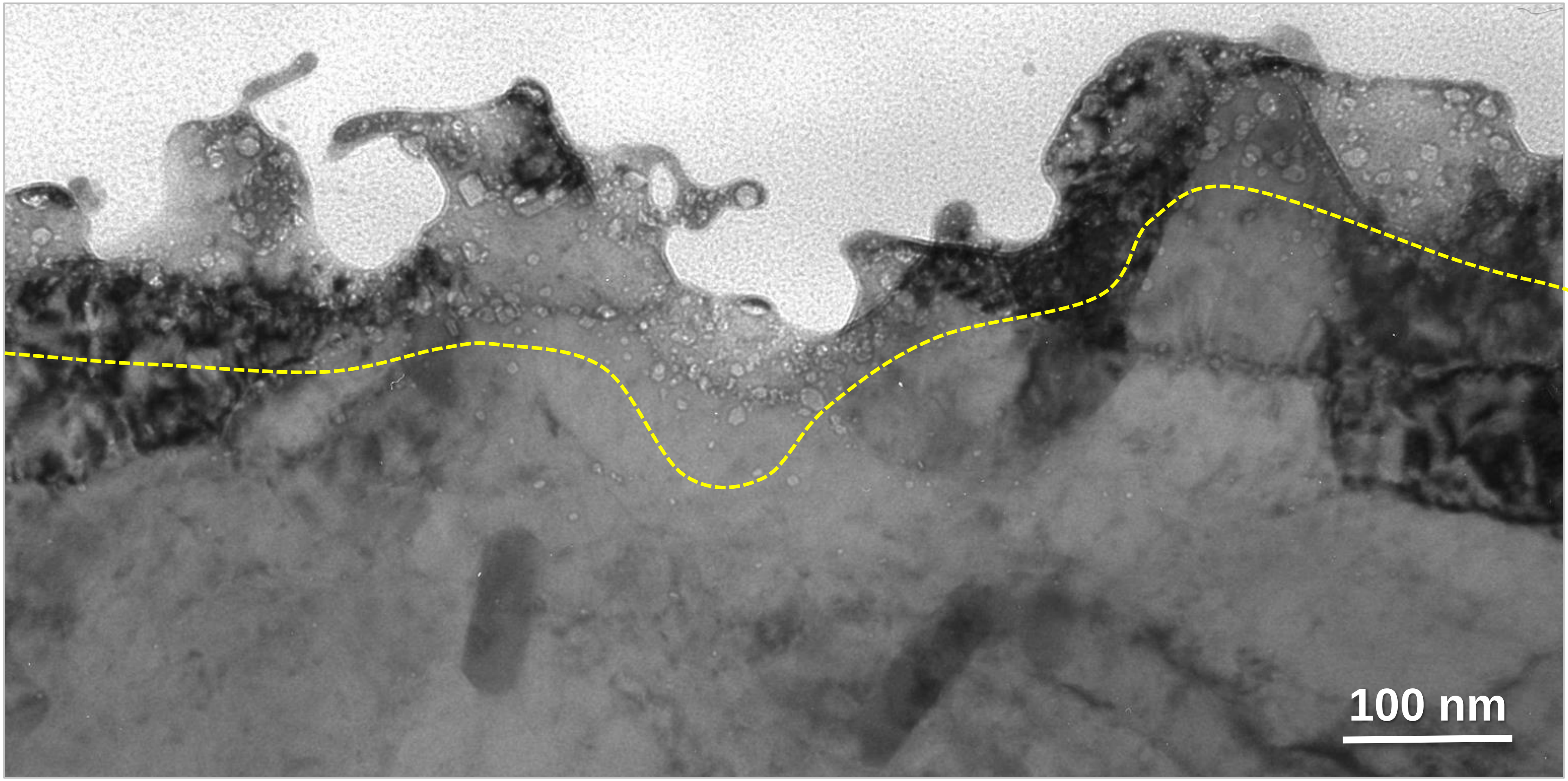
He irr.(200V) =>D plasma (100V)



