US-Japan Workshop（2003.7)

High Heat Flux Experiment on Tungsten by Helium Beam Irradiation

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Workshop Agenda

Background/Objective

- Tungsten is potential candidates of the plasma facing armor materials of the next fusion devices due to their very low erosion yield and high temperature properties.

- However, heat load, hydrogen and helium atoms from the plasma, which affect on damage accumulation and mechanical properties, may reduce these superior properties of tungsten.

- In the present study, electron and ion beam irradiation experiments have been performed to investigate the synergistic effects between the heat loading and the particle load(hydrogen, helium) on modification of tungsten.

- **Contents of the presentation:**
  Mainly of high heat flux experiment using helium beam

High heat flux experiments

- **Heating facility(JAERI)**
  - **Ion beam heating**

    Particle Beam Engineering Facility (PBEF)

    Hydrogen beam : ~20 keV, $\leq 10^{21}$ H/m^{2}s

    Helium beam:, ~ 14 keV, $\leq 2\times10^{21}$ He/m^{2}s

  - **Electron beam heating**

    JAERI Electron Beam Irradiation Stand (JEBIS)

    Electron beam : 30 keV ~ 40keV

  - **Heat flux** :

    2.5、5、10、15 MW/m^2

Sample (1)

- **Powder metallurgy tungsten**

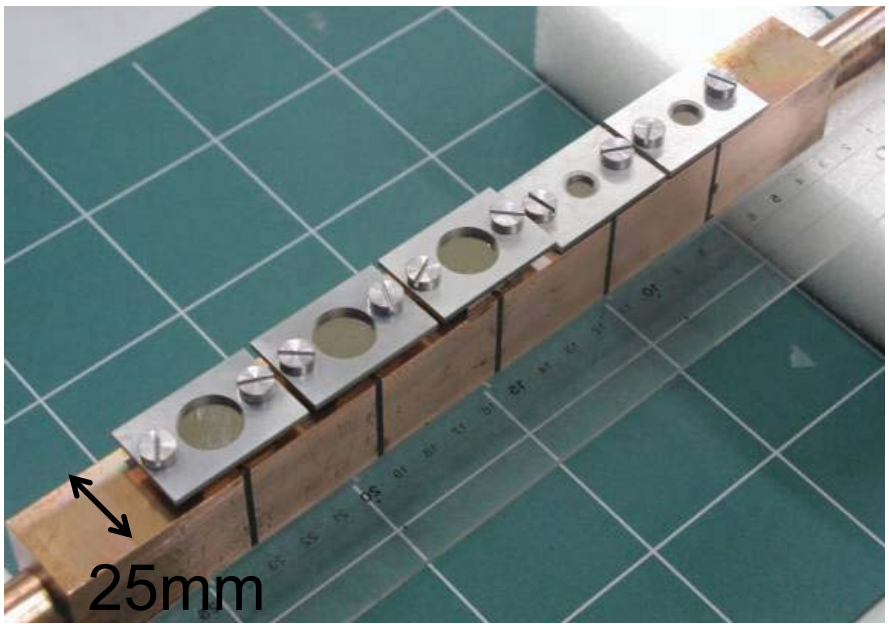
  : 20mm x 20mm x 5mm

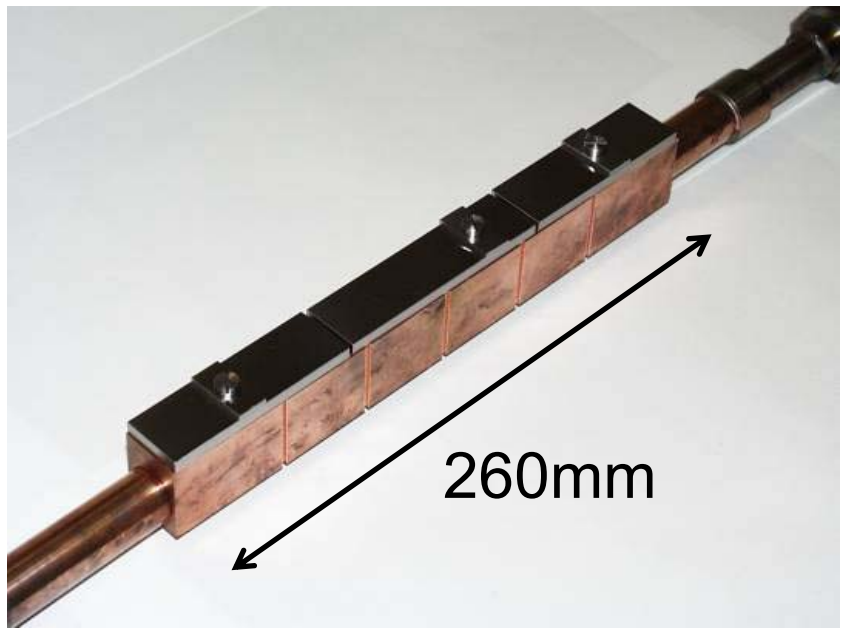
  : 10mm x 10mm x 1mm

  : 20mm x 20mm x 0.1mm

  : 10mm x 10mm x 0.1mm

  : 94 mm x 25 mm x 5mm, 79 mm x 25 mm x 5mm



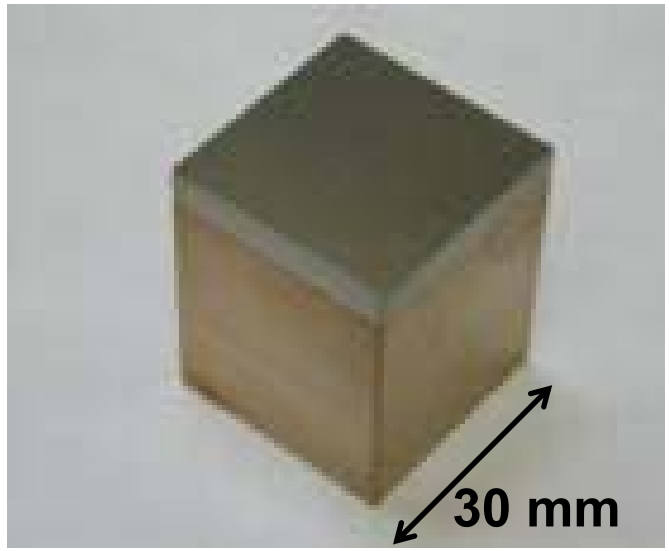


Samples are mechanically fixed on copper block actively cooled with water.

Sample (2)

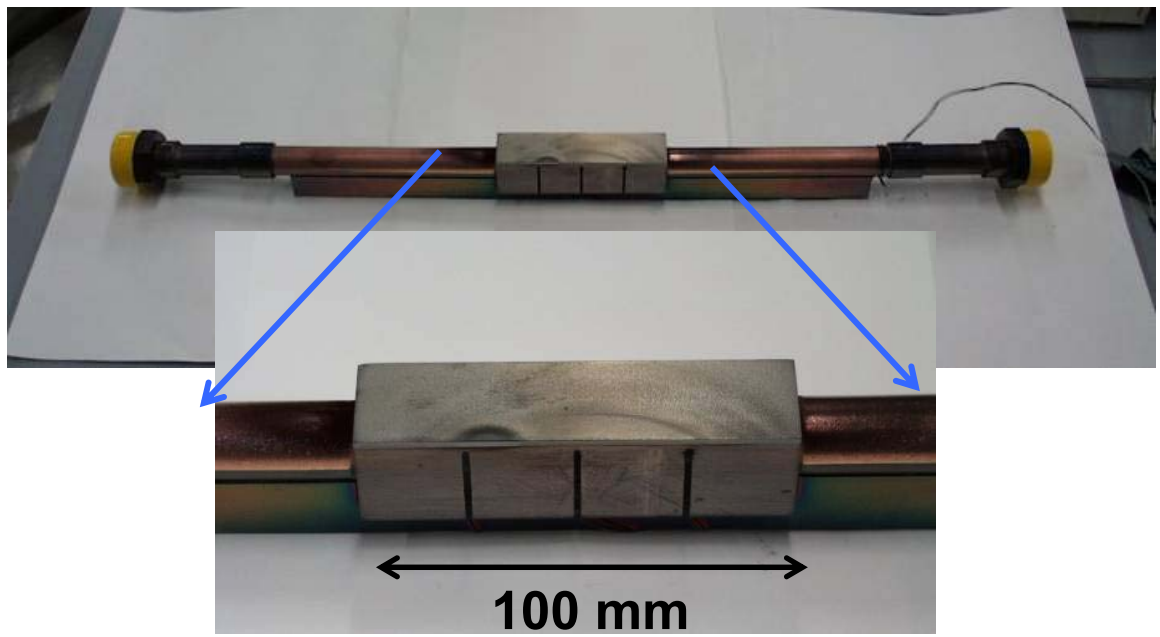
- **CVD-W coated on W-Cu alloy :**

  30 mm x 30 mm x 35 mm
  Thickness of W: 5 mm



- **CVD-W coated Cu block with cooling tube**

  Thickness of W : 2 mm



Experimental conditions, Irradiation

Facility : PBEF

Beam : Helium

Heat flux : 6 MW/m^2, 2x10^{21} He/m^{2}s (at center)

