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Dependence of Surface Temperature and Incidental Ion Energy for Bubble Formation on Tungsten Surface Irradiated by Low Energy and High Flux Helium Plasma

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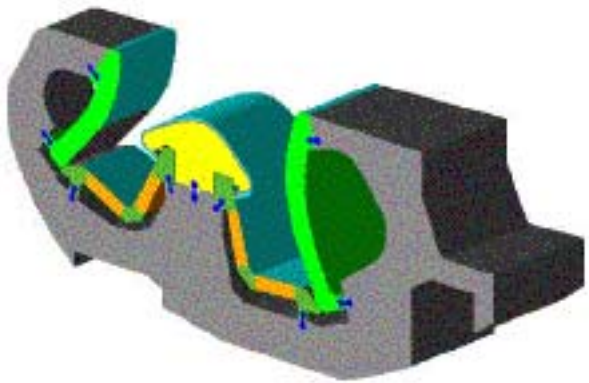
Workshop Agenda

Background I

The diverter plasma condition

Low energy (< 100 eV) High flux (~$10^{23\text{-}25}/m^2s$)



Tungsten

High melt. temp. ~ 3600 K

Low sputtering yield

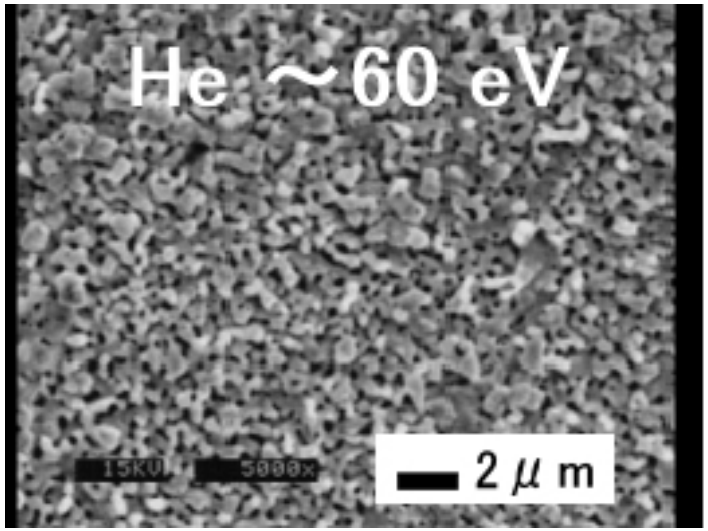
Low solubility of H-isotopes

Helium (He) plasma

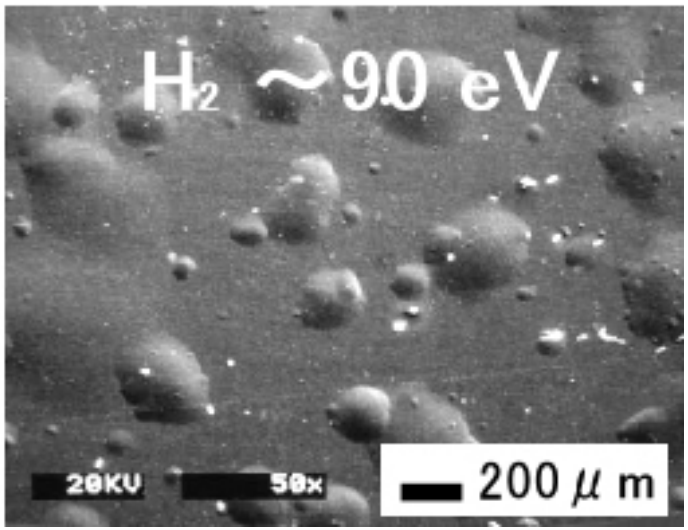
$D + T \rightarrow {}^4He + n$ About 10 % to total plasma

Background II

Low energy plasma irradiations make damages on the W surface.



D. Nishijima, et al,. Nucl. Matr. **313-316** (2003) 99-103.



M. Y. Ye, et al,. Nucl. Matr. **313-316** (2003) 72-76.

Concerned Matters

Erosion of W → High Z impurity

Gas retention → Plasma density control

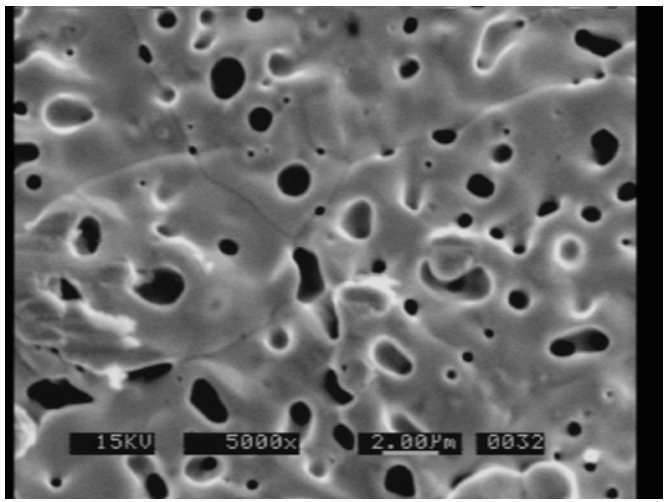
Objective

To investigate
the mechanism of bubble formation(B.F.) and the dependence of variant parameters.

Incident ion energy (E_{in})

Surface temperature (T_s)

