Reduction and Recovery of Optical Reflectivity of Mo Mirror Irradiated by Low Energy Helium Ions

N. Yoshida[1], A. Ebihara[2], M. Tokitani[2], K. Tokunaga[1], T. Fujiwara[1], A. Sagara[3]

Presented by Tatsuo Sugie

[1]Research Institute for Applied Mechanics, Kyushu University
Kasuga, Fukuoka, Japan
[2]Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga, Fukuoka, Japan
[3]National Institute for Fusion Science, Toki, Gifu, Japan

Advanced Diagnostics for Burning Plasmas

Purpose and Exp. Procedures

Radiation effects of He ions on optical reflectivity of Mo at the first wall relevant conditions have been studied.

- **To acquire the data of optical reflectivity for wide range of wave length**
- **To identify the origins of the reduction of reflectivity**
- **To show the methods to recover the reflectivity**

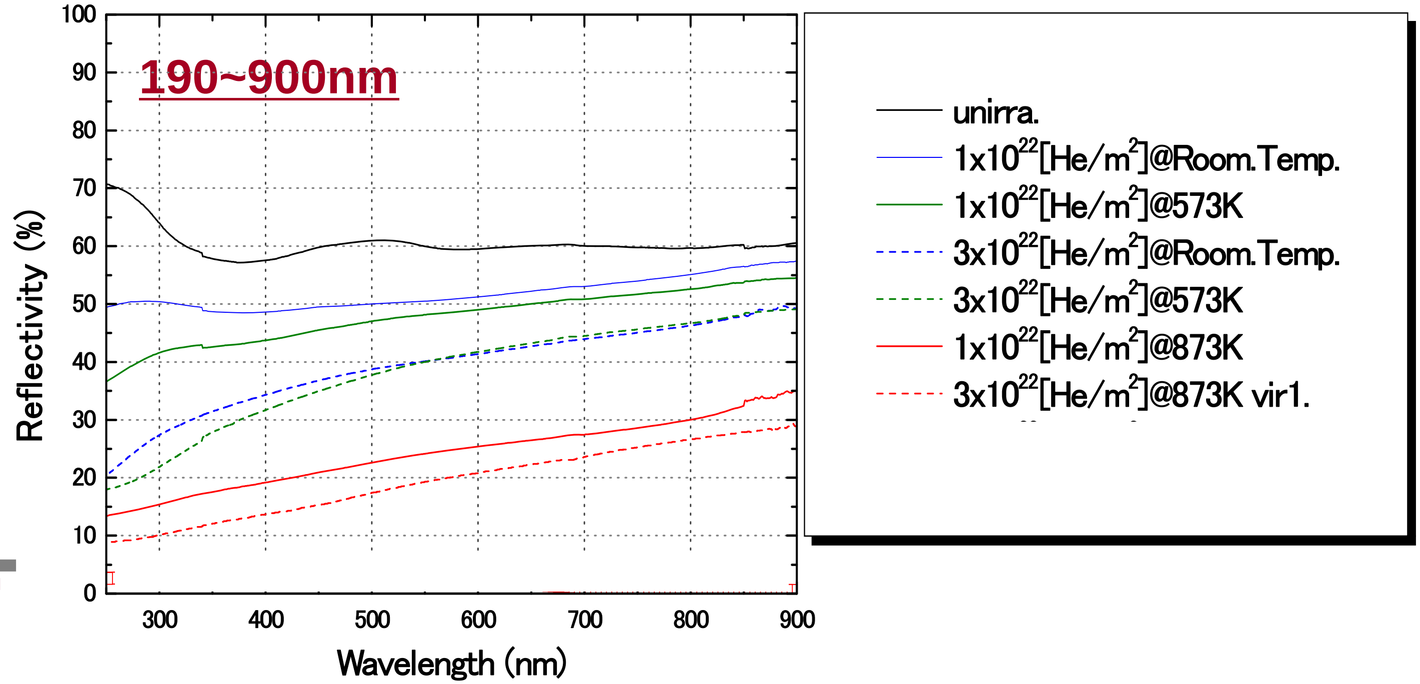
Irradiation Conditions

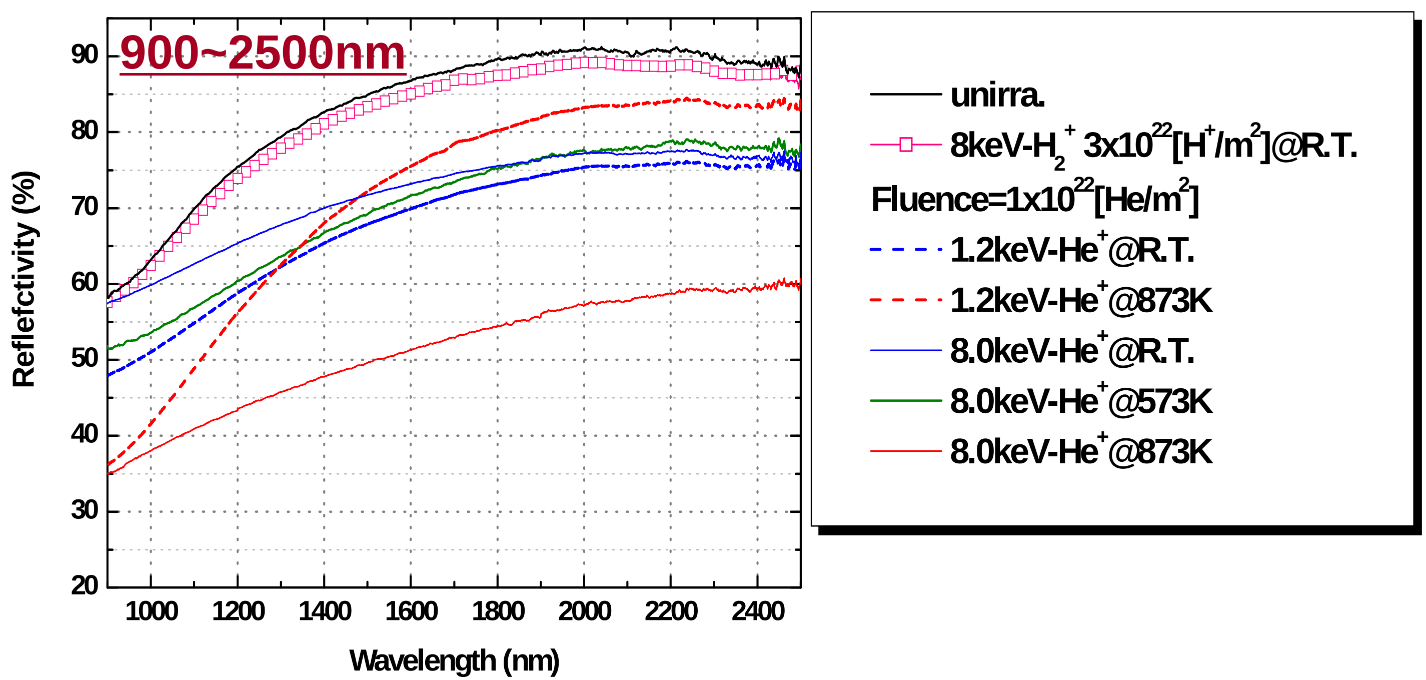
- **Helium ion energy: 1.2keV, 8keV**
- **Irradiation temperature: 300K, 573K, 873K**
- **Fluence: $3x10^{21}$~$3x10^{22}/m^2$**