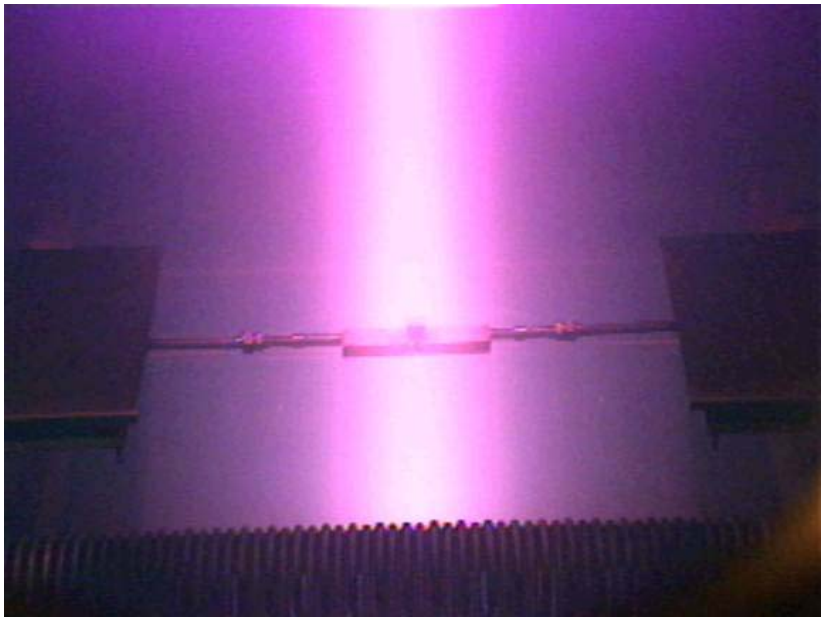
Energy : 14 keV

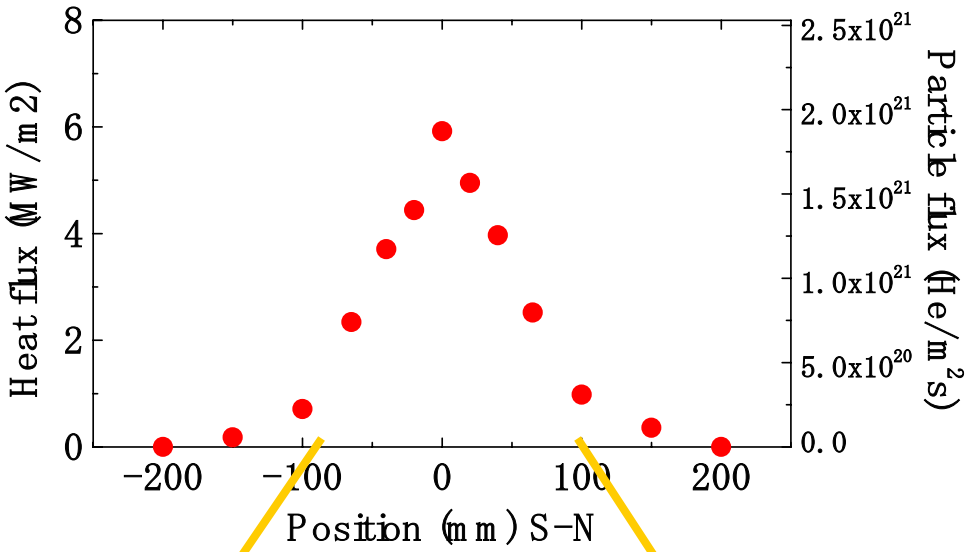
Heating duration : 3 ~ 3.9 s

Number of repeated irradiation : 7 ~ 170 shots

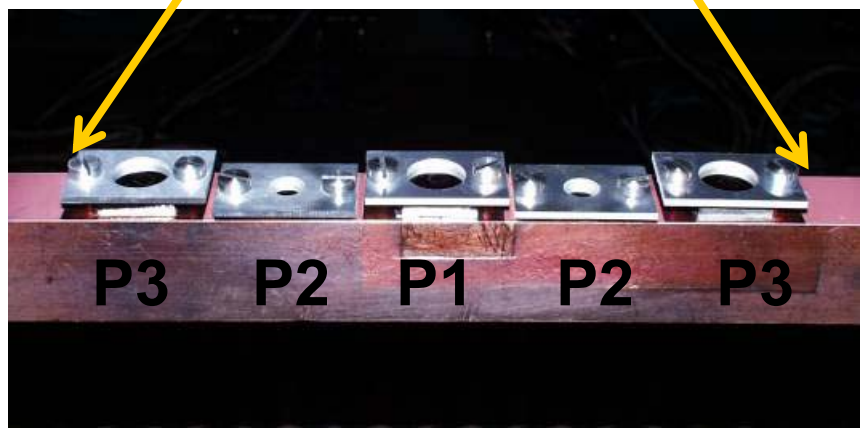
Fluence : 10^{22} ~ 10^{24} He/m^2

Helium beam profile



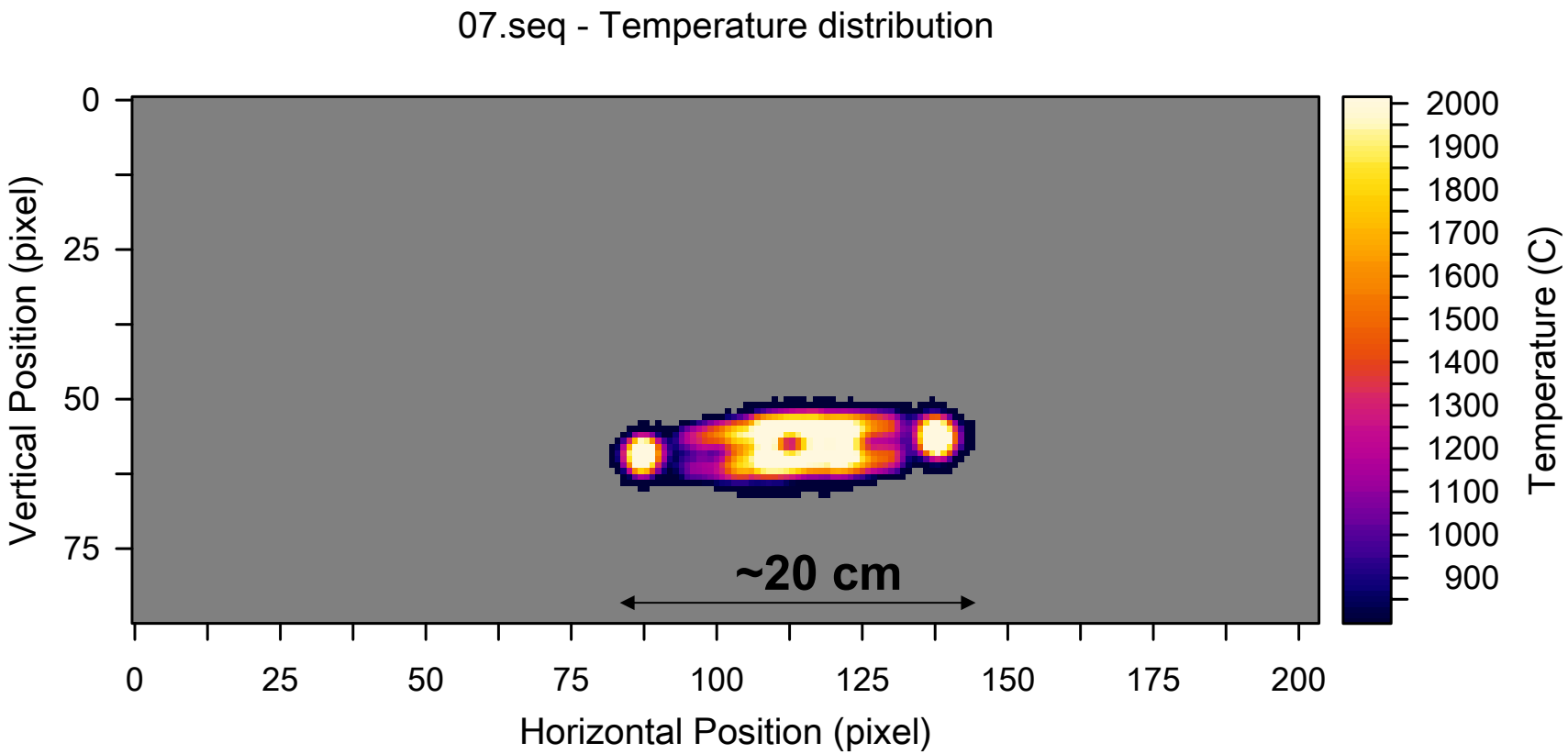


- Wide beam but intensity is not uniform



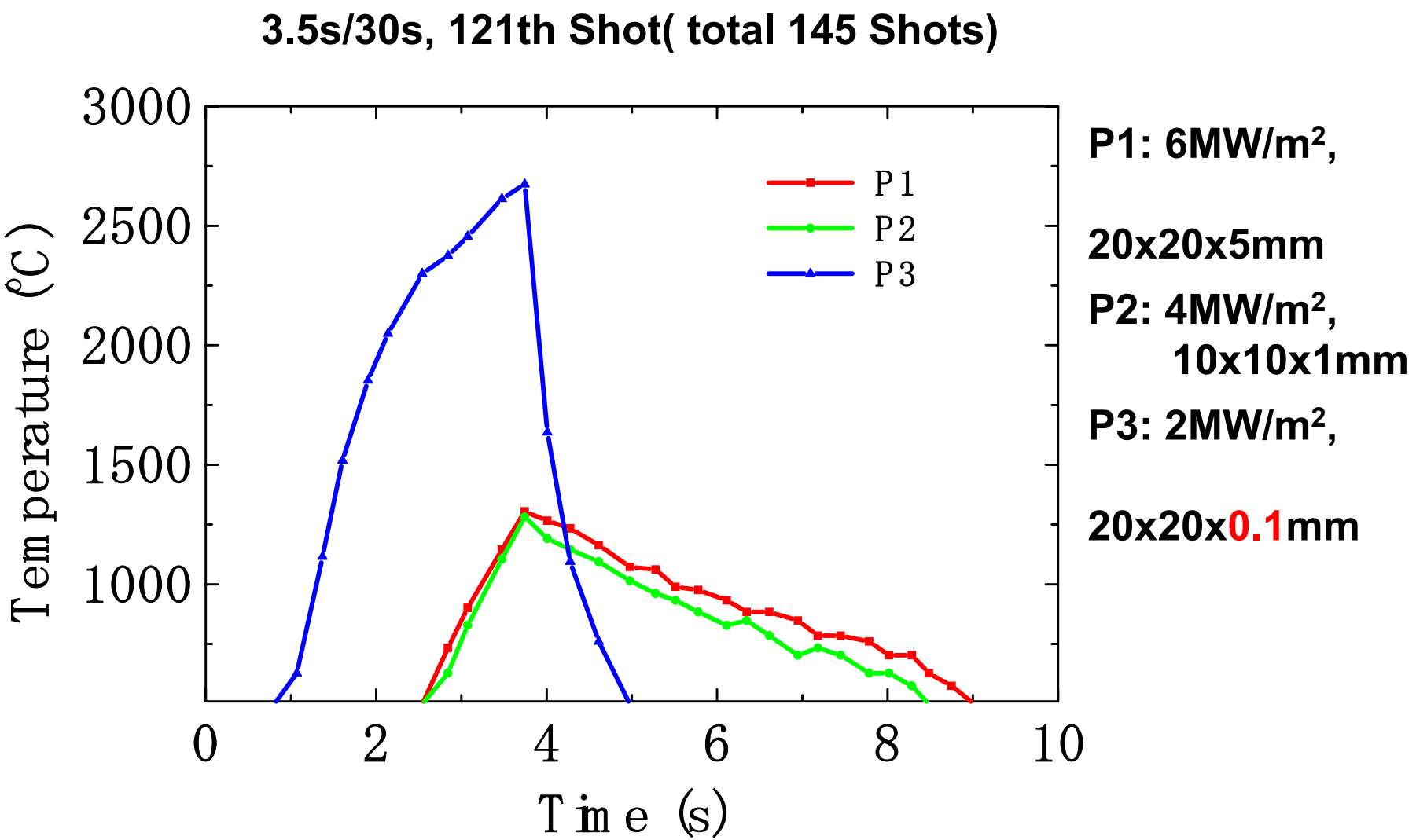
Temperature distribution