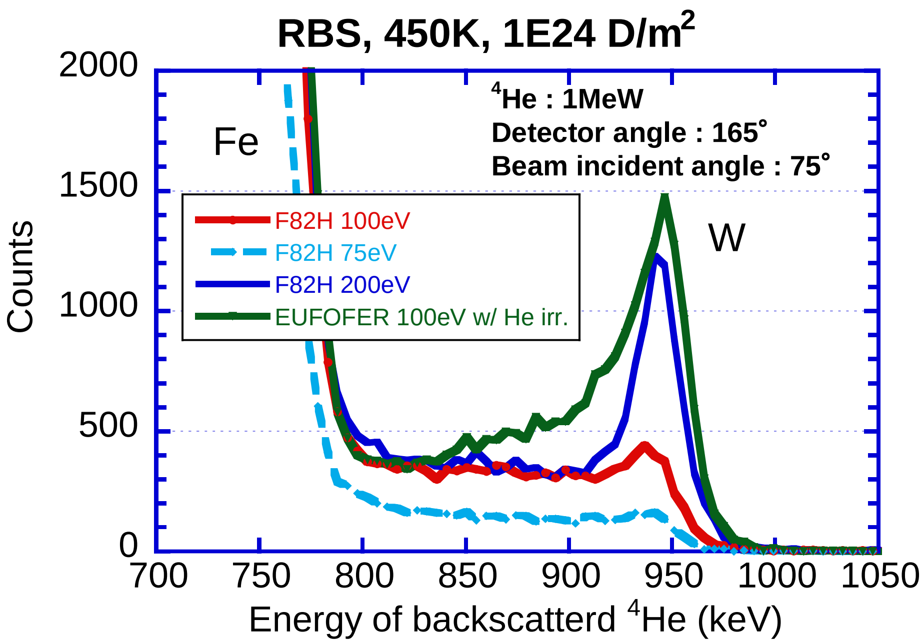
Cross-section image (FIB) , F82H（450K）

- Large surface rough ness (up and down) and microstructures of 10nm.
- He bubbles
- About 100 nm regions from top surface have amorphous structures

He irr.(200V) =>D plasma (100V)

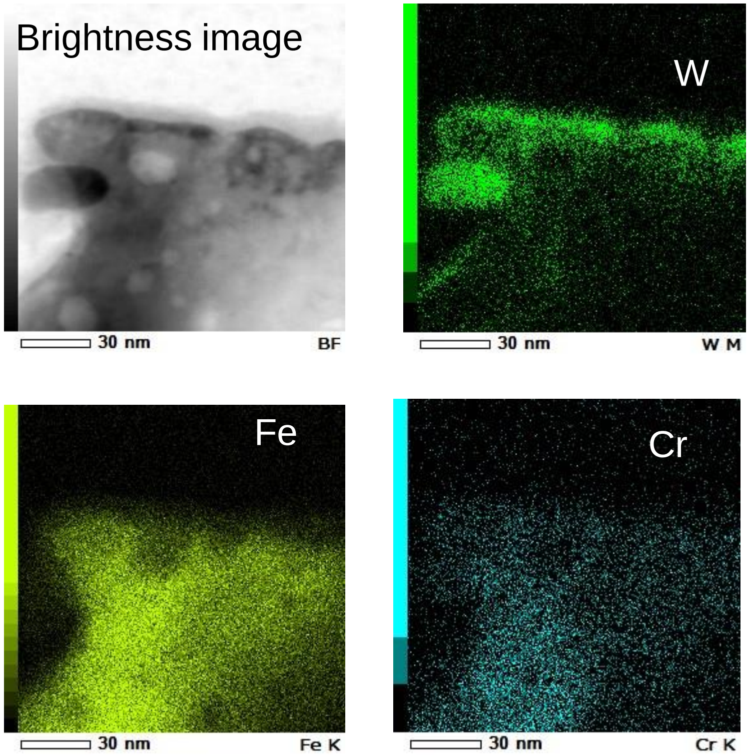


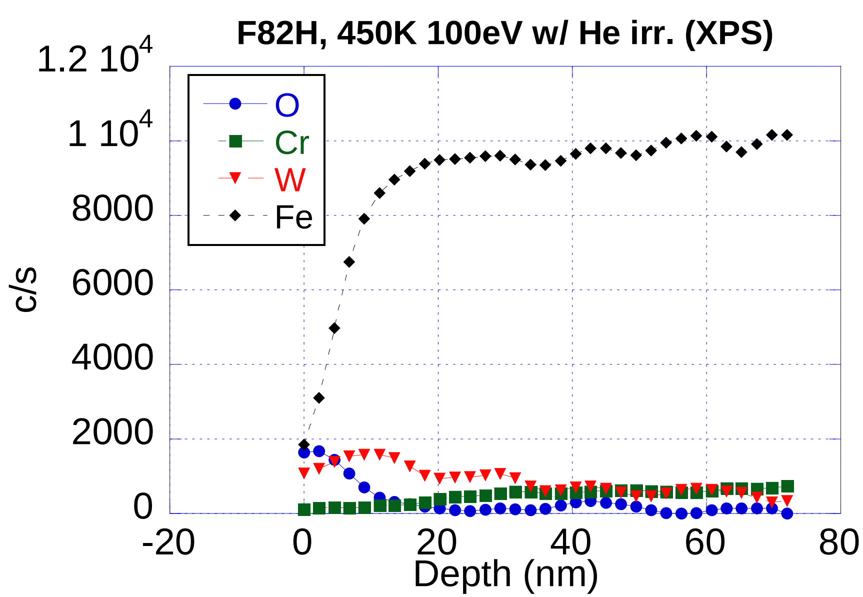
Tungsten enrichment on the surface, F82H



He irr.(200V) =>D plasma (100V)

EDX observation for TEM/FIB cross-section images





Summary (1)

◆ Deuterium retention in F82H and EUROFER after helium plasma bombardment are measured by RBS , SEM, XPS, NRA and TEM.

◆ Surface morphologies after helium plasma bombardments were changed to compare with that after deuterium plasma bombardments. Coral structures are observed on a plasma facing side. Each length of coral structure is less than 200 nm.