Post Irradiation Experiments

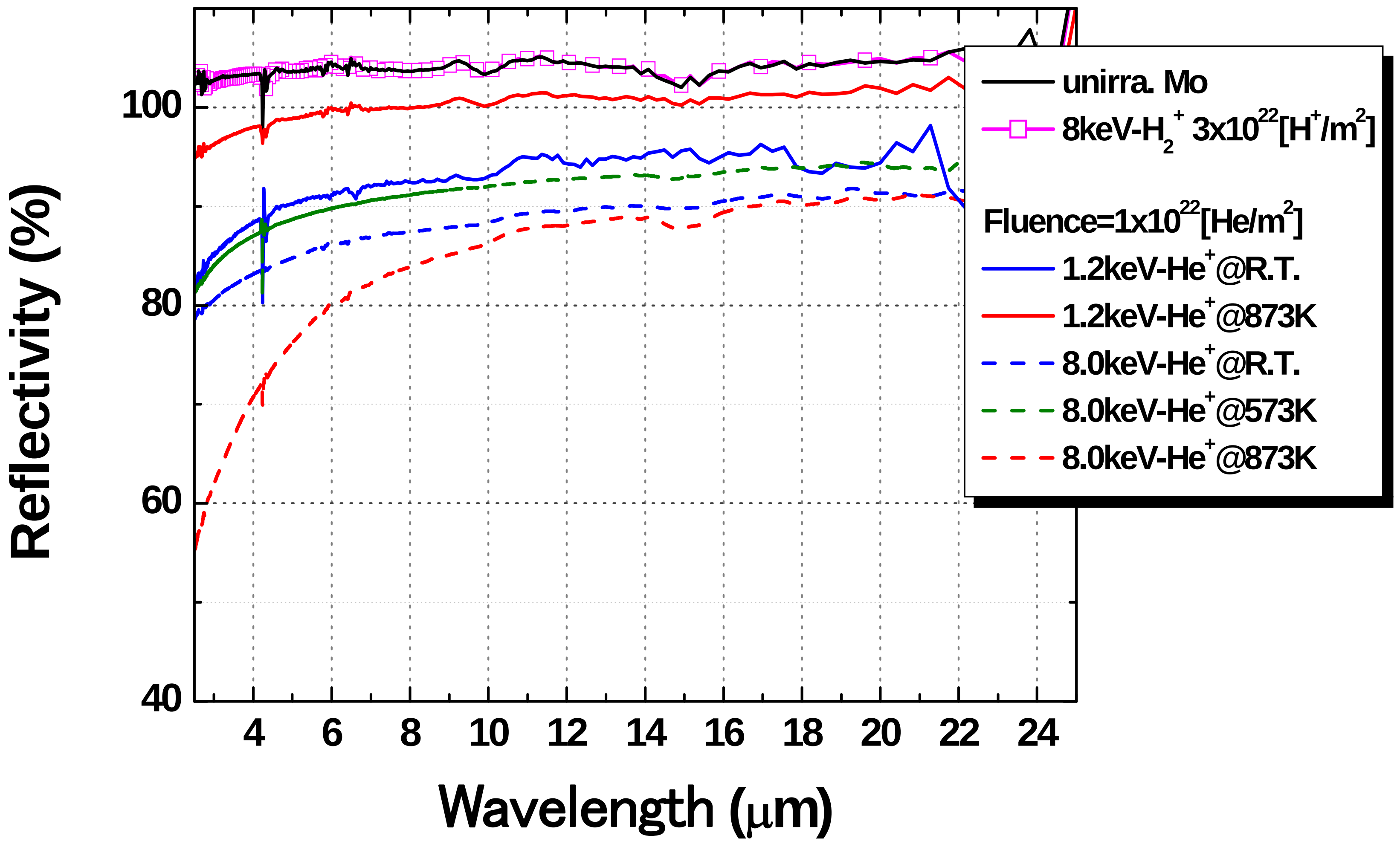
- **Measurements of optical reflectivity at the wide range of wave length (190nm ~ 20μm)**
- **SEM & AFM observations of surface morphology and roughness**
- **TEM observation of internal damage structure (top view and cross sectional view)**

Reduction of Reflectivity by He Ion Irradiations at Various Conditions (190~2500nm)