6 MW/m^2, 3.5s/30s, 121th Shot (total: 145 Shots)



- **Surface temperature depends on the position of the specimen and its thickness.**
- **Temperature is rather uniform in each specimen.**

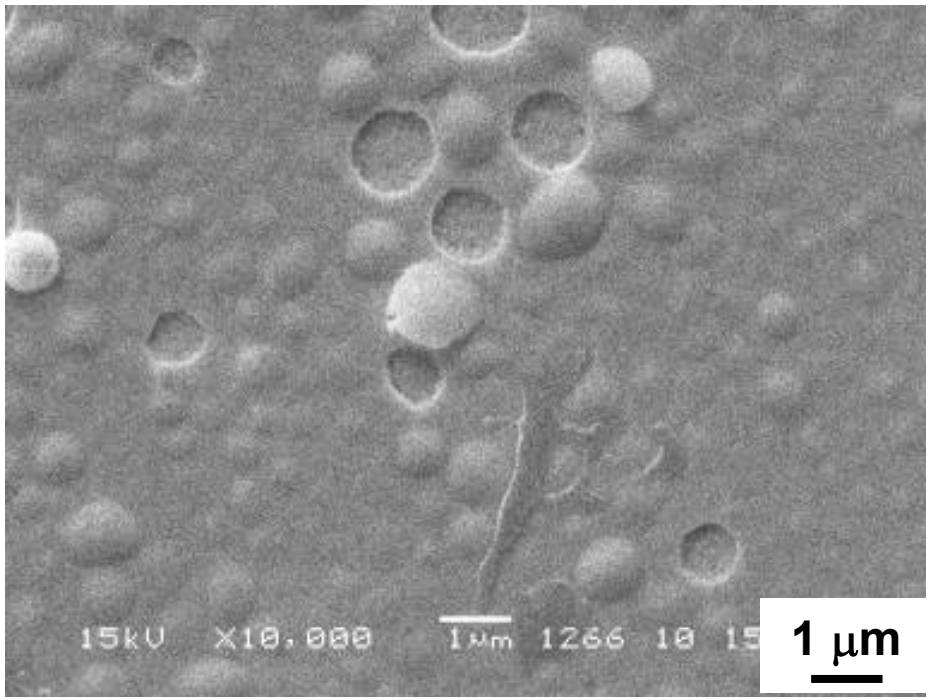
Time evolution of Temperature

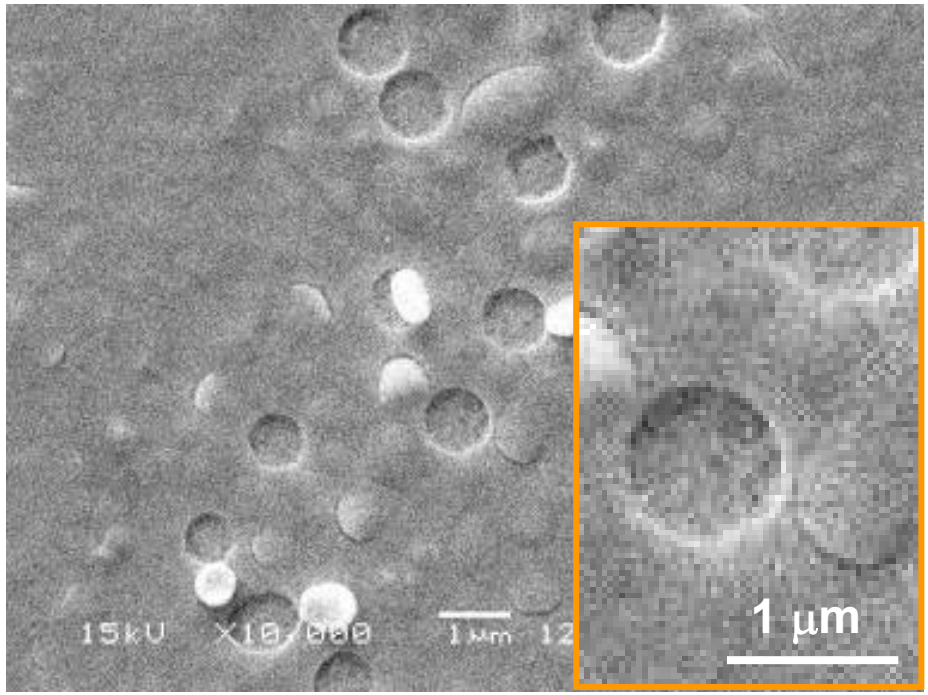


Observation/Analyses

- Surface morphology (SEM SPM)
- Structure changes(SEM, TEM)
- Surface composition(EDS, AES,SIMS)
- Thermal desorption (TDS)
- Hardness
- Weight loss