Fluence



Ion flux

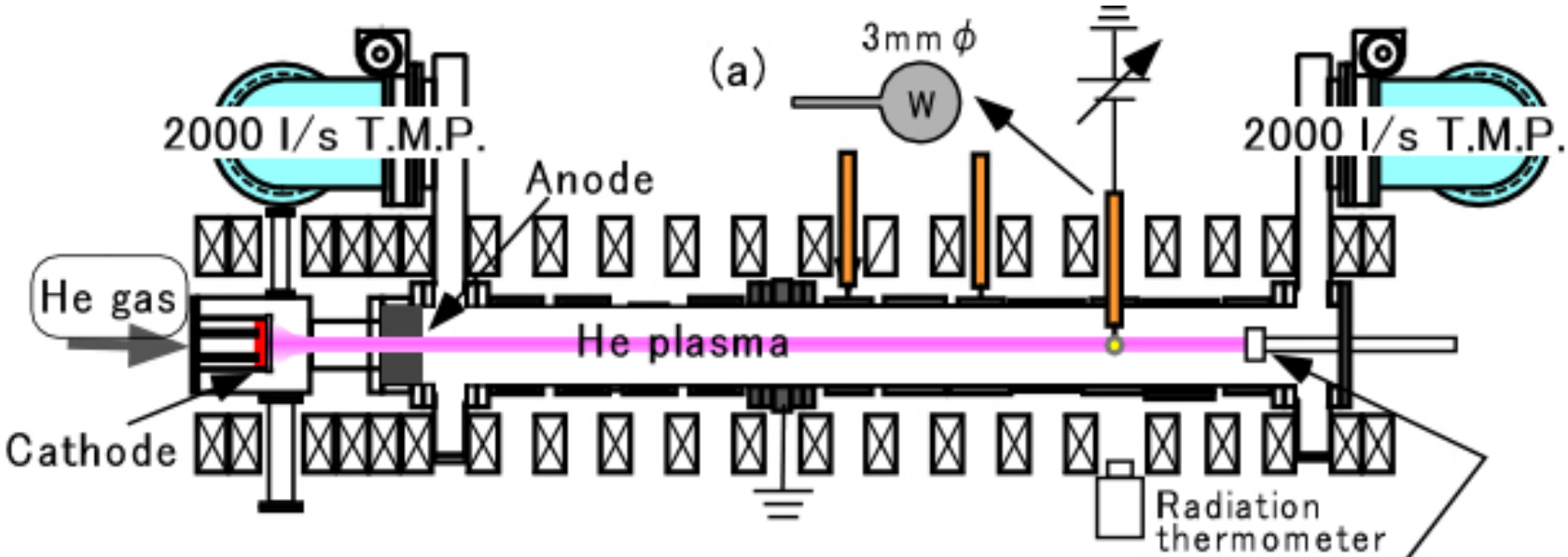
Irradiation time

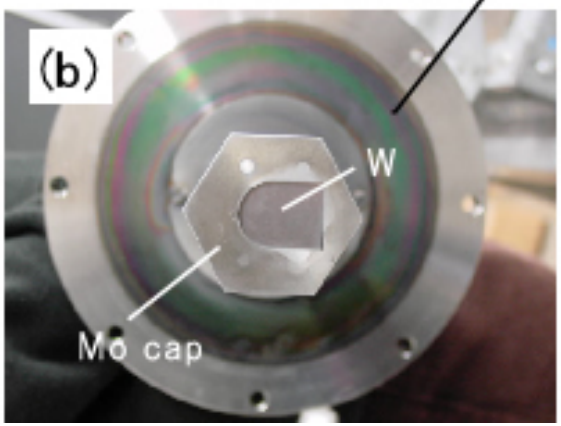
History of irradiation

Hybrid gas irradiation

Experimental Setup

Linear Divertor Plasma Simulator NAGDIS-II





Electron density : ~ $10^{18\sim19}$ /m^3

Electron temp. : 5 ~10 eV

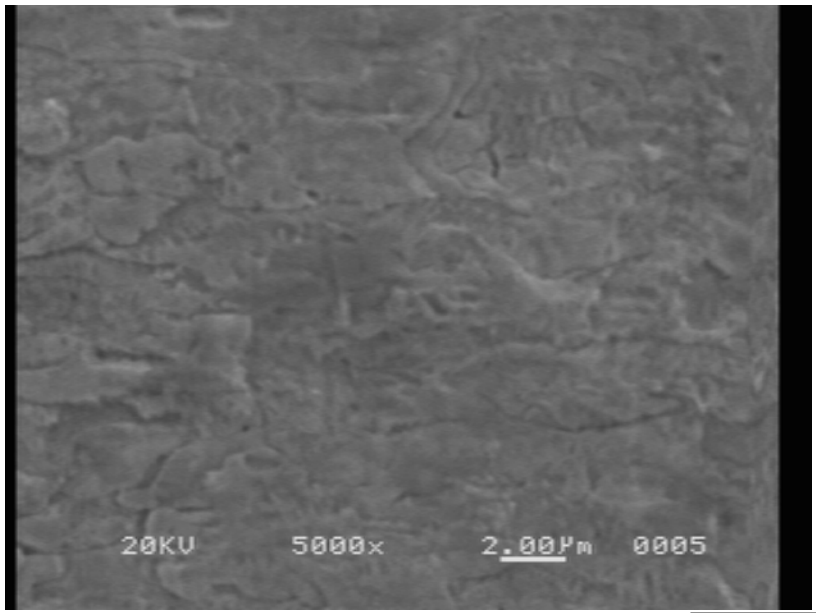
Ion temp : 1 ~ 2 eV

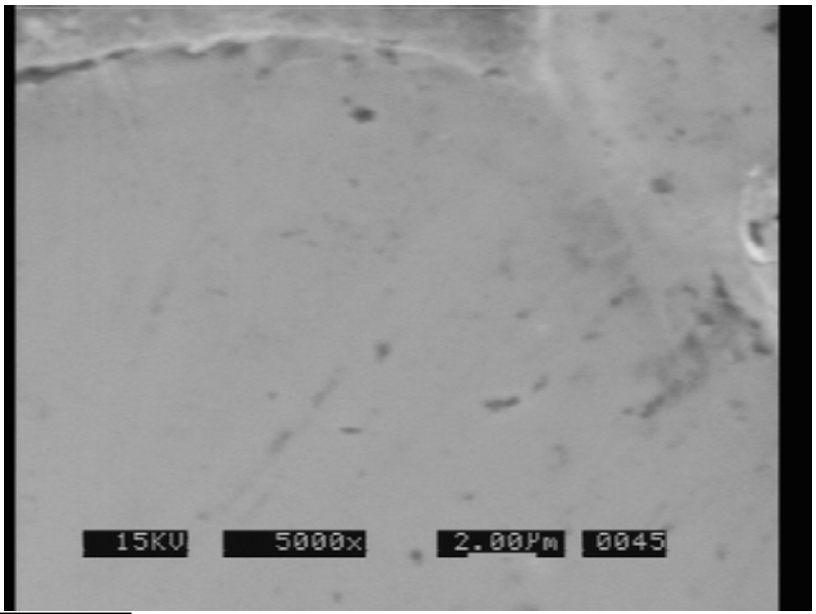
Working gases : He, H_2, D_2, Ar

Virgin sample

Powder metallurgy W
(Polycrystalline W)