◆ Three kinds of analytical results, measured by RBS, XPS and EDX/TEM on a cross-section, show tungsten enrichment during the thickness of 5 nm from the top surface. These tungsten enrichment observed at the top surface of the coral structure.

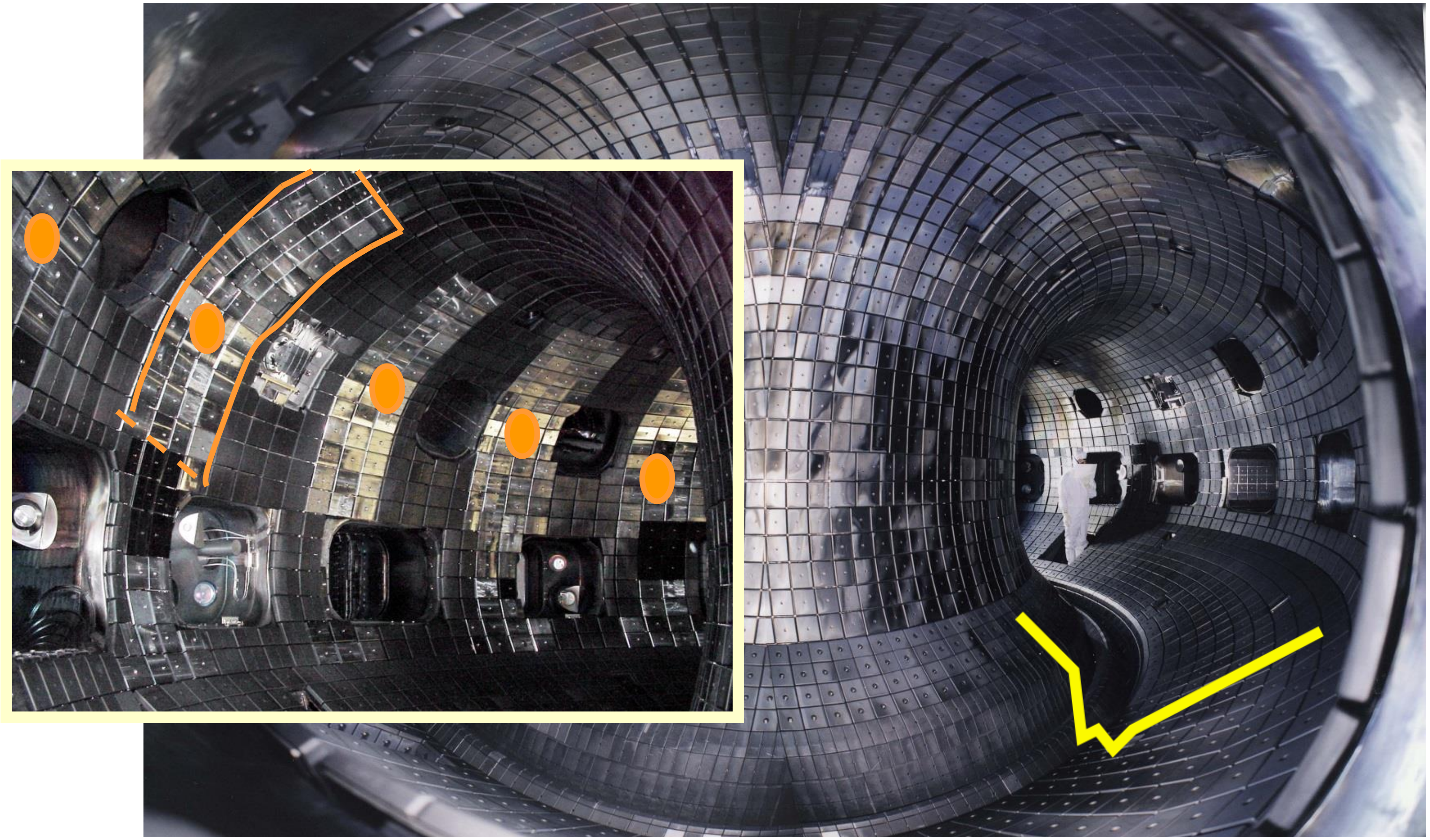
◆ A difference between F82H and EUROFER is almost negligible.

F82H tiles in JT-60U

Naoko Ashikawa (NIFS)

M. Fukumoto, T. Nakano (QST)

F82H tiles in JT-60U(2005-2010)