Low Temp. / Low Fluence





800ºC, 1.7 x 10^{22} He/m^2

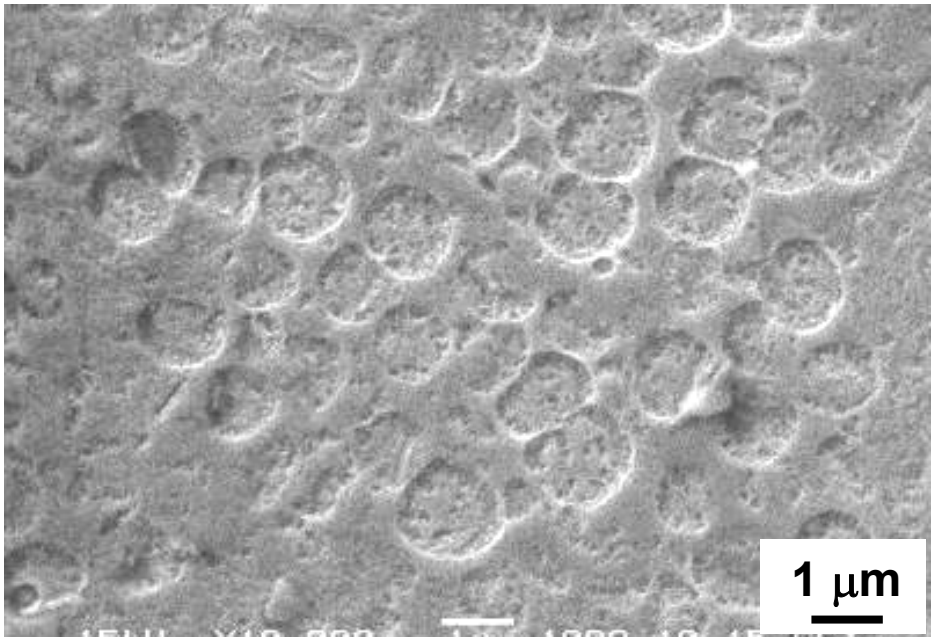
3.9s/30s(7 Shots)
14 keV, 6.7 x 10^{20} He/m^2s
WB-9 (10x10x1mm)

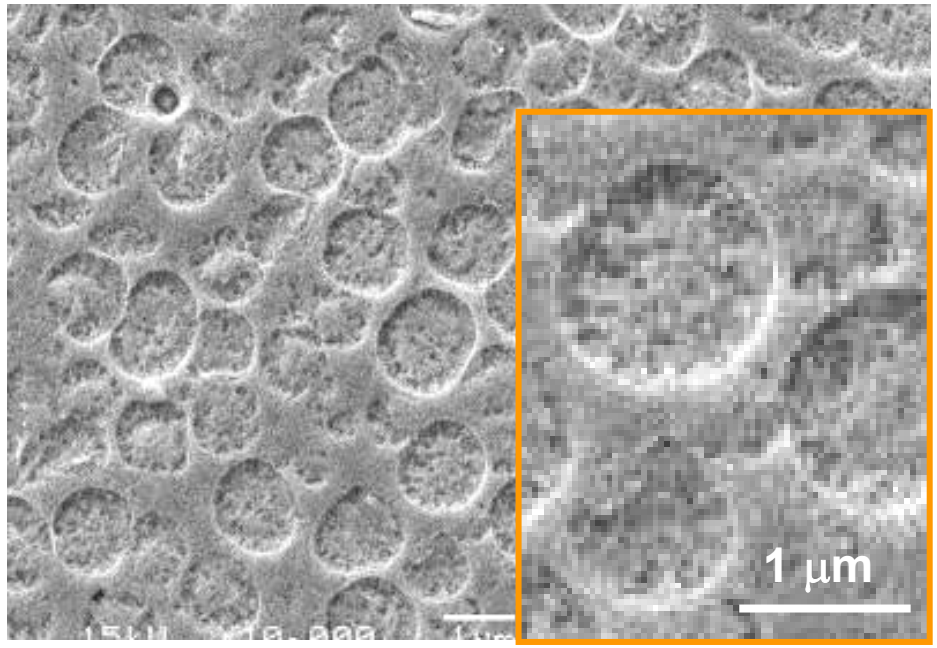
900ºC, 2.5 x 10^{22} He/m^2

3s/30s(9 Shots)
14 keV, 1.0 x 10^{21} He/m^2s
WC-4 (10x10x1mm)

- As well known blisters of about 1 μm in size are formed.
- Some smooth of them are flaked.
- Rather surface.

Low Tem. / High Fluence





450ºC, 3.3 x 10^{23} He/m^2

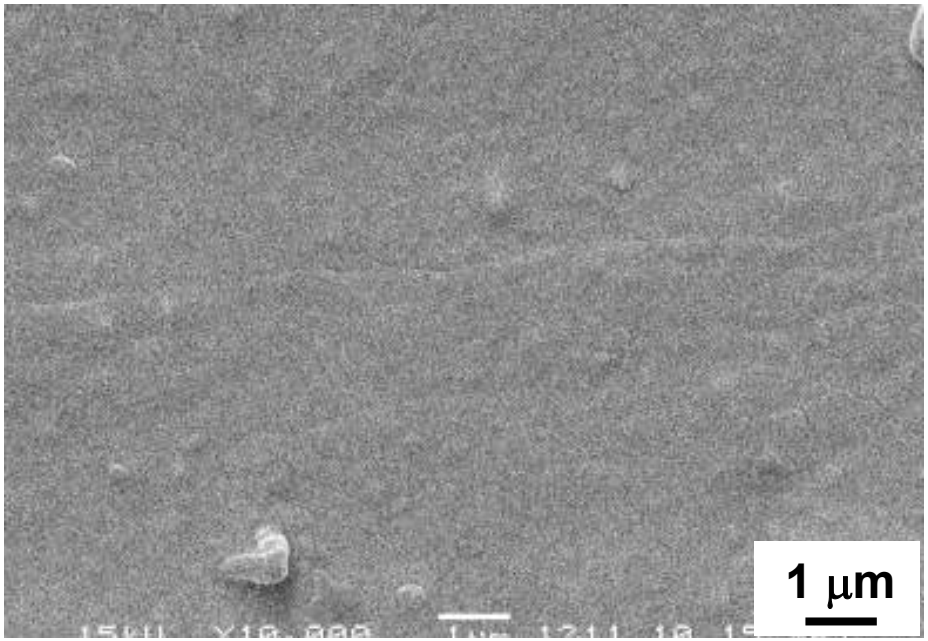
3.0～3.2s/30s(170S)
14 keV, 6.7x 10^{20} He/m^2s
WA-4(20x20x5mm)

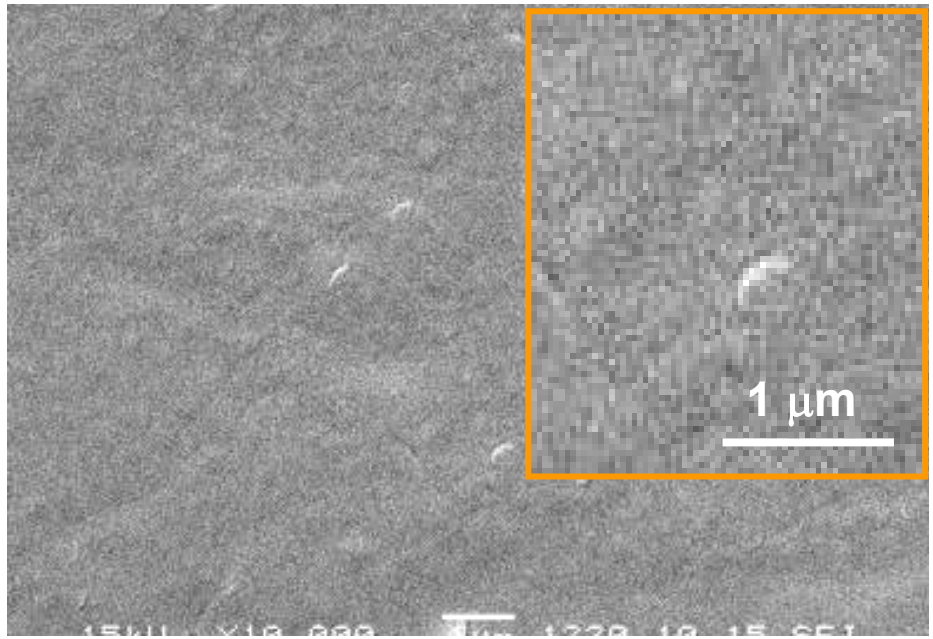
800ºC, 3.3 x 10^{23} He/m^2

3.7～3.9s/30s(128S)
14 keV, 6.7x 10^{20} He/m^2s
WB-7(10x10x1mm)