Single crystal W





W1 ~ W7, W9

2 μm

W8

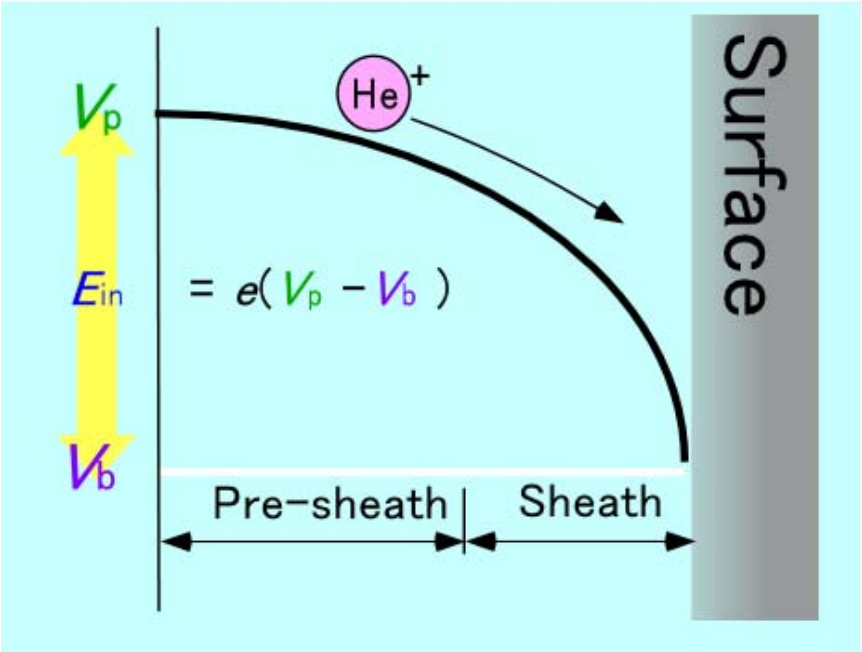
Purity: 99.95 %
Thickness: 0.1 or 0.2 mm