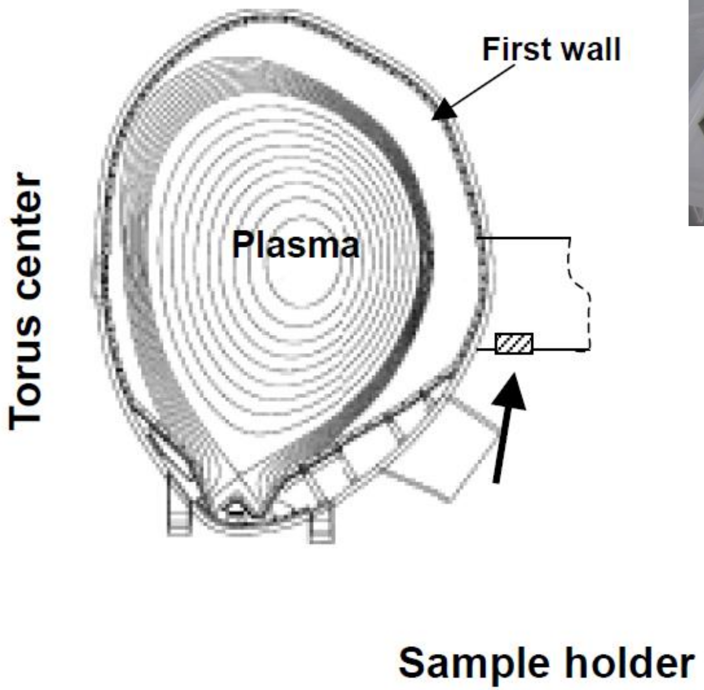
◆Carbon(Div + FW)

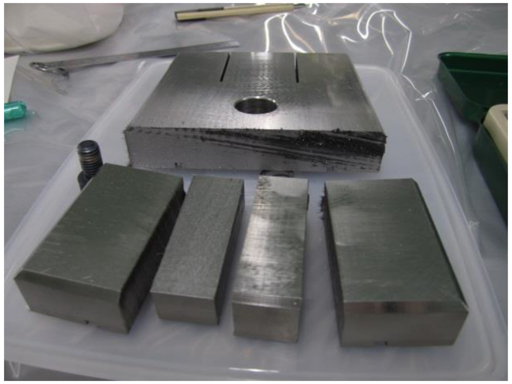
◆F82H (FW:122 tiles・9%)

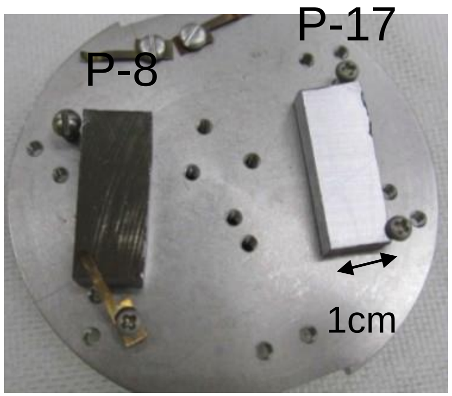
◆W(Div, 12 tiles)

Tiles of F82H were cut in JT-60U

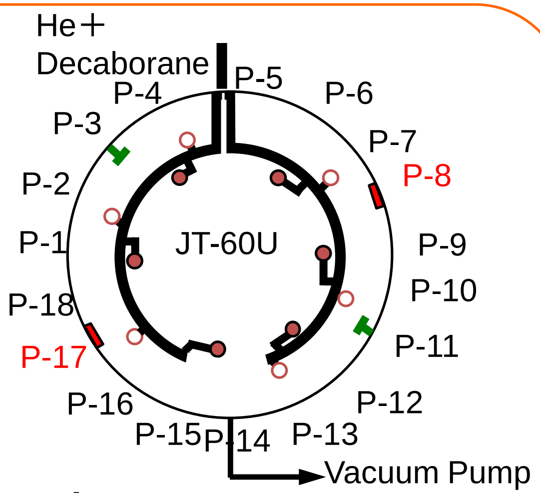
- ✓ No experience for metal tiles in QST (2010)
- ✓ Dry cut (No water cooling)
  - JAEA (QST) Naka site





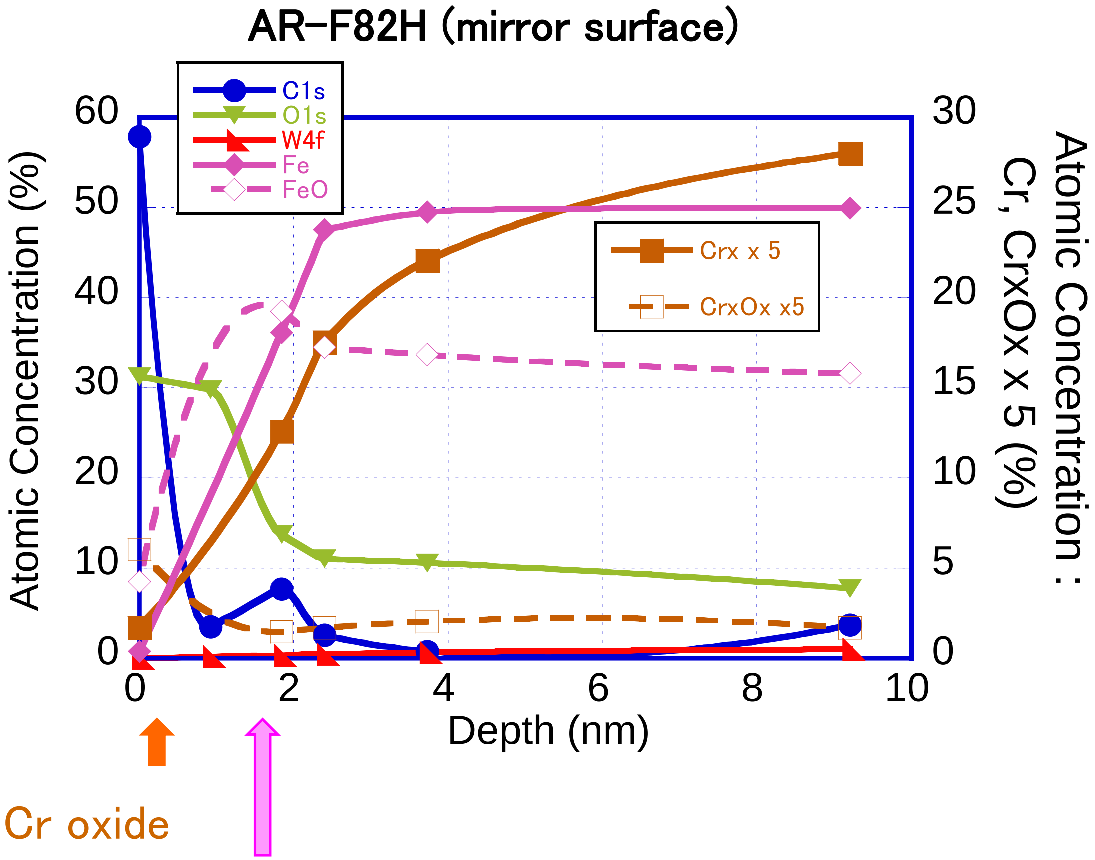


Specimens from tiles



Ports in JT-60U

AR-F82H specimen with mirror polish

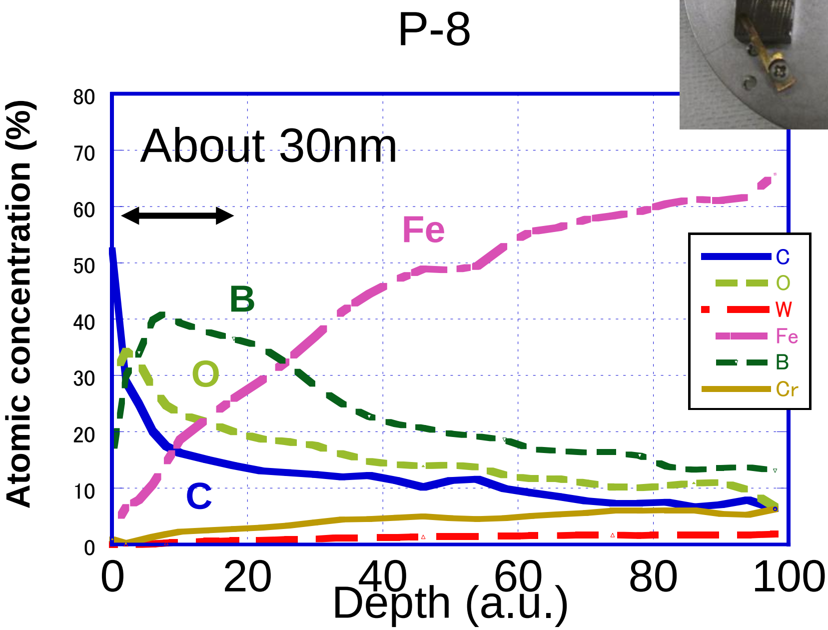


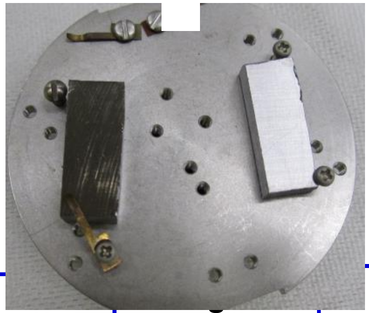
Peak of Cr oxide

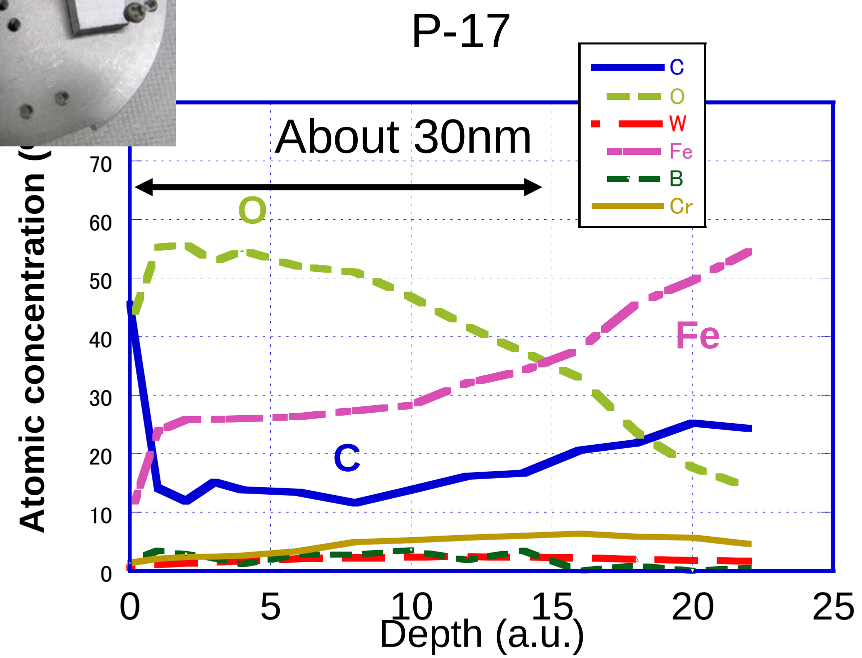
Peal of Fe oxide

Oxide layer of 2 nm from the top surface including Cr– and Fe are observed by sputtered XPS (Ar, 4keV).

Atomic concentrations in P-8 and P-17



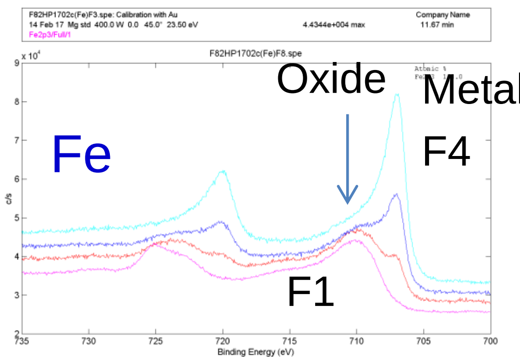