- All of the blisters are flaked.
- Fine uneven surface morphology

Medium Temp. / Low Fluence





1560 ºC, 2.5 x 10^{22} He/m^2

3.9s/30s(7S)

14 keV, 1.0x 10^{21} He/m^2s

WC-10(10x10x1mm)

1900 ºC, 2.5x 10^{22} He/m^2

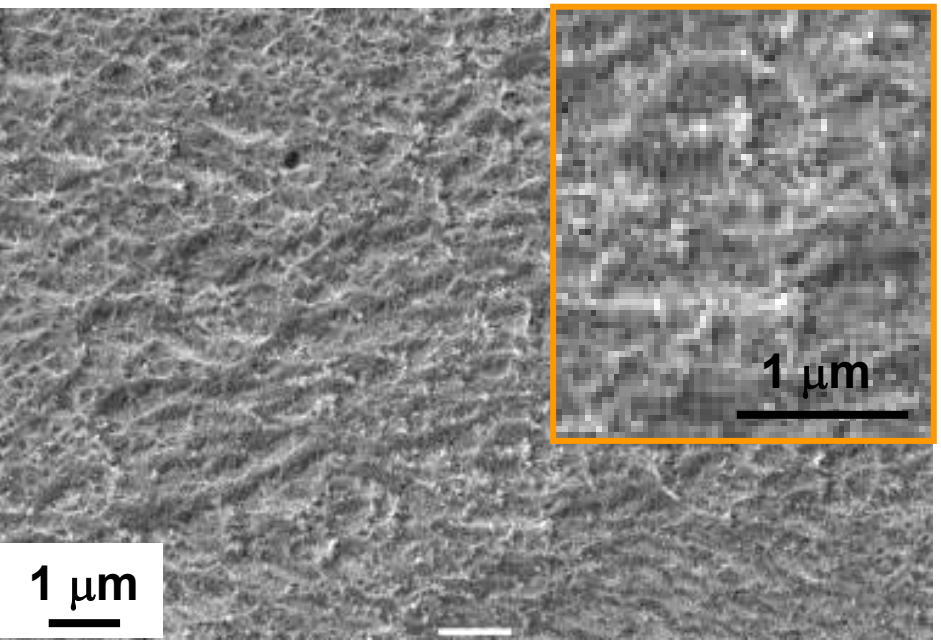
3.5s/30s(8S)

14 keV, 1.0 x 10^{21} He/m^2s

WC-6(10x10x1mm)

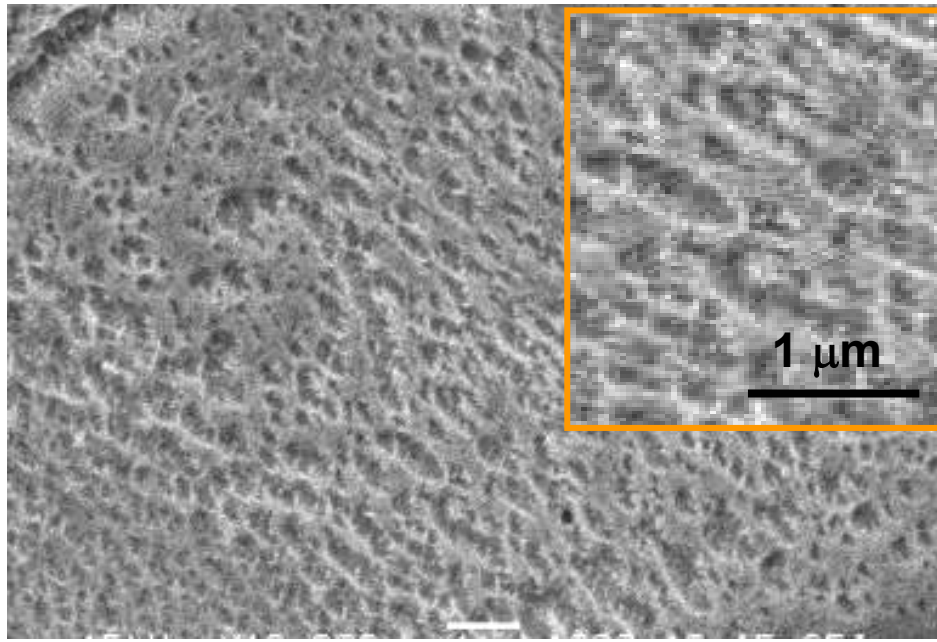
- **Rather smooth surface. Suppression of blister formation.**

Medium Temp. / High Fluence



1400ºC, 5.0x 10^{23} He/m^2

3.5s/30s(145S)
14 keV, 1.0x 10^{21} He/m^2s
WB-4(10x10x1mm)