Purity: 99.95 %
Thickness: 1 mm

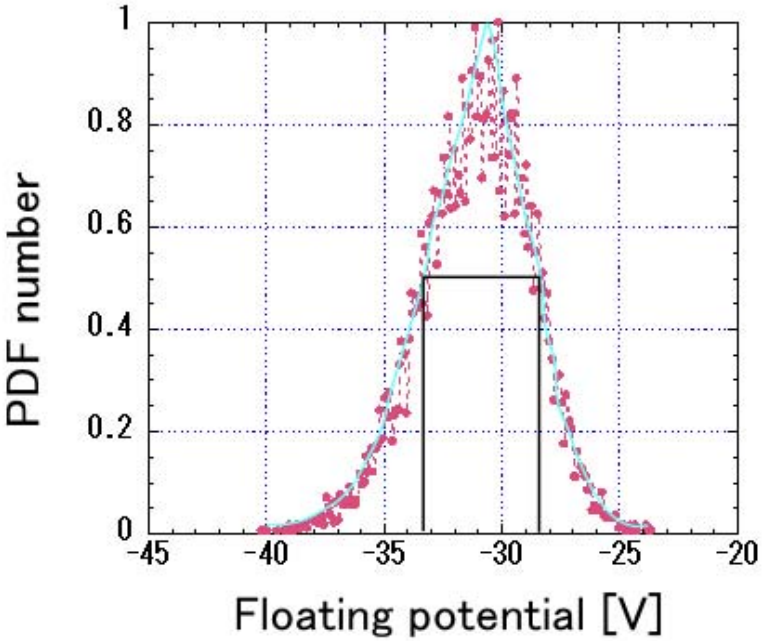
Controlling of E_{in}

V_p : Plasma space potential

V_b : Bias voltage of the target



Probability density function analysis of floating potential fluctuation



Spread of E_{in}

± 4 eV

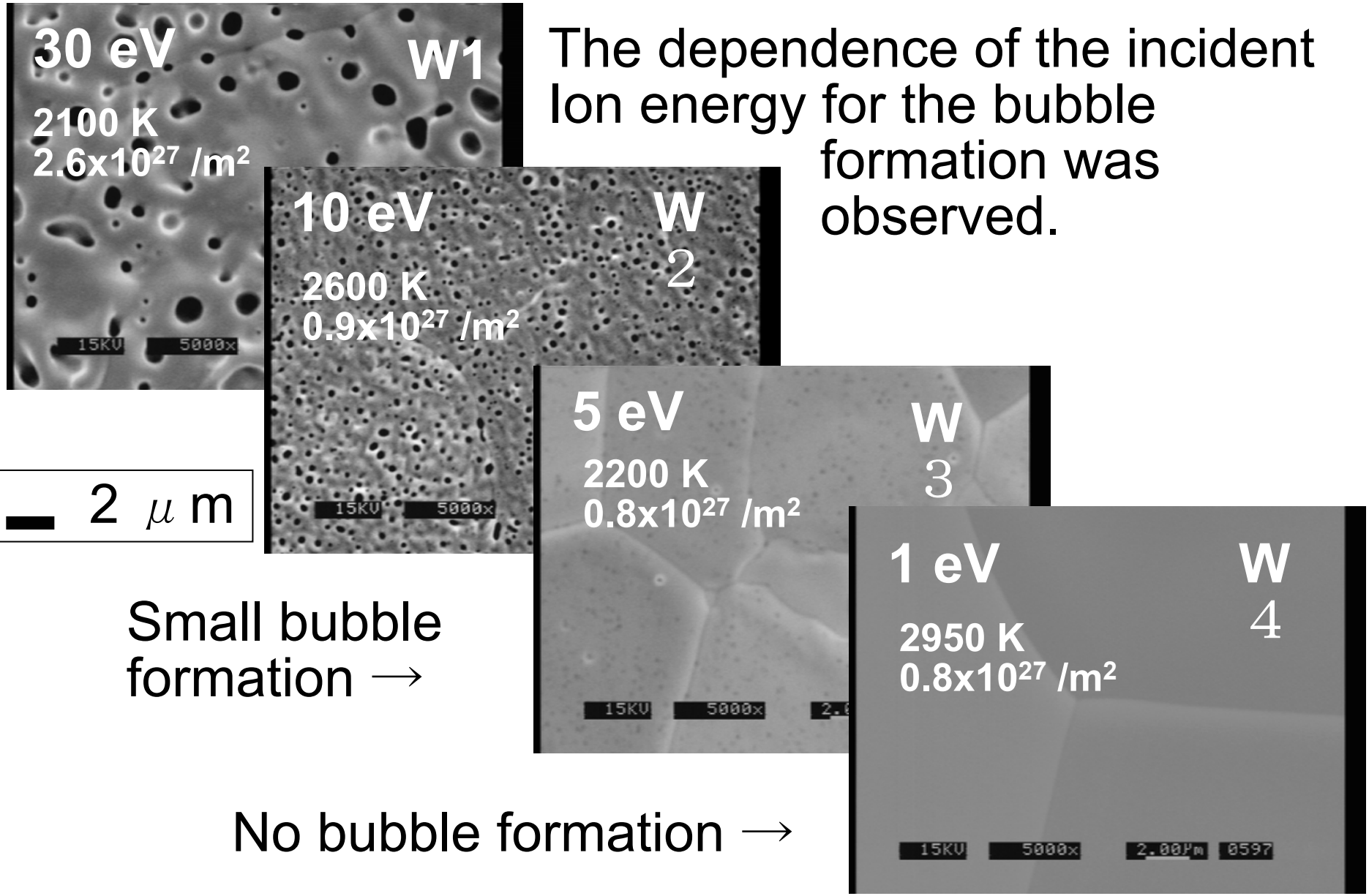
⇦

Potential fluctuation : 3 ~ 5 $V_{p\text{-}p}$

Ion temperature : 1 ~ 2 eV

Incident Energy Dependence for B.F.

The dependence of the incident Ion energy for the bubble formation was observed.