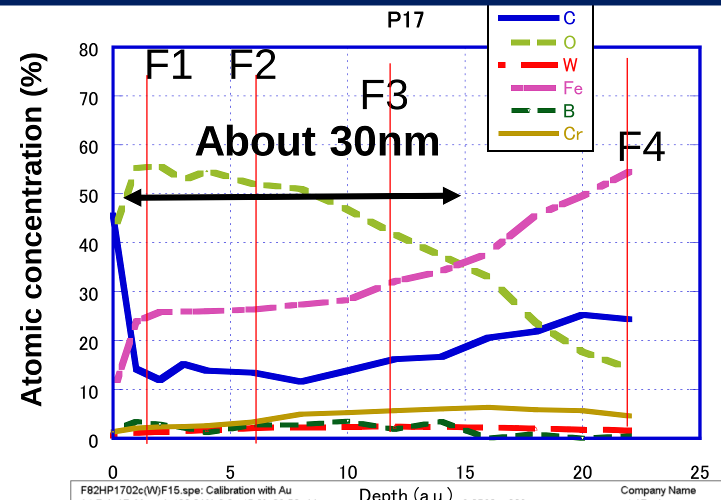


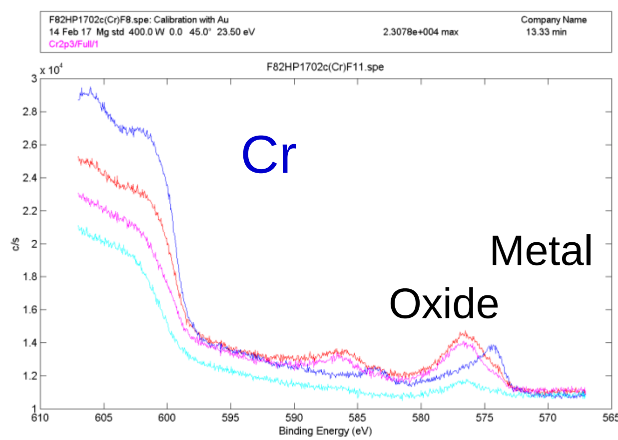
- ➢Coated boron was observed a specimen in P-8. It is not clear oxidation.
- ➢P-17 is erosion dominant region, and low deposited carbon and boron. Hence higher oxide layer was observed.
  - ✓ The thick oxide layer was observed. Fe, Cr, and W oxide were produced.

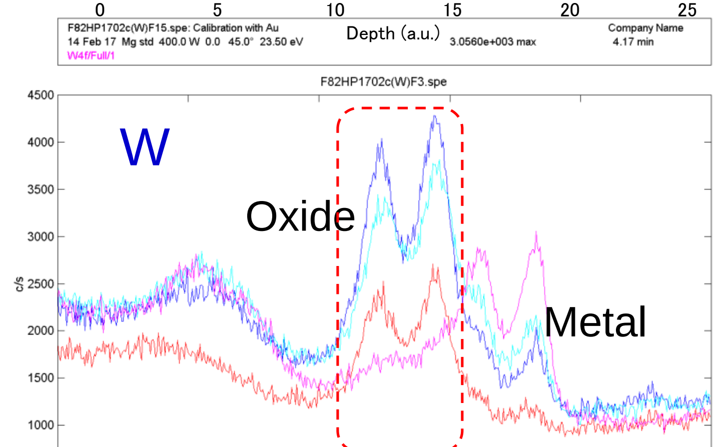
    >>>   The oxide layer might be produced under vacuum.

Passivity layer of F82H was changed in JT-60U









Surface

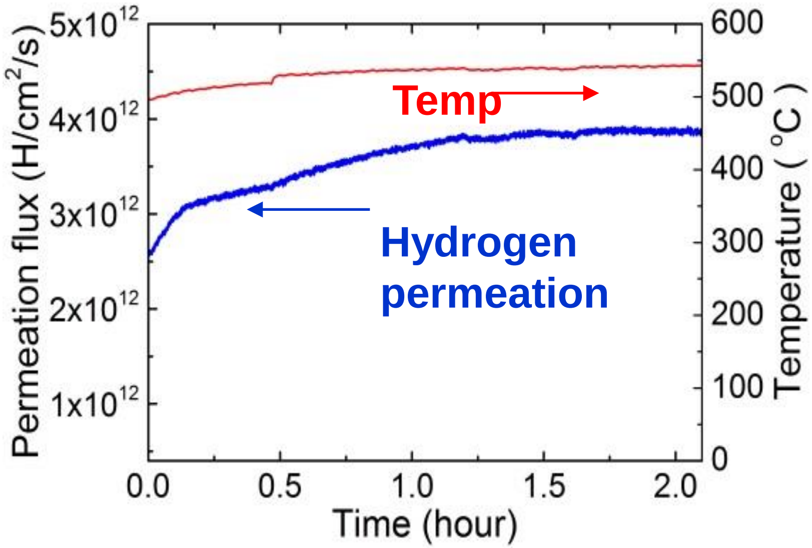
	Fe	Cr	W
F1	Oxide（Fe2O3, so on）	Oxide（Cr2O3, so on）	Oxide(WO3, so on）
F2	Oxide	Oxide	Oxide
F3	**Metal>Oxide**	Oxide	Oxide
F4	**Metal**	**Metal**	**Metal>Oxide**

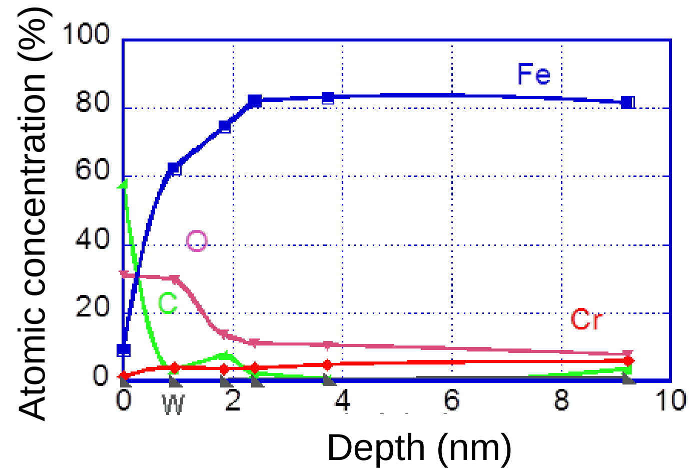
Hydrogen permeation on F82H with O-layer is low（Vehicle-1 ）

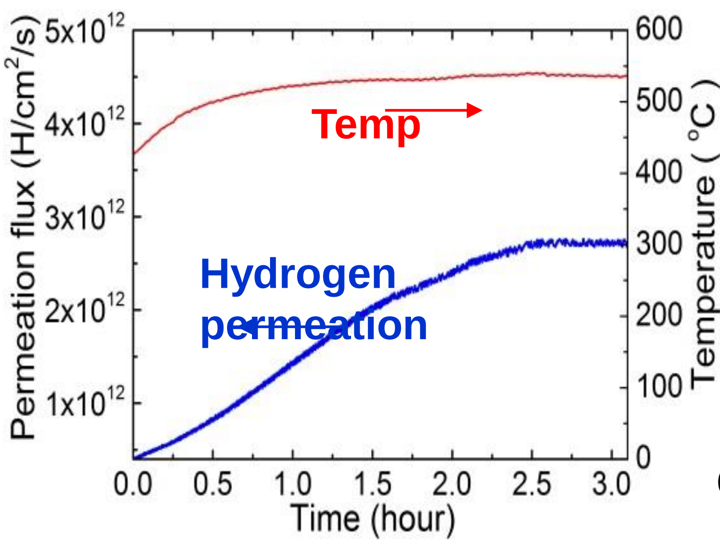
Hydrogen permeation

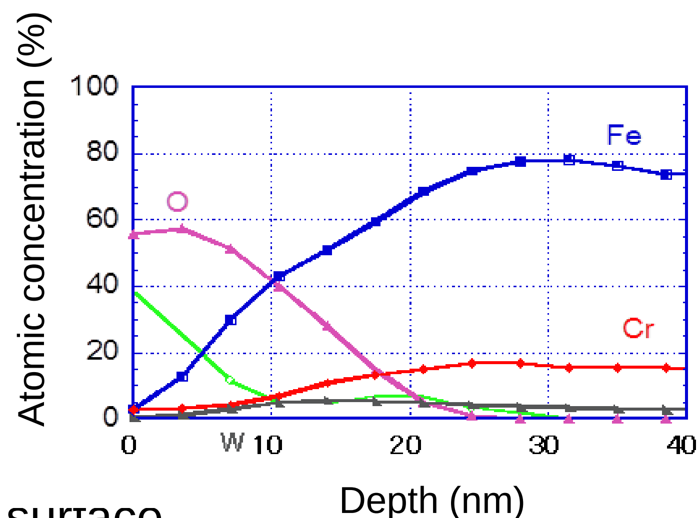
Clean surface

Atomic concentration





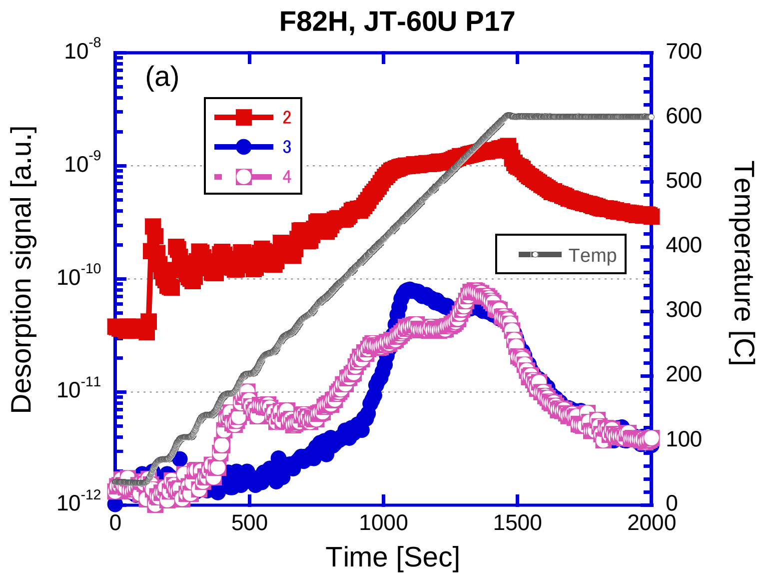


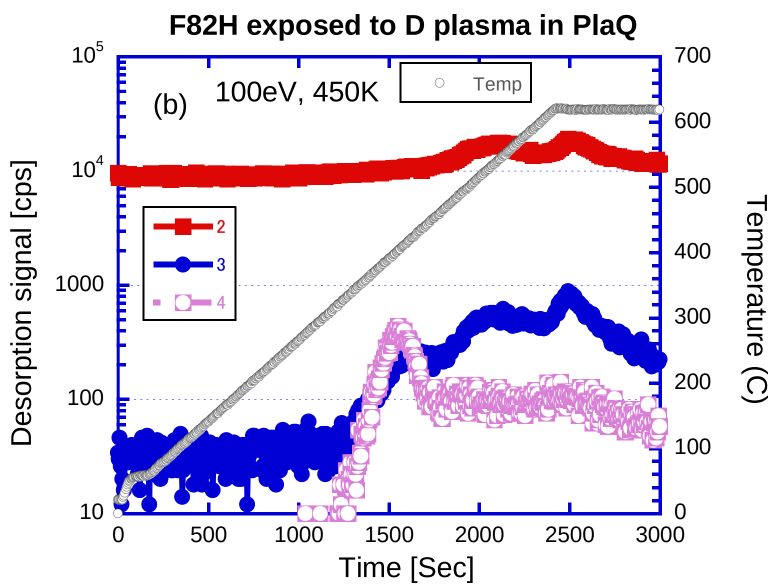


Oxide surface

H.S.Zhou（Ph.D thises, 2014)

Broad D and HD spectrum are observed in the tile of JT-60U





D retention was measures by TDS.

(a) P-17 specimen from F82H tile in P-17

(b) D-plasma exposure in Pla-Q ：ECR plasma（100eV, 450K）

In JT-60U, broad D and HD spectrum observed to compare with Pla-Q, and D release is increasing until 600 C

On the tile, candidate D tapping sites, He irradiation, rough surface morphologies, thick oxide, high energy implantation, are considered (but it is not summarized).

Toroidal distributions before and after F82H

Table.1 Thickness of deposition layer with main deposition source in 2003-04 and 2005-06. A relative amount of deposited iron by photoelectron counting and ratios to P-8 in 2005-06.

	2003-04 (before)	2005-06 (after)		
Sample position	Thickness (nm) of deposition layer and main deposition source		Photoelectron counting Fe2p3	Ratio
P5	600 (B)	135 (B)	$5.0x10^5$	0.11
P8	280 (B)	75 (B)	$4.5x10^6$	1
P10	60 (C)			
P15	40 (C)	25 (C)	$4.3x10^6$	0.96
P17	15(C)	15 (C)	$7.1x10^5$	0.16

Summary (2)

- In JT-60U, F82H(8Cr2W) tile was installed before a experimental campaign in 2005. Motivation of F82H project is reduction of ripple loss and it was successfully obtained.

  (Takenaga, et al.,NF(2007))

- One of characterizations on ferritic steel is a thick oxide layer to compare with SUS304/316 tiles. Specimens from F82H tiles show oxide bonding at different depth for W, Cr, Fe.

- Iron impurity was increasing after F82H installation. At erosion dominant region, higher iron deposition was observed.