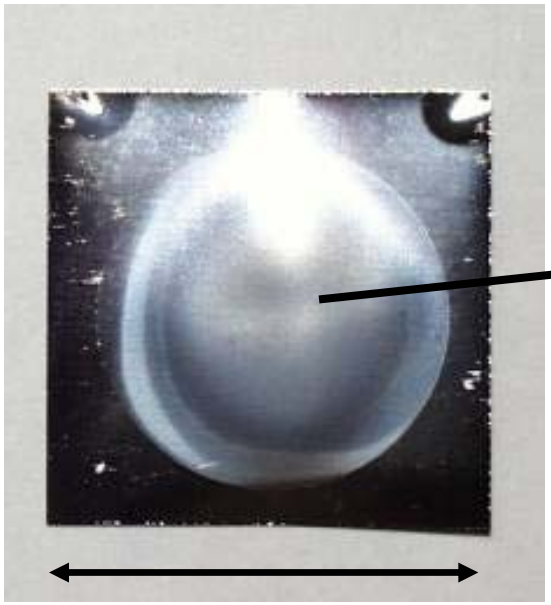


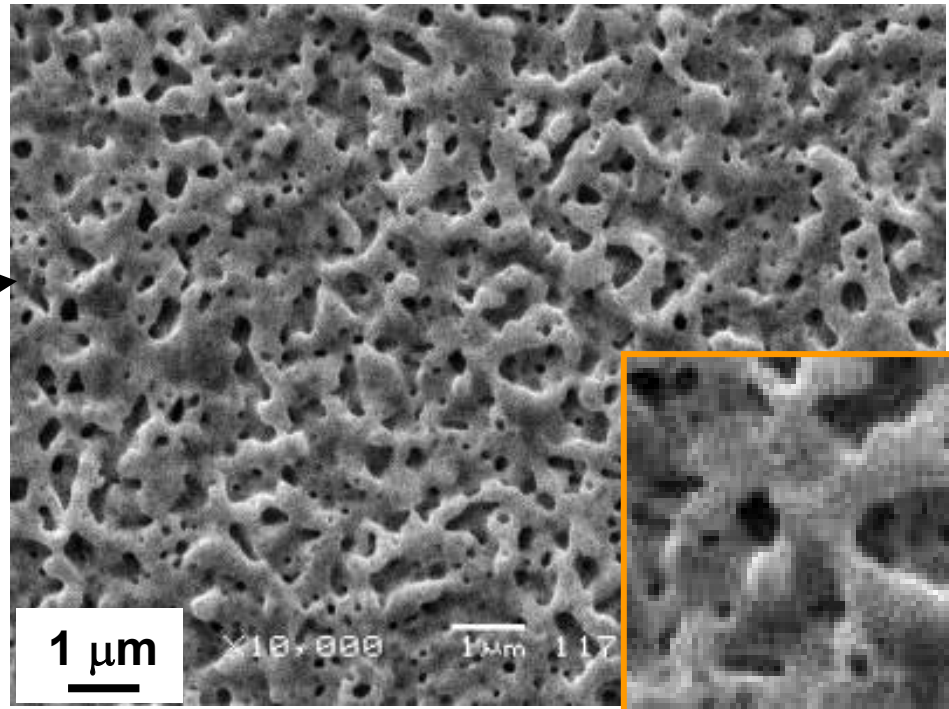
1460ºC, 1.0 x 10^{24} He/m^2

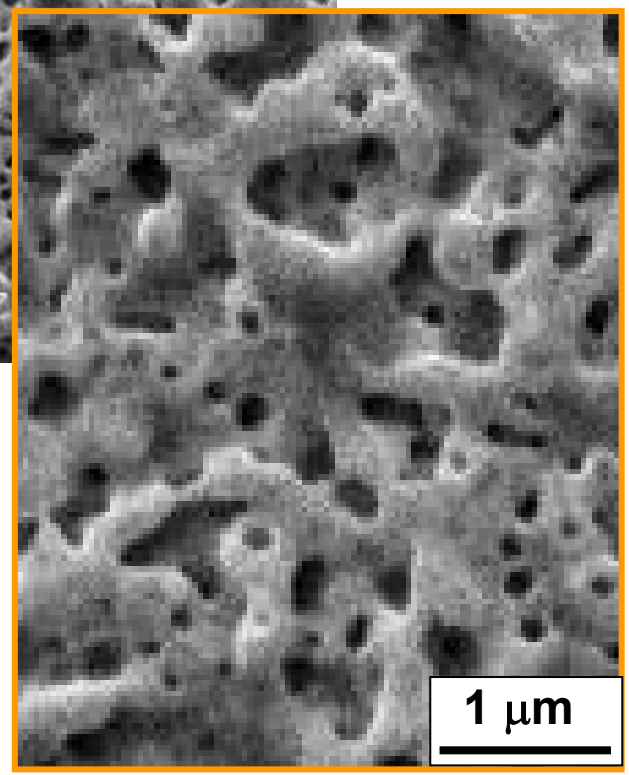
3.5s/30s(145S)
14 keV, 2.0x 10^{21} He/m^2s
WA-8(20x20x5mm)

- No blisters
- Uneven eroded surface

High Temp. / Low Fluence







2500°C, 1.7x 10^{22} He/m^2

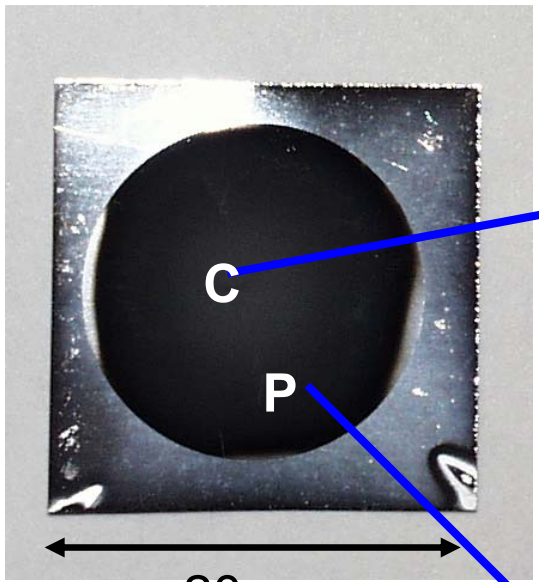
3.5s/30s(8S)

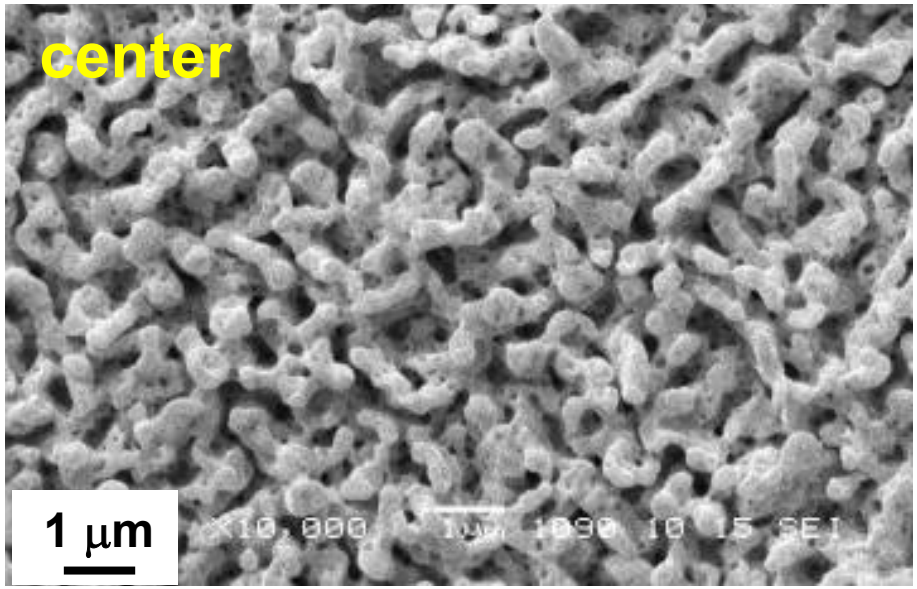
14 keV, 6.7x 10^{20} He/m^2s

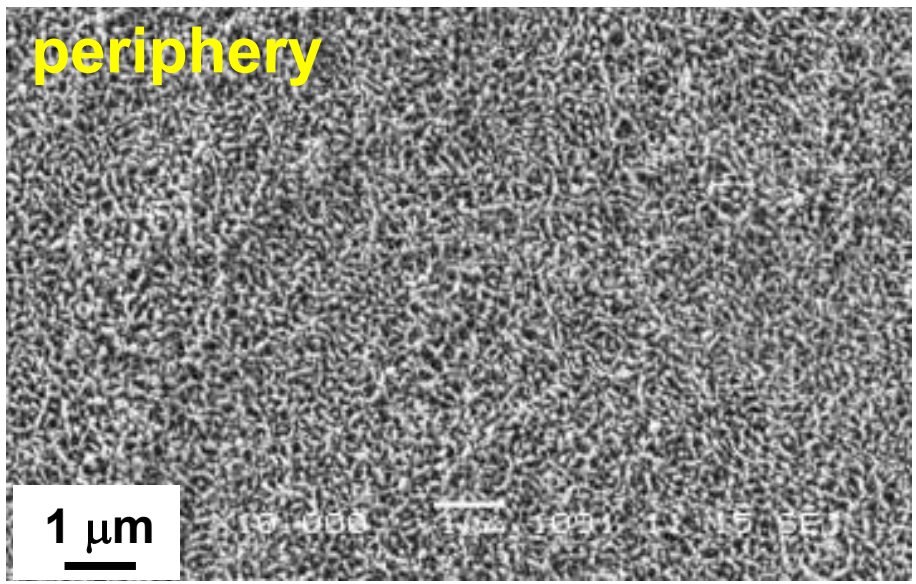
WF-6(20x20x0.1mm)

- **Change of color (gray)**
- **Rough surface (complicated hole structure)**

High Temp. / High Fluence







2500ºC, 3.3x 10^{23} He/m^2

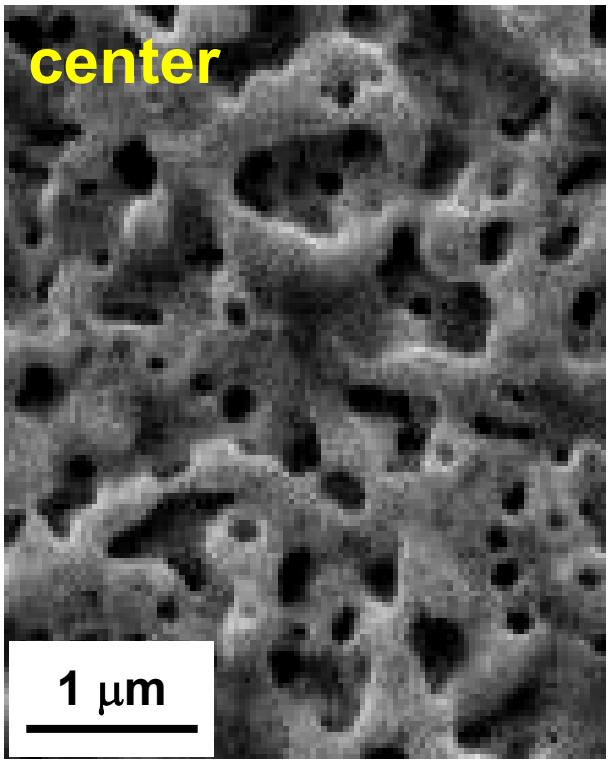
3.5s/30s(145S)