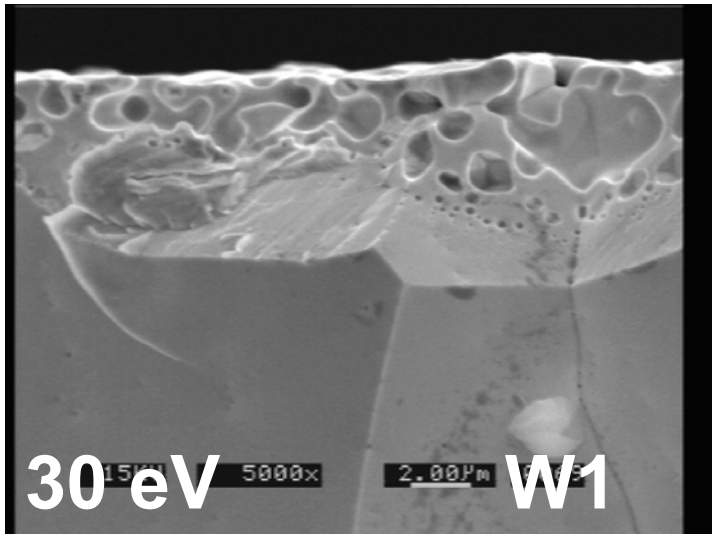


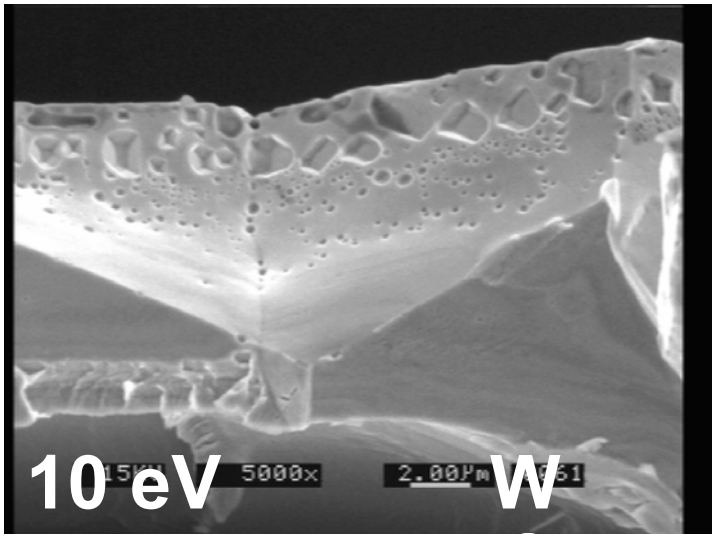
2 μm

Small bubble formation →

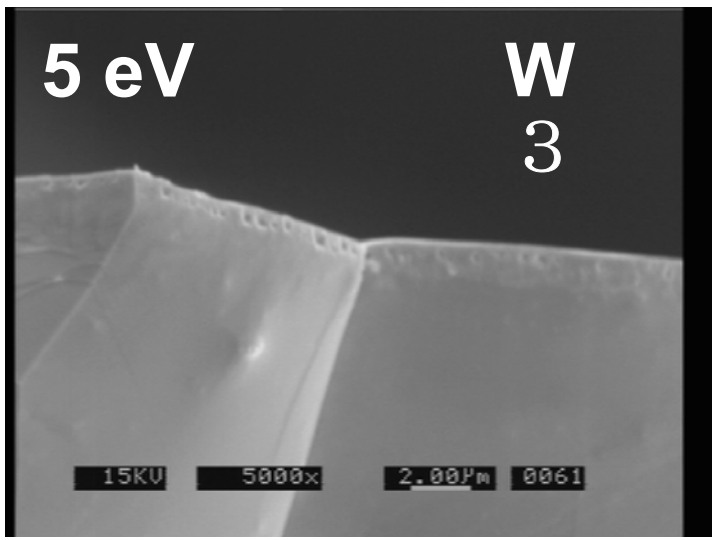
No bubble formation →

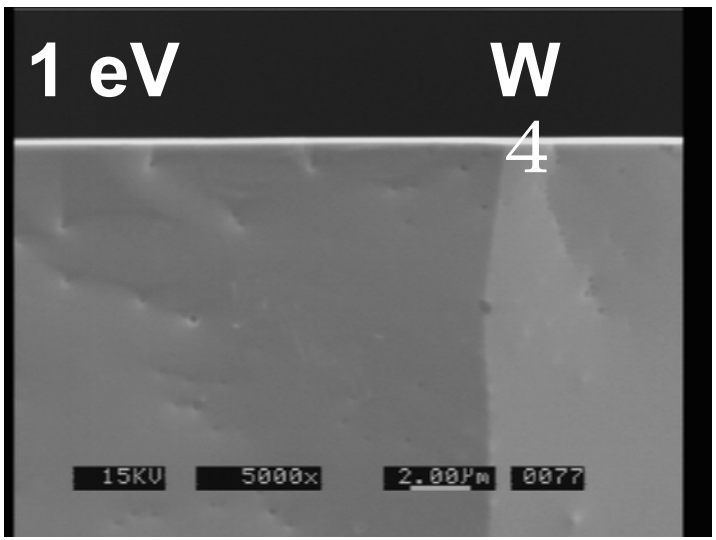
Cross-Section





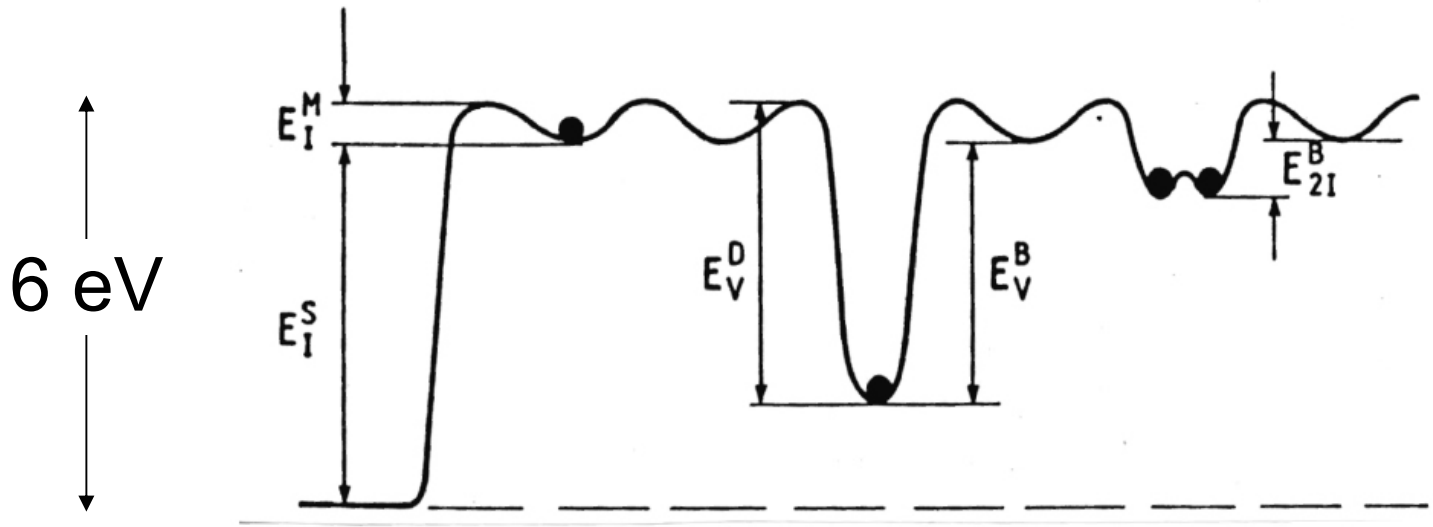
2 μm





Surface potential barrier

Low energy(< 6 eV) He ions cannot enter into the W interior due to the surface potential barrier of the W. As a result, no bubble formation.