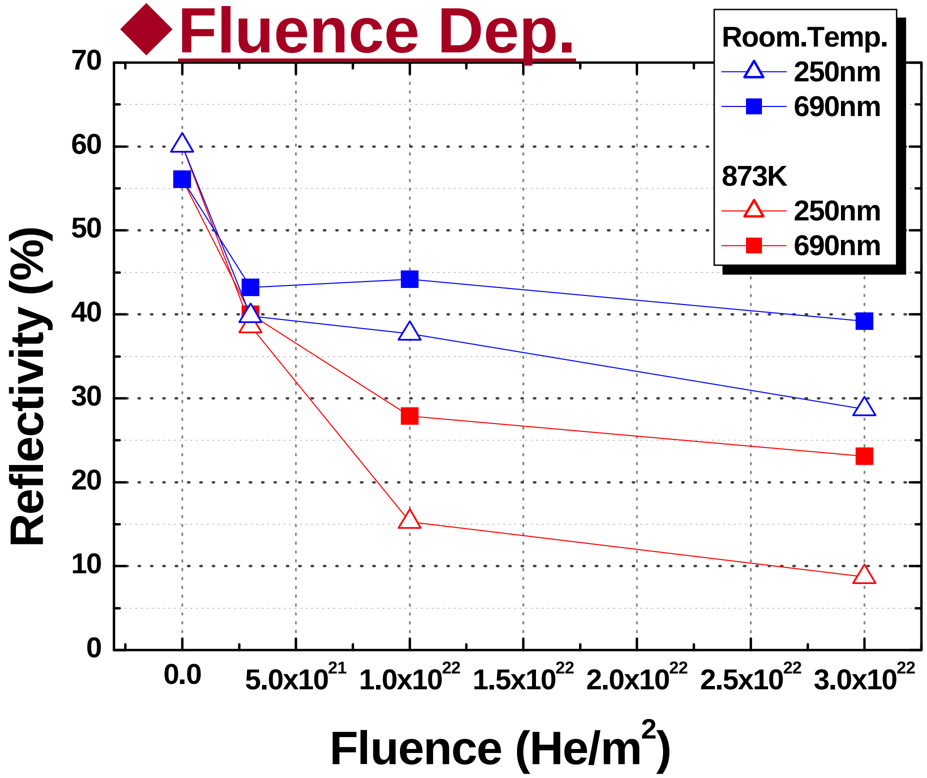


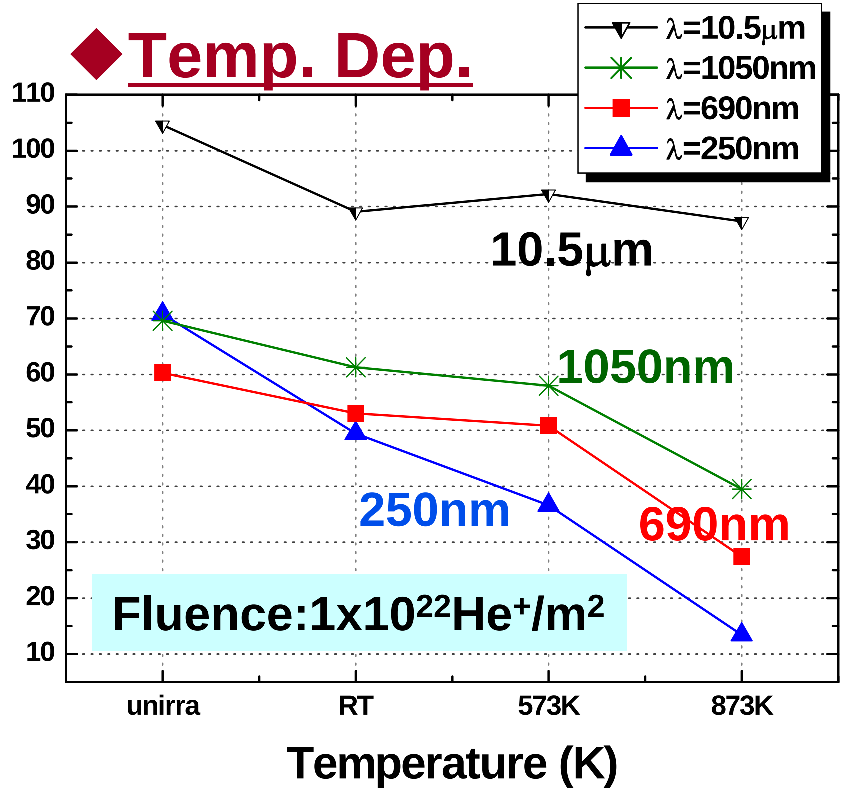
Reduction of Reflectivity by He Ion Irr. at various Conditions (2.5μm~22μm)



Fluence and Temp. Dep. of Reflectivity

Mo, 8keV-He$^+$



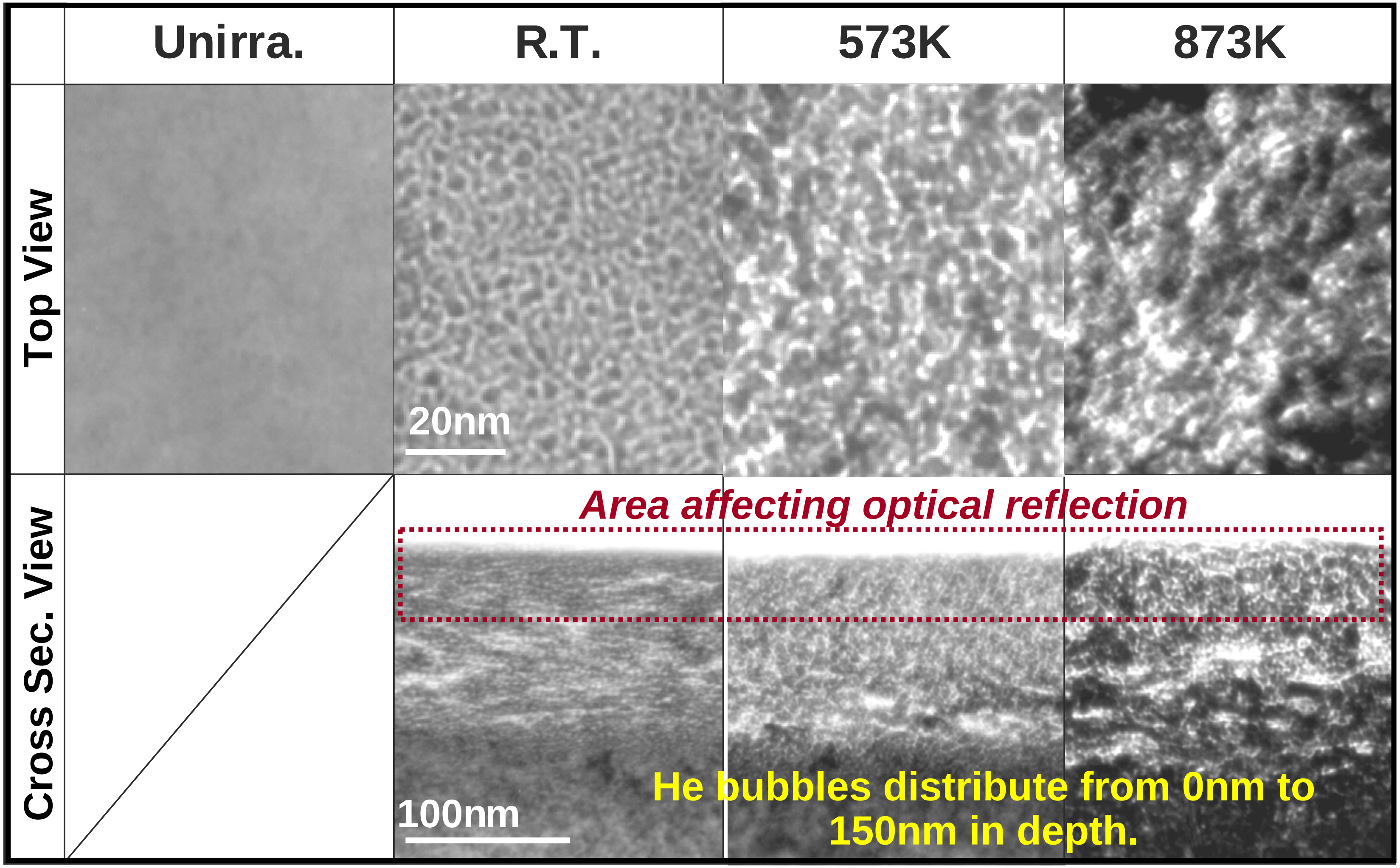


- Remarkable reduction of reflectivity occurs even at low fluence of about $3x10^{21}He^+/m^2$.
- Reflectivity reduces with increasing fluence and irradiation temp..
- The effect is more remarkable at shorter wave length.

TEM Images Showing Internal Damage

Mo: 8keV-He^+, $1x10^{22} He^+/m^2$, R. Temp. , 573K, 873K

- At all examined temps. nano-size very dense He bubbles form porous structure at the sub-surface region where interaction with light occurs.

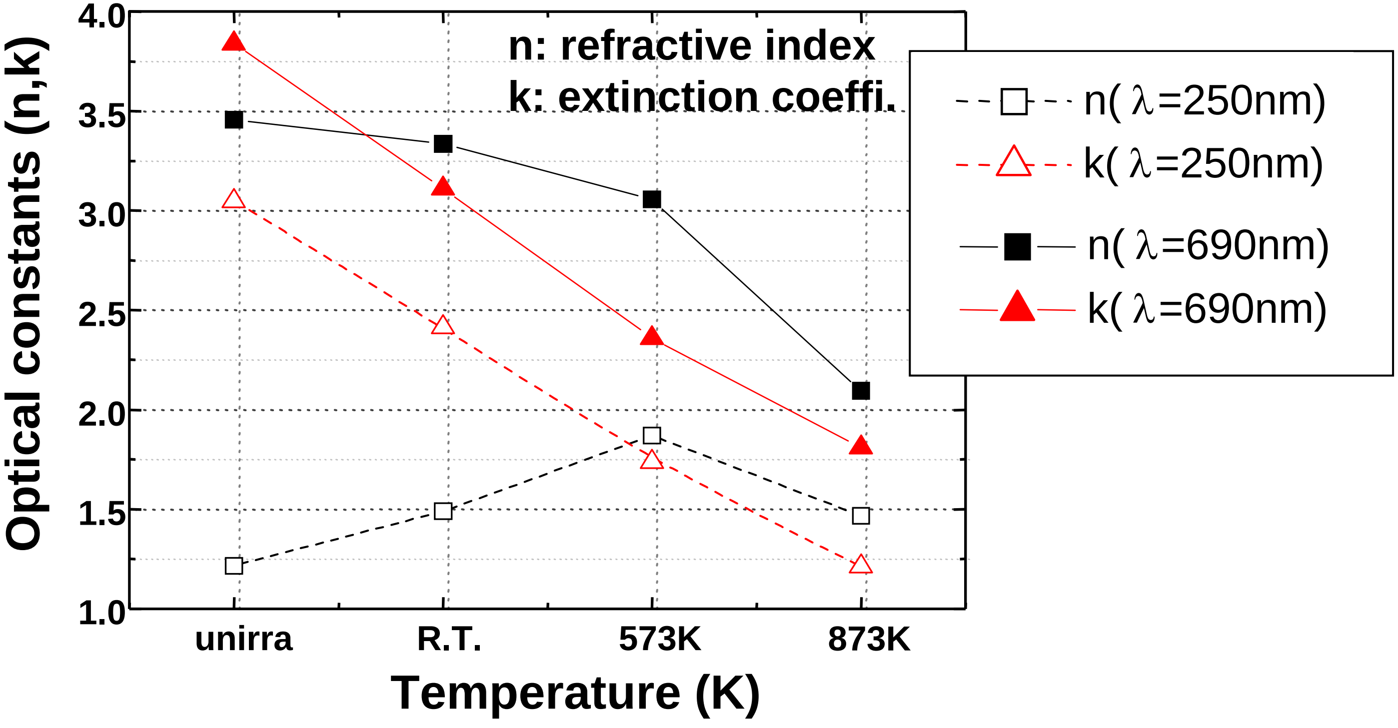


Refractive Index (n) and Extinction Coeffi. (k)

n and k were estimated by using an optical elipsometer.

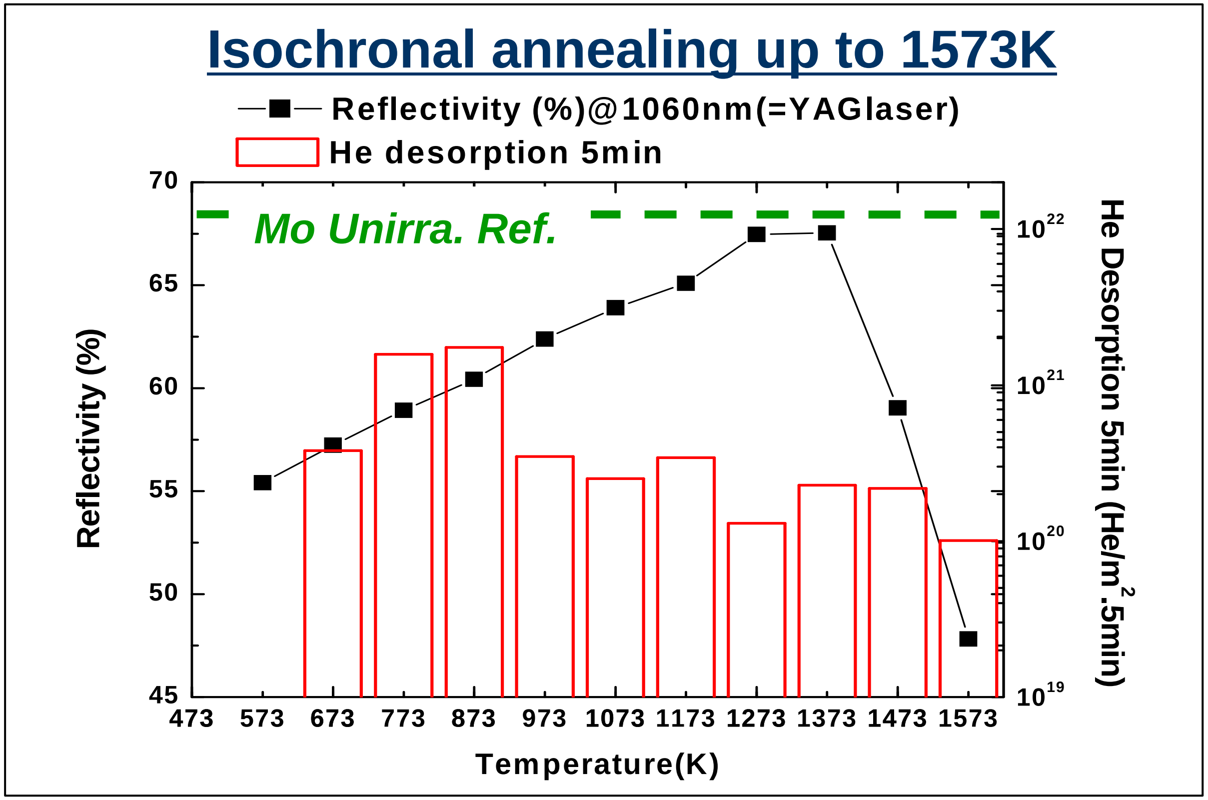
- **Reduction of n and k indicates that the material becomes "dilute". This result corresponds well with "porous structure" observed by TEM.**
- **Observed reduction of the optical reflectivity can be roughly explained by using the estimated values of the n and k.**
- **Detail analysis of the data measured by the optical elipsometer is on-going.**

Mo: 8keV-He^+, $1x10^{22}$ He/m^2, R. Temp. , 573K, 873K



Recovery of Reflectivity by Annealing (1)

Mo @573K, 8keV-He^+, $1x10^{22}$ He^+/m^2



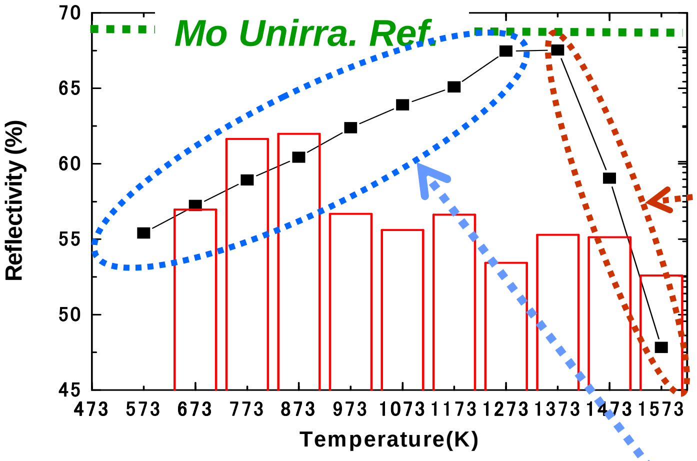
- With increasing annealing temperature, reflectivity increases gradually and almost recovers at 1273K. It decreases again at higher temperatures.
- Desorption of injected He, which are mainly trapped in bubbles, occurs during annealing.

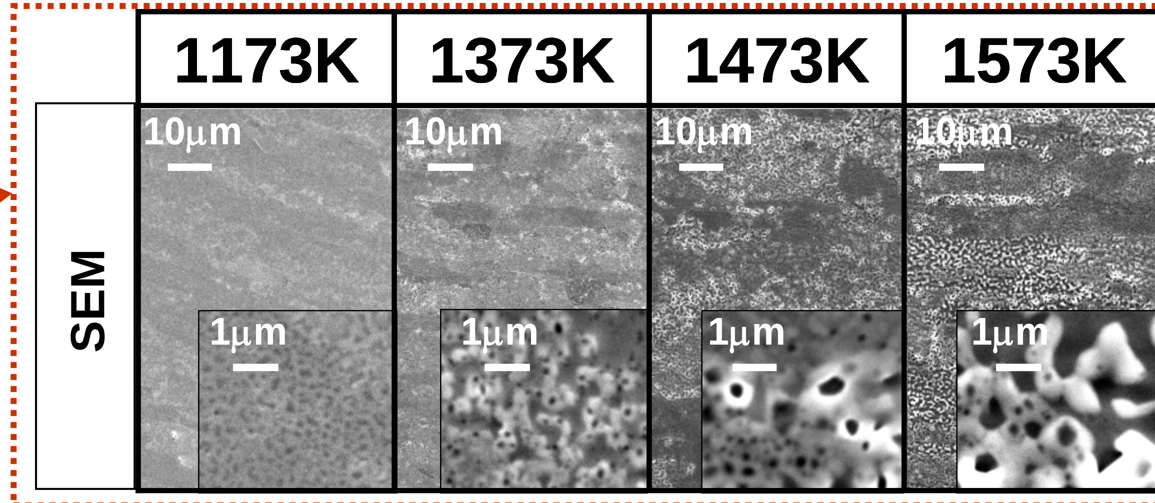
To know the reasons, TEM and SEM observations were carried out.

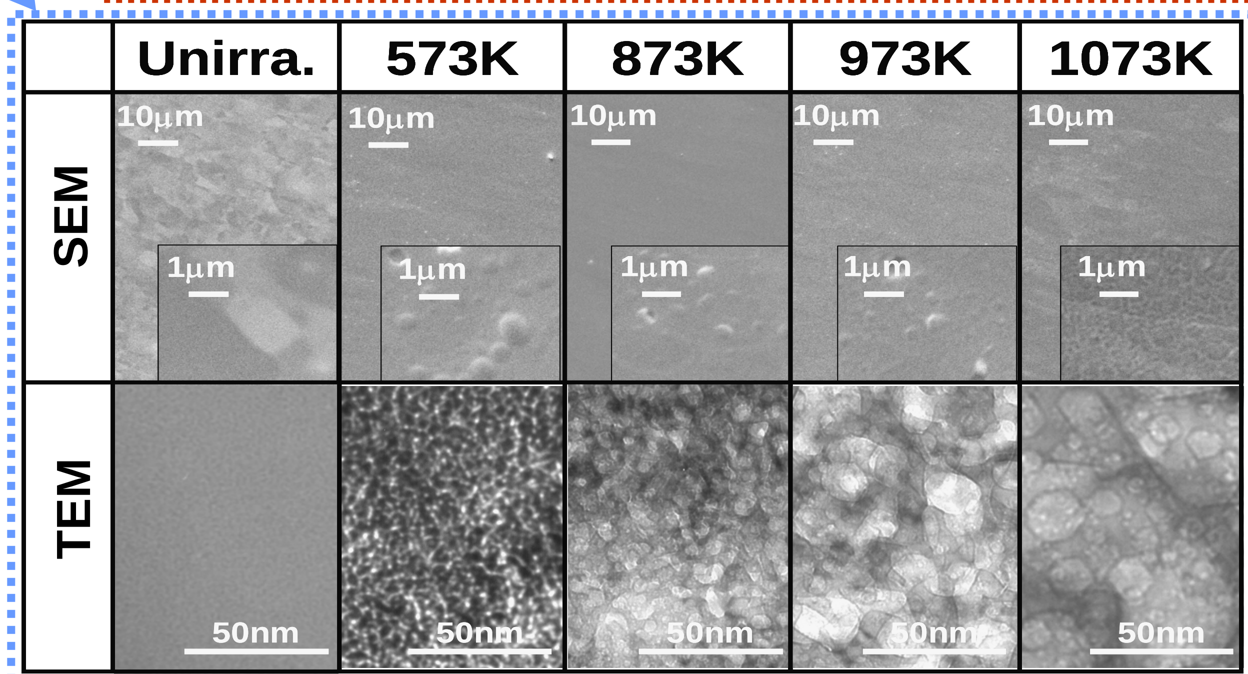
See Next VG

Recovery of Reflectivity by Annealing (2)

Mo @573K, 8keV-He^+, $1x10^{22}$ He^+/m^2







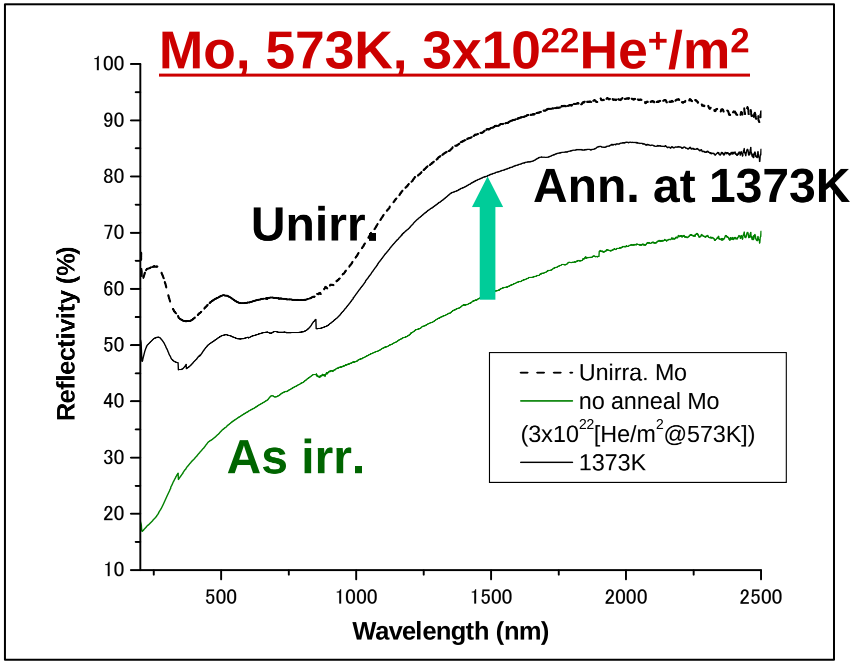
673K~1273K

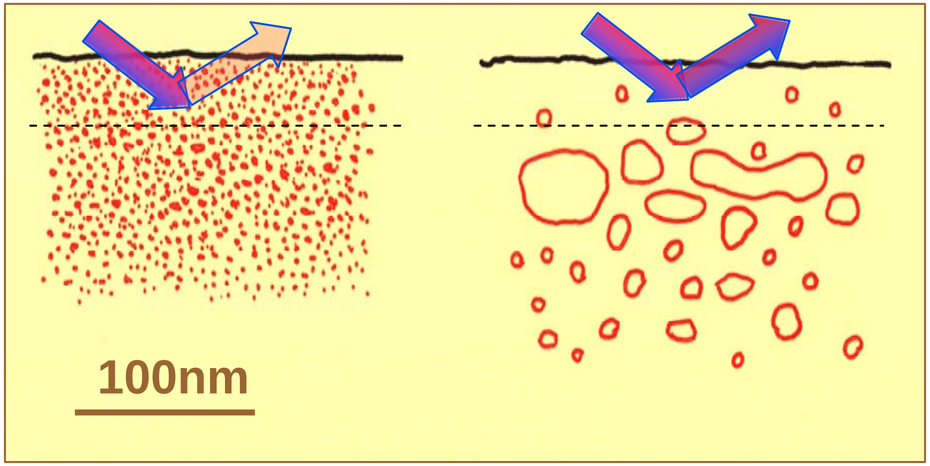
Migration, coalescence and annihilation at the surface of He bubbles.

1173K~1573K

Formation of large pin holes at the surface, which causes surface roughening.

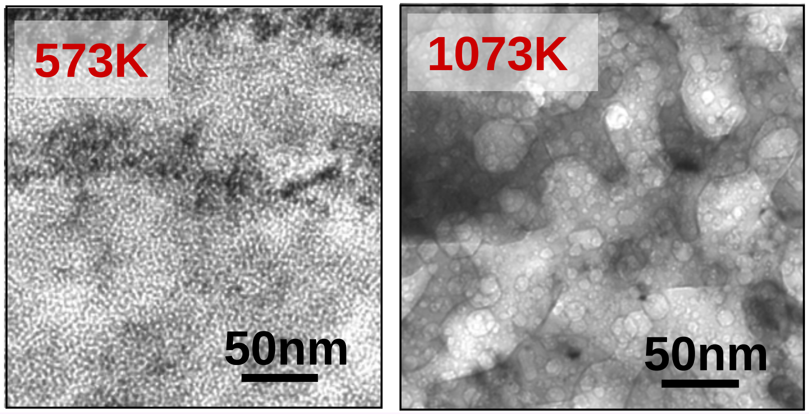
Recovery Mechanism of Reflectivity by Ann.





Recovery of Damage (Isochronal ann.)

Mo @573K, 8keV He^+, $1x10^{22}He^+/m^2$

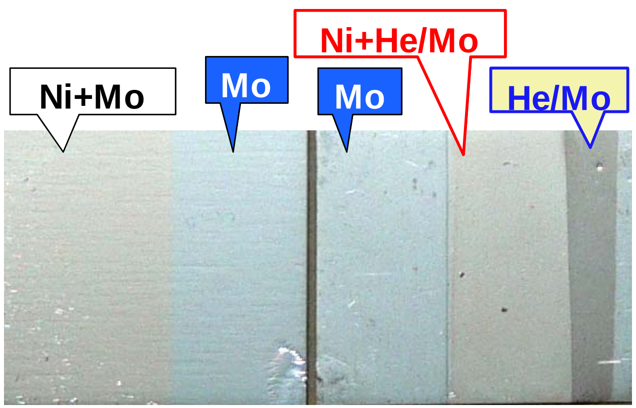


- With increasing temperature, He bubbles become thermally mobile above 673K (start from the smaller ones).
- The mobile He bubbles near the surface disappear preferentially at the surface and result in a denuded zone of bubbles at the sub-surface region. Continuous desorption of He suggests coming out of He bubbles at the surface.
- Due to the formation of the He bubbles free region at the sub-surface, reflectivity recovers.
- In deeper area, larger He bubbles still remain. At higher temperatures such as 1573K, they aggregate as very large bubbles and finally form μm-size pin holes by reaching the surface.

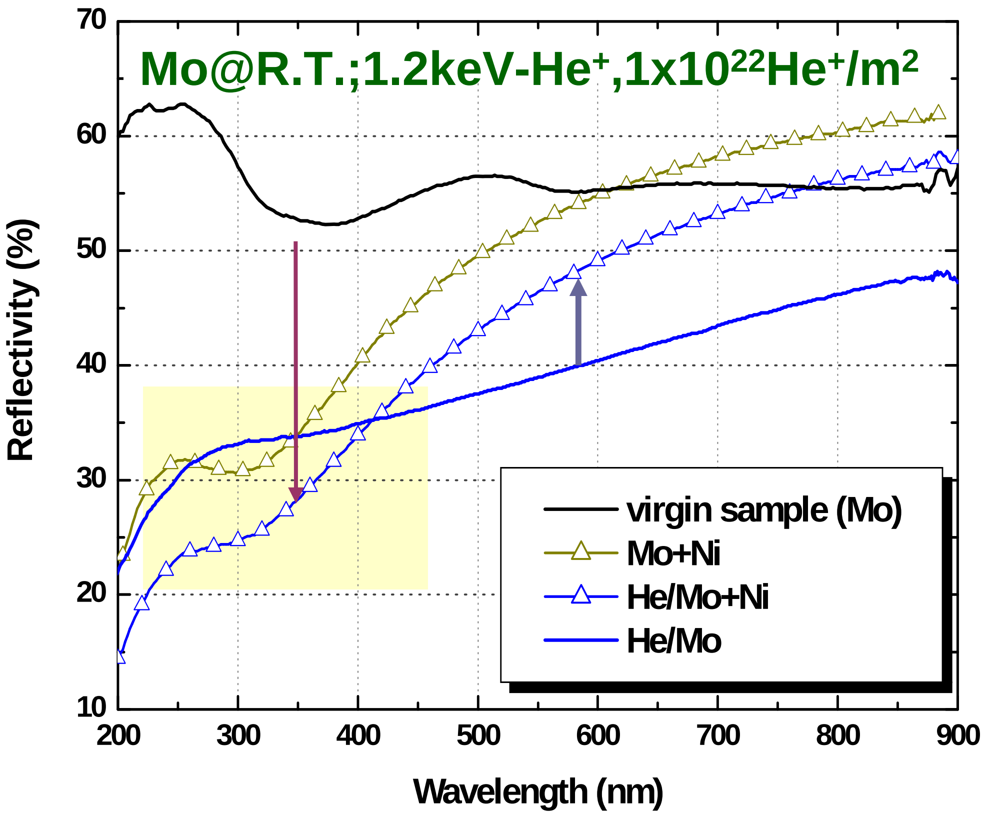
Recovery of Reflectivity by Metal Deposition

- **If the porous structure at the sub-surface region causes reduction of the optical reflectivity, one can expect that the reflectivity can be recovered by depositing thin metallic layer sufficiently thicker than the optical extinction distance.**
- **As expected, the reflectivity was recovered by depositing a Ni layer of about 300nm-thick in a vacuum.**

Effect of Ni deposition



By depositing Ni layer (300nm) on the He irradiated Mo (Ni+He/Mo) the reflectivity becomes similar to that of Ni/Mo.



Summary

- Supposing irradiation effect of He particles near the first wall, He irradiation experiments with keV-order energy were performed for well polished Mo at room temperature, 573K and 873K.
- Degradation of the optical reflectivity becomes detectable by the irradiation above $3\times10^{21}He^+/m^2$. Reduction of the reflectivity occurs even in the far infrared region.
- ***Origins of Reflectivity Reduction***

  ① Roughening by blistering（>keV, <$3\times10^{22}He^+/m^2$）

  ② Change of physical properties due to porous structures with fine dense He bubbles.（>$10^{22}He^+/m^2$）

  ③ Roughening by μm-size pin holes (in samples annealed up to 1573K)
- ***Recovery of Reflectivity (measures to fine He bubbles)***

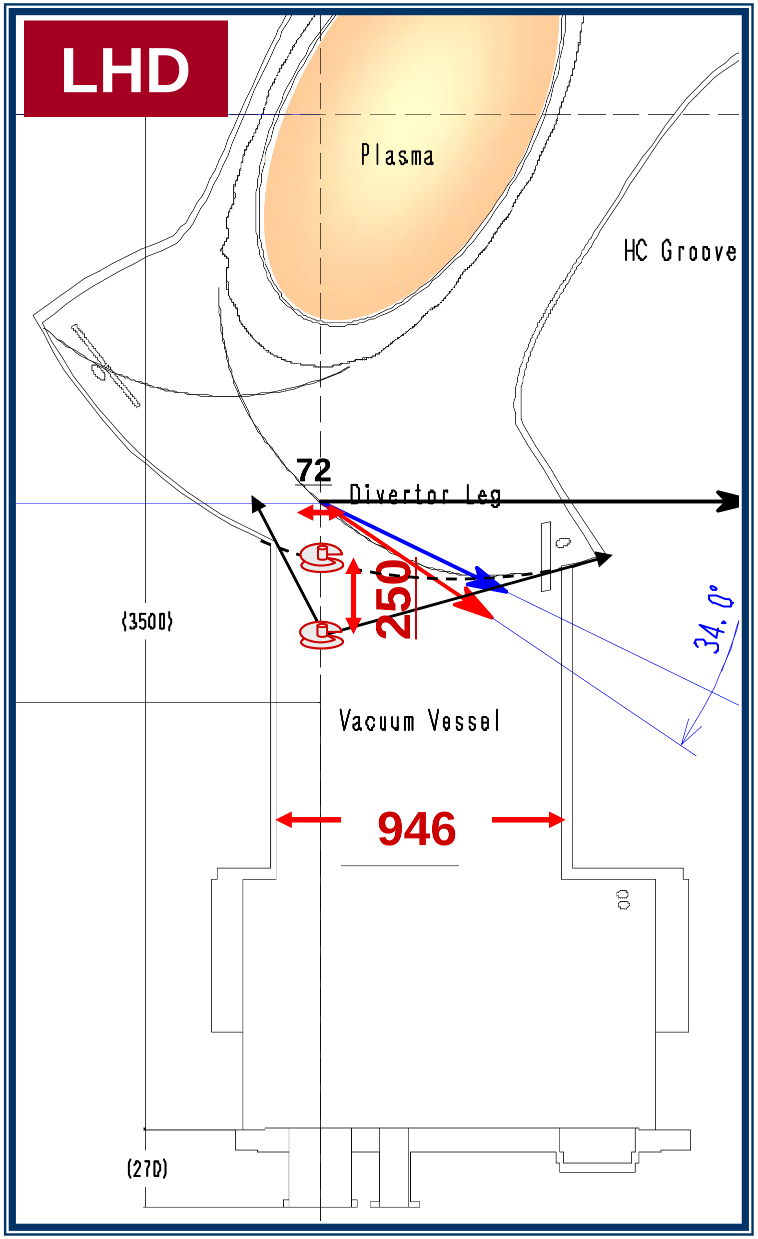
  ① Annealing up to 1273K, ② Vacuum deposition of a thin metallic layer
- ***Subjects in Near Future***

  Synergistic effects of He irradiation and impurity deposition.

Concerning Damage in Ports of LHD

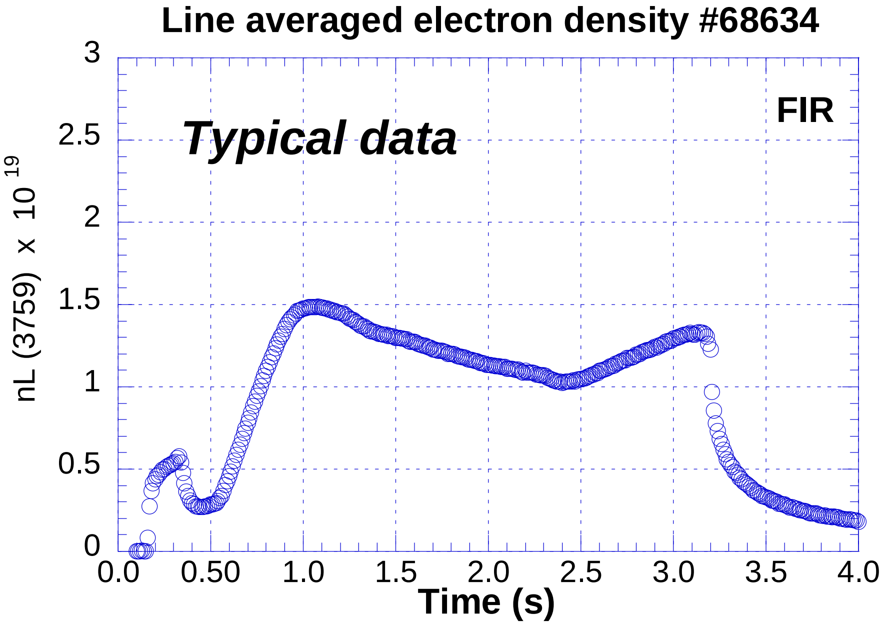
- In order to estimate the damage in ports by plasma particles, Mo and SUS were exposed to He plasmas heated by ICRF or NBI at the position of 0cm (wall position), -5cm and -25cm by using retractable material probe.
- Internal damage and optical reflectivity were observed.