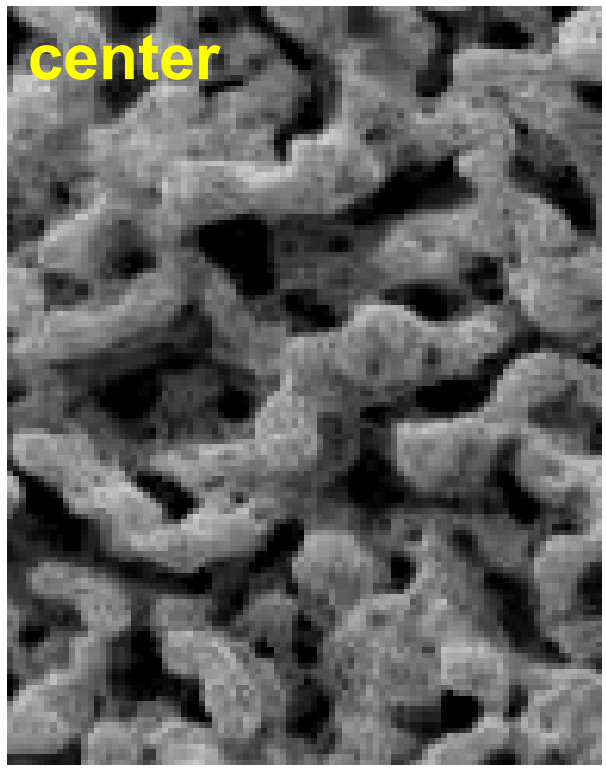
14 keV, 6.7x 10^{20} He/m^2s

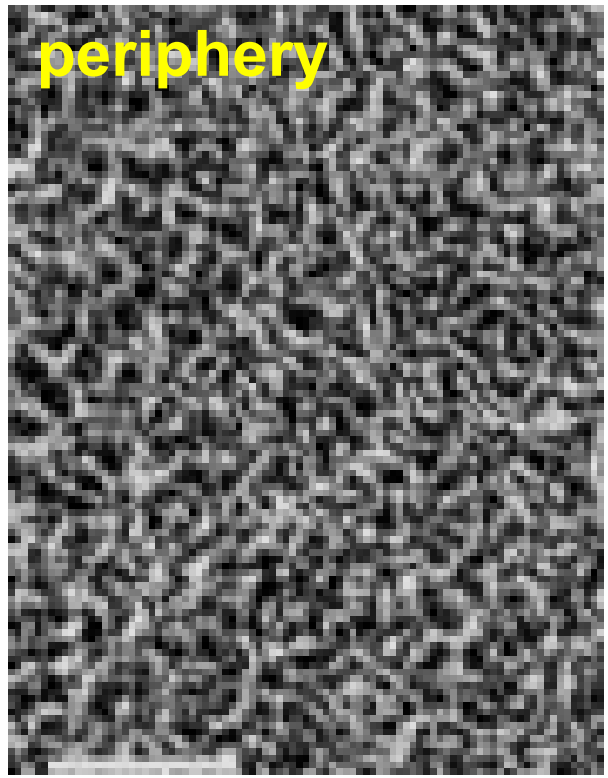
WF-2(20x20x0.1mm)

- **Surface turned to black like a charcoal.**

Formation of Black Rough Surface







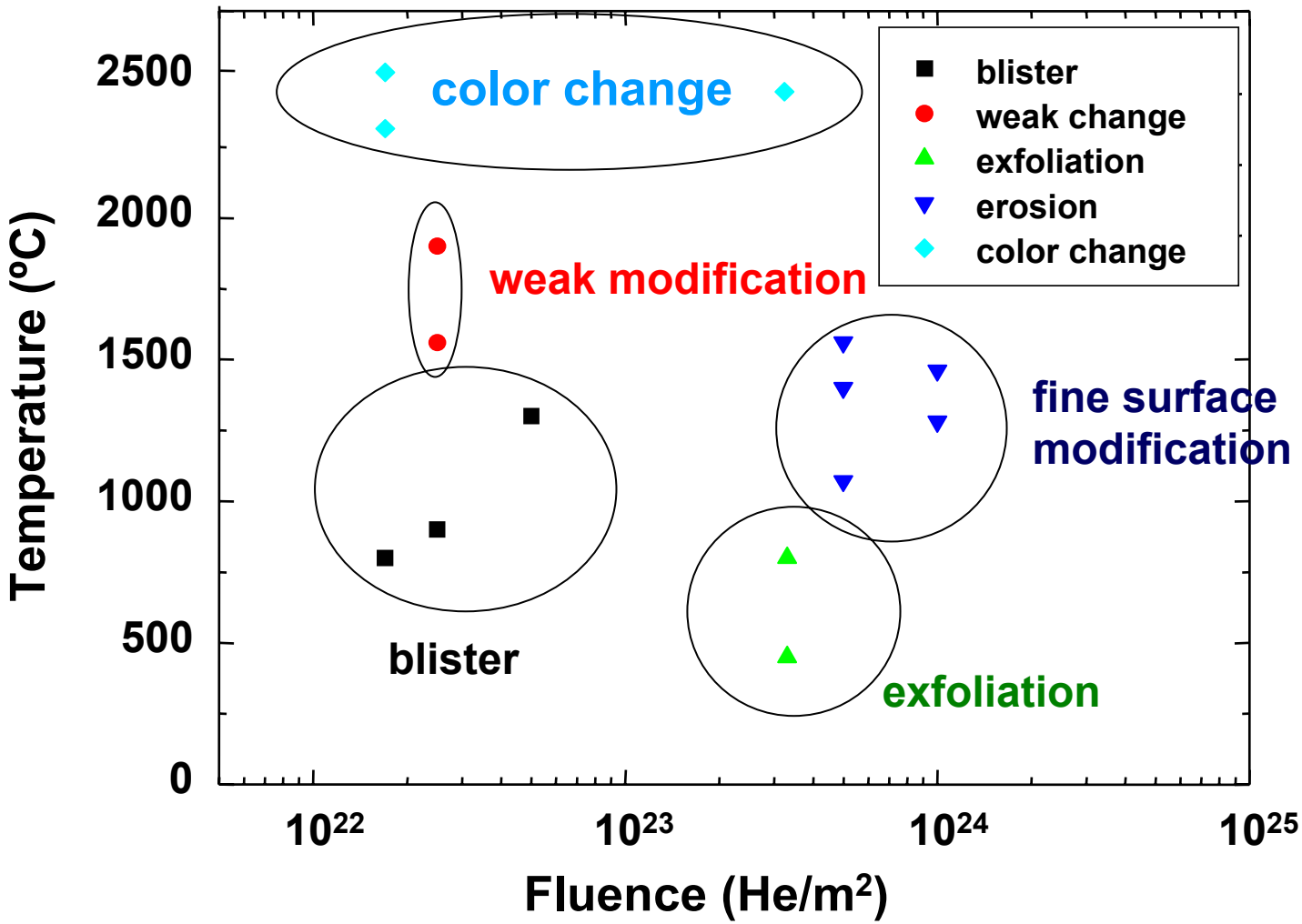
2500ºC,
1.7x 10^{22} He/m^2
gray

2500ºC,
3.3x 10^{23} He/m^2
black

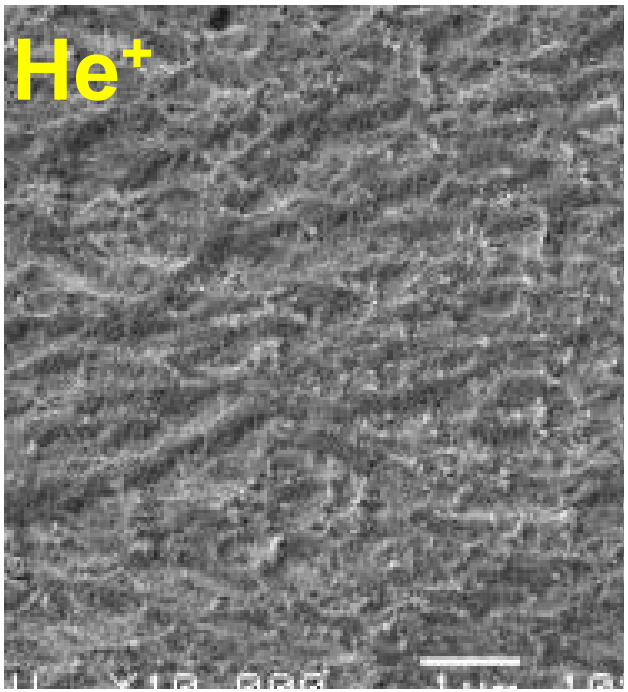
≤ 2500ºC,
3.3x 10^{23} He/m^2
real black

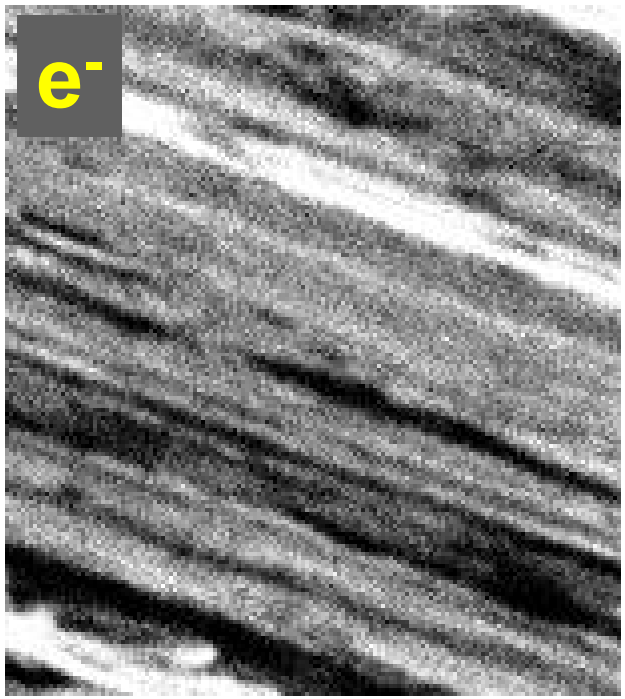
- Relation of color and surface morphology

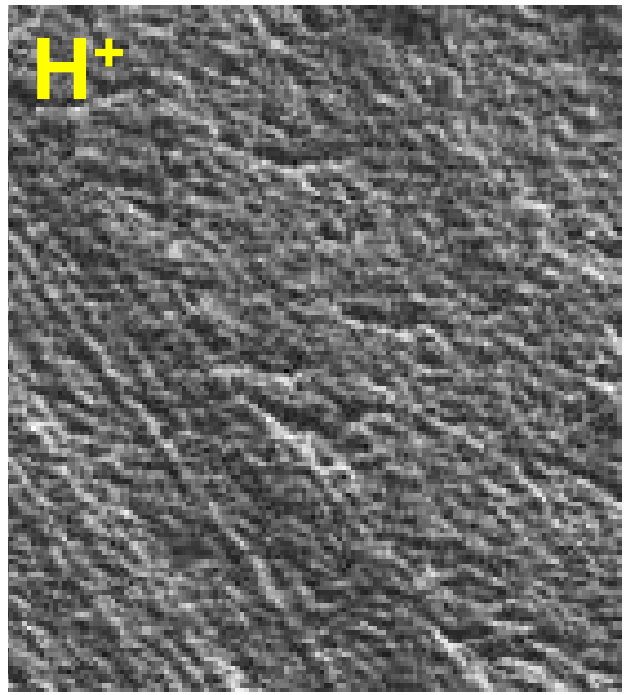
Surface modification v.s. (Fluence–Peak Temp.)



Comparison with He^+, e^- and H^+ Heating





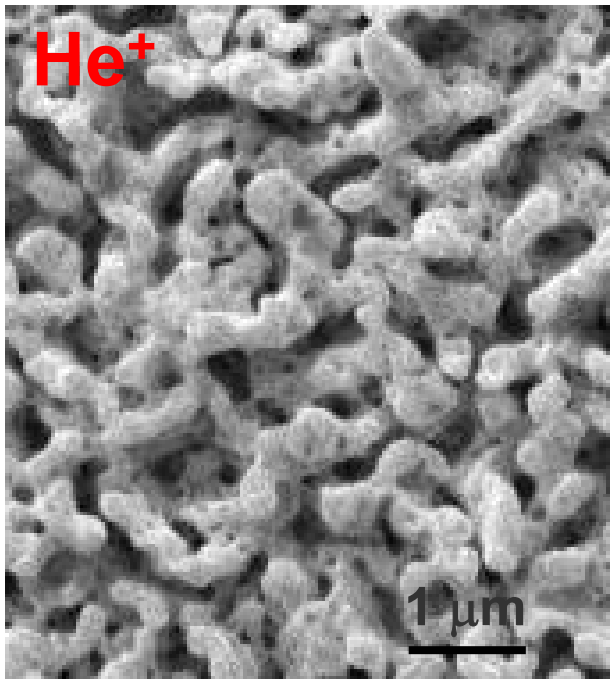


1400ºC, 5.0x 10^{23} He/m^2
3.5s/30s(145S)
14 keV, He
1.0x 10^{21} He/m^2s
3 MW/m^2
WB-4(10x10x1mm)

1600ºC,
1.8 s x 100 S
30 keV, e
5 MW/m^2
PM-W(30x30x5mm)

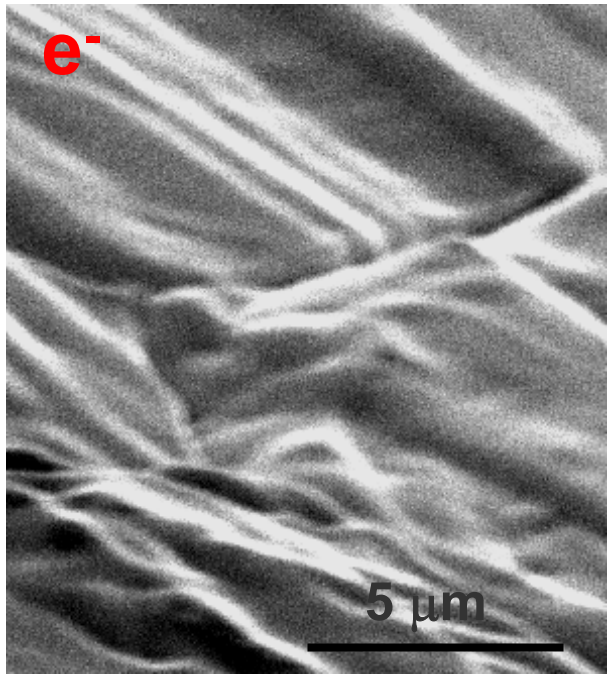
1600ºC, 2.9 x 10^{23} H/m^2
1.8 s x 100 S
18.3 keV, H
1.6x 10^{21} H/m^2s
5 MW/m^2
PM-W(30x30x5mm)

Comparison with He, e and H heating



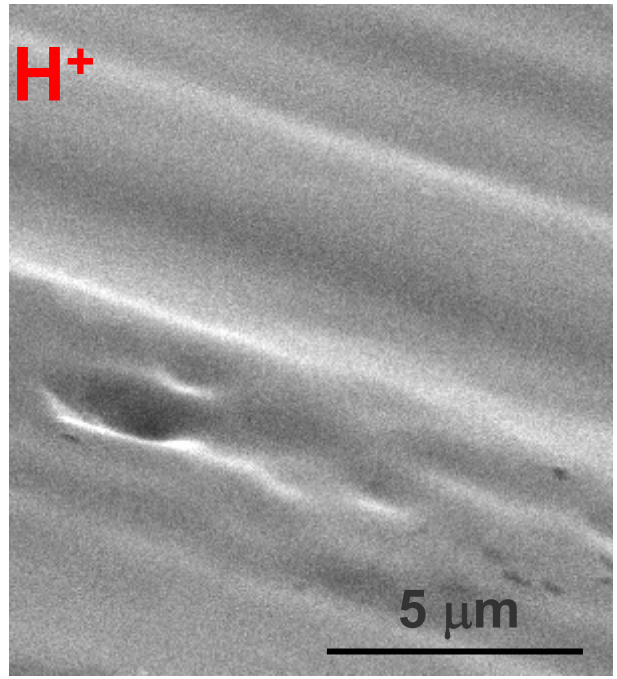
2500℃、

3.3x 10^{23} He/m^2
3.5s/30s(145S)
14 keV, He
6.7x 10^{20} He/m^2s
2 MW/m^2
WB-4(20x20x0.1mm)



1150℃→2700℃

2.0 s x 100 S
34 keV, e
10 MW/m^2
PM-W(30x30x5mm)

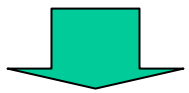


1100℃→2700℃

5.0 x 10^{23} H/m^2
2.0 s x 100 S
23.6 keV, H
2.5 x 10^{21} H/m^2s
10 MW/m^2
PM-W(30x30x5mm)

Future plan of Observation/Analyses

- Surface morphology (SEM SPM)
- Structure changes(SEM, TEM)
- Surface composition(EDS, AES, SIMS)
- Thermal desorption (TDS)
- Hardness
- Weight loss



- Effect of helium irradiation on material property

Conclusions

- He enhances the surface modification due to high helium retention at high temperatures even above 2000ºC because of the very strong binding to defects (vacancy, cavity) in tungsten.
- This does not depend much on the energy of He ions.
- Present results indicate the importance of synergistic effects of helium and heat load on surface modification and erosion of tungsten under the fusion environment.

Workshop Agenda