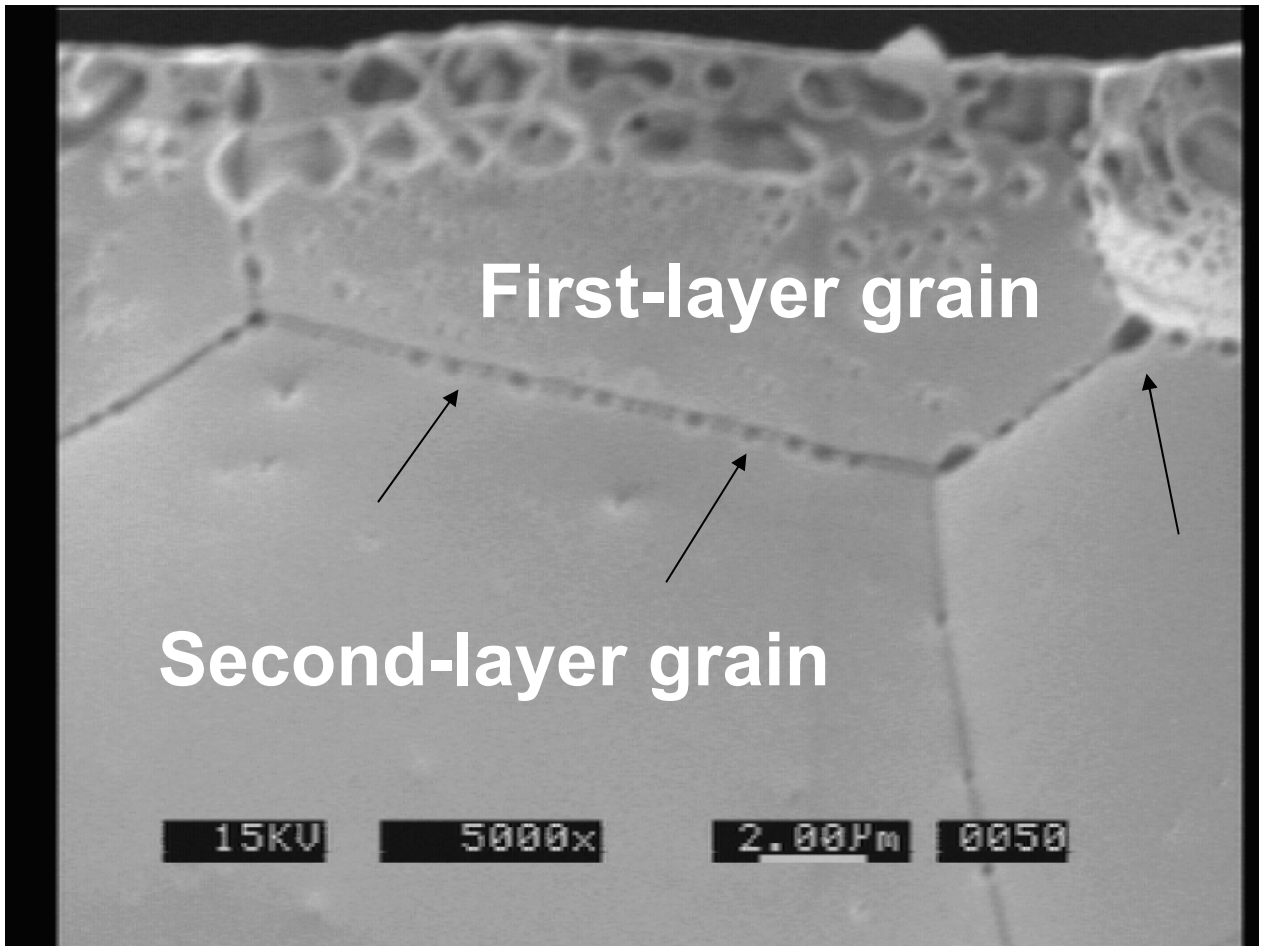


H. Ullmaier Nucl. Fusion, **24**, No.8(1984) 1039.

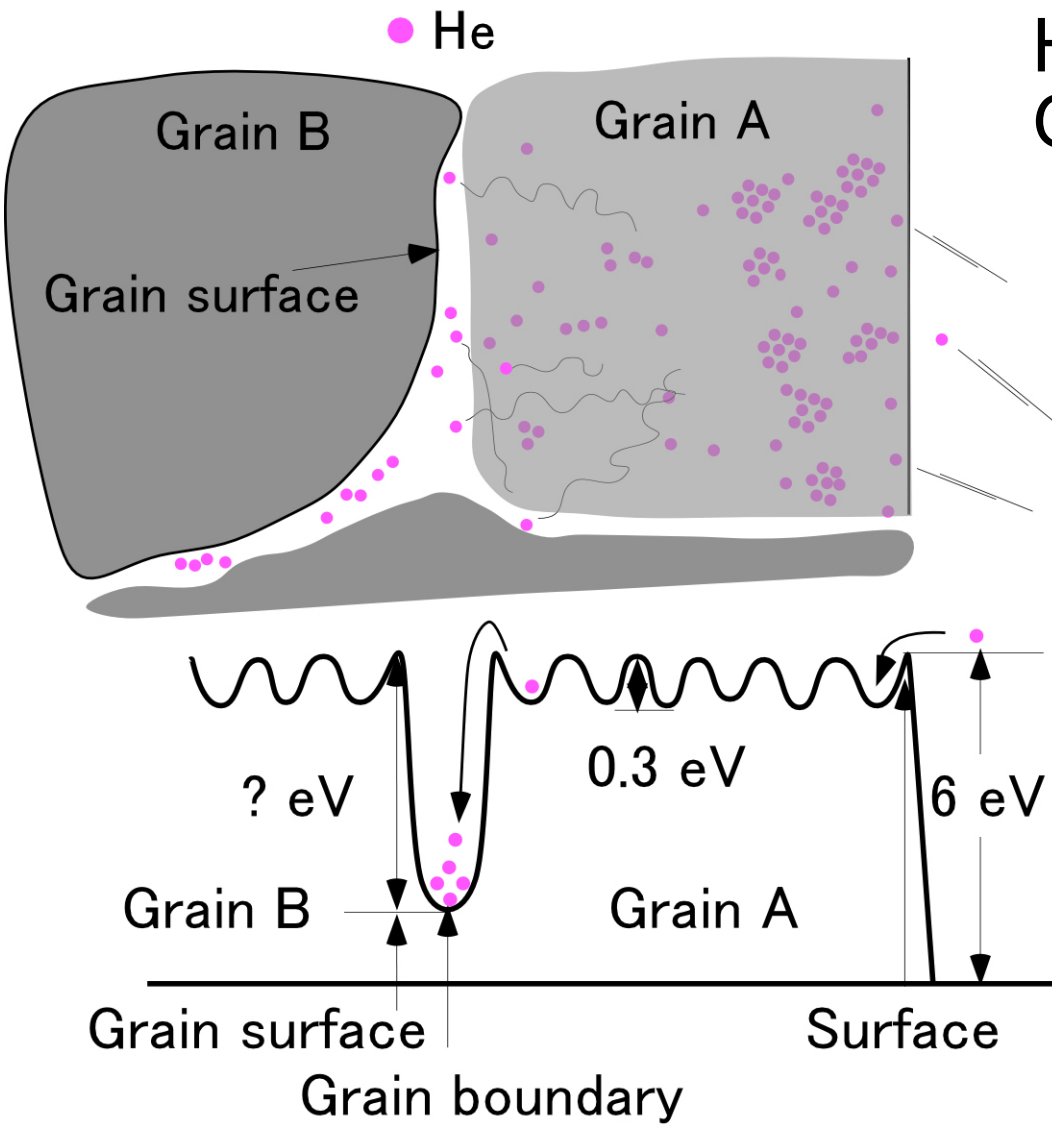
B.F. at grain boundary

Preferential bubble formation at first-layer grain and along grain boundary.

10 eV



Discussion of Preferential B.F.



He intrusion into the Grain A.

Bubble formation or diffusing through the interior of Grain A.

Exit to the surface of Grain A.

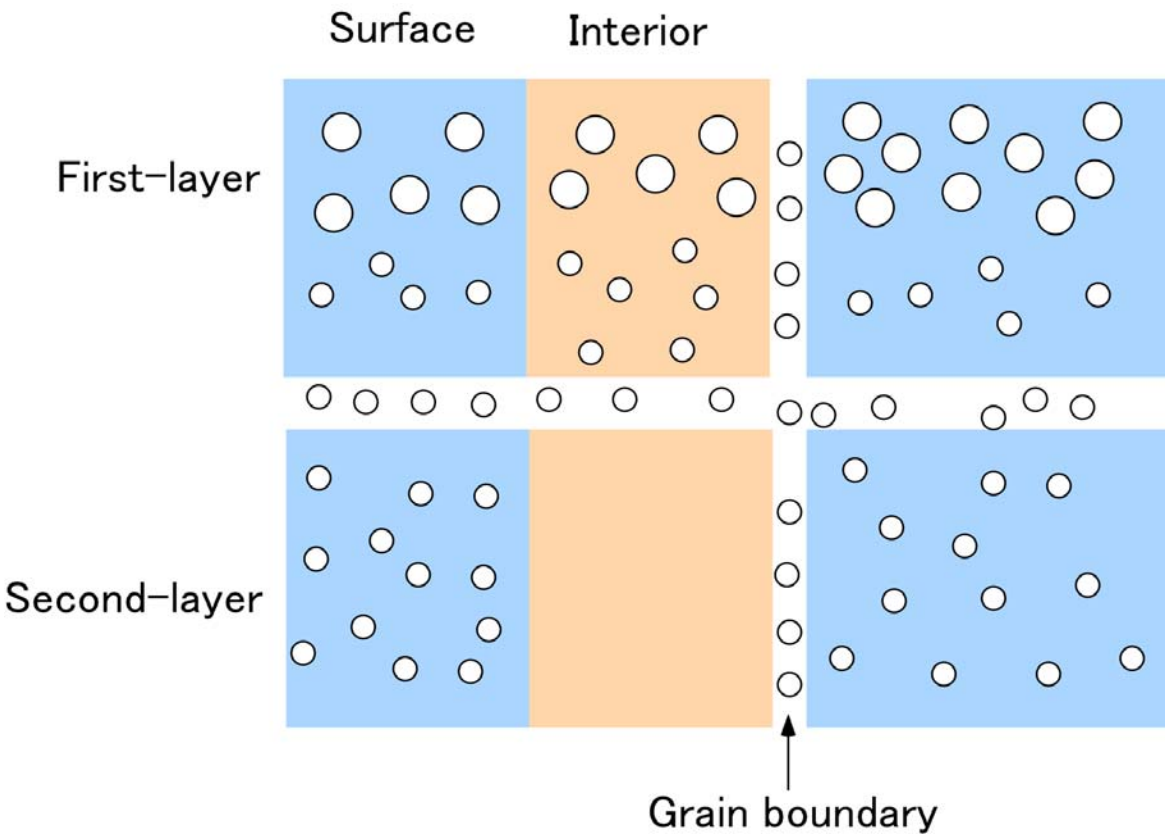
Insufficient energy to climb up the surface potential of Grain B.

B.F. or Diffusing along the grain boundary.

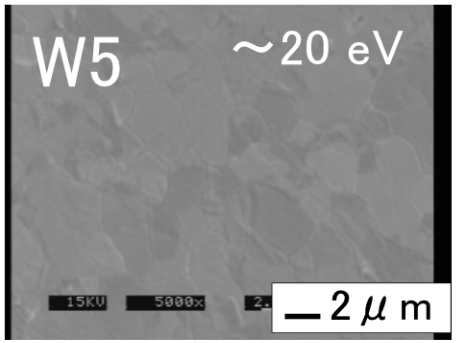
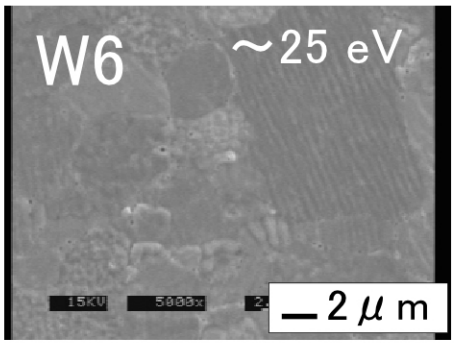
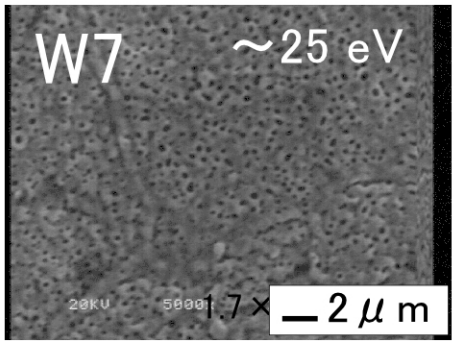
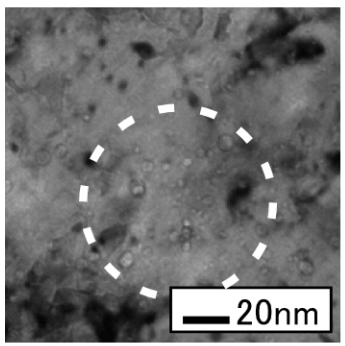
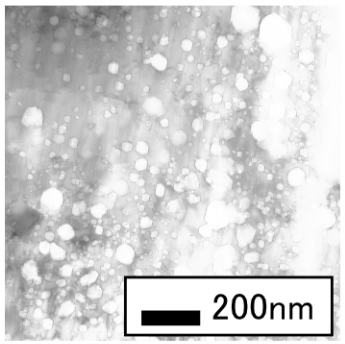
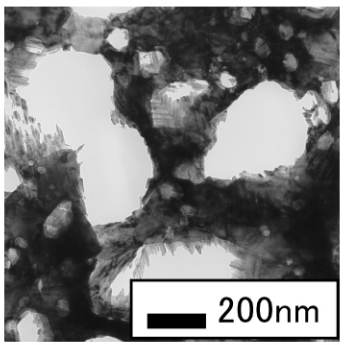
No B.F. at Inside of Second-Layer grain

Prediction

Bubble formation will be observed only on the surfaces(along the grain boundary) but not at inside of grains below first-layer grains.



Temperature Dependence

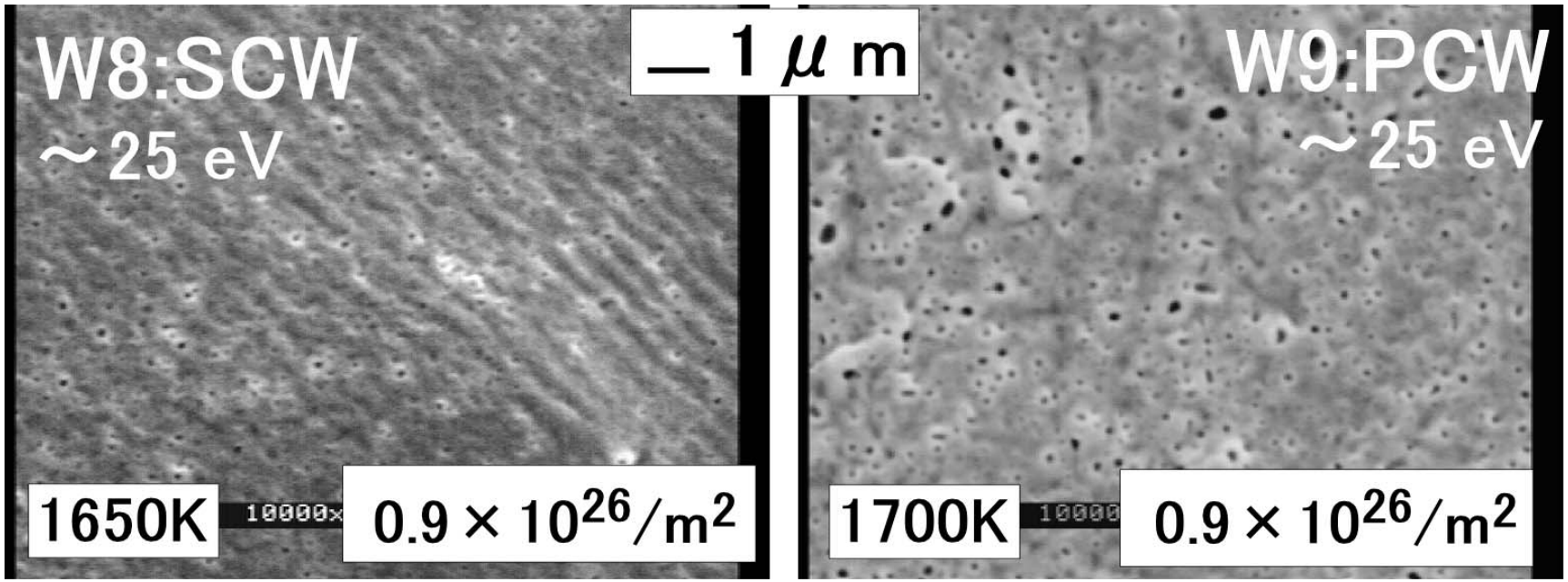
Fluence Time Ion flux Temp	3.5×10^{26} /m² 3600 s 1.0×10^{23} /m²s 1300 K	1.8×10^{26} /m² 1800 s 1.0×10^{23} /m²s 1650 K	1.7×10^{26} /m² 660 s 2.6×10^{23} /m²s 1950 K
SEM			
TEM			
Bubble size	< 5 nm	< 200 nm	< 500 nm

Thermal vacancy density, Diffusivity → $\exp(-E/kT)$

Effect of Primary Defects

Density of Primary Defects

Single crystal W(SCW) << Polycrystalline W(PCW)



Bubble size

SCW : < 100 nm PCW : < 500 nm

Discussion about Primary defects

Thermal vacancy ⇨ Basic nucleus of bubbles

↪ Uniform bubble formation

Primary interstitial defects ⇨ Promotion element of bubble growth

↪ Difference of bubble size

It is considered that thermal vacancies play a critical role in the bubble formation

Summary and Conclusions

Fundamentals of bubble formation

A. He intrusion through the W surface.

→ Related to the surface potential energy (~ 6 eV), incident ion energy

B. Existence of trap site for He atoms.

→ Thermal vacancy (main), primary interstitial defects

C. Mobility of He atom and vacancy.

→ Related to temperature, diffusion coefficient of He and vacancy, shear modulus of the material

Future works

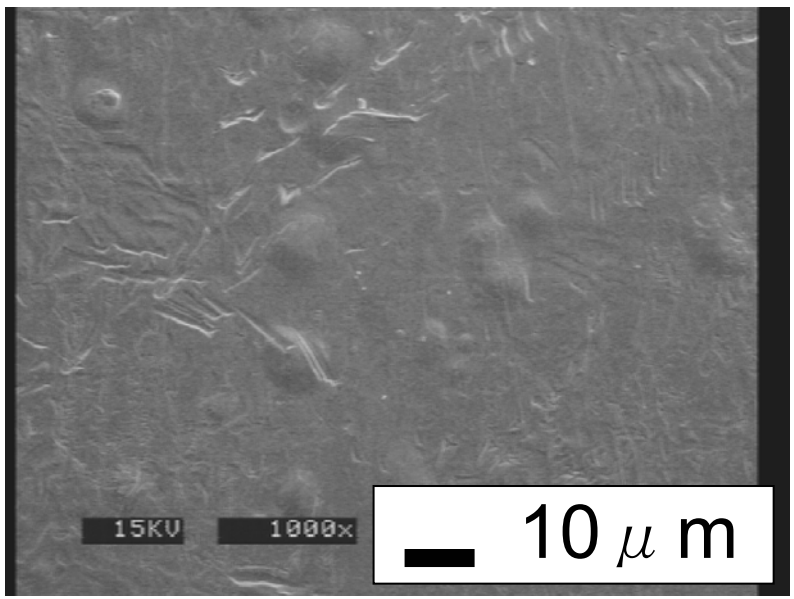
Workshop Agenda

Dependence of Fluence

- Investigation of the relation between the fluence and bubble size.
- Modeling of the bubble growth.

Hybrid plasma irradiation

Preliminary experiment

H_2 : 90 sccm, He : 70 sccm

~ 700K, 2h, ~ 10^{22} /m^2s,
~ 10^{26} /m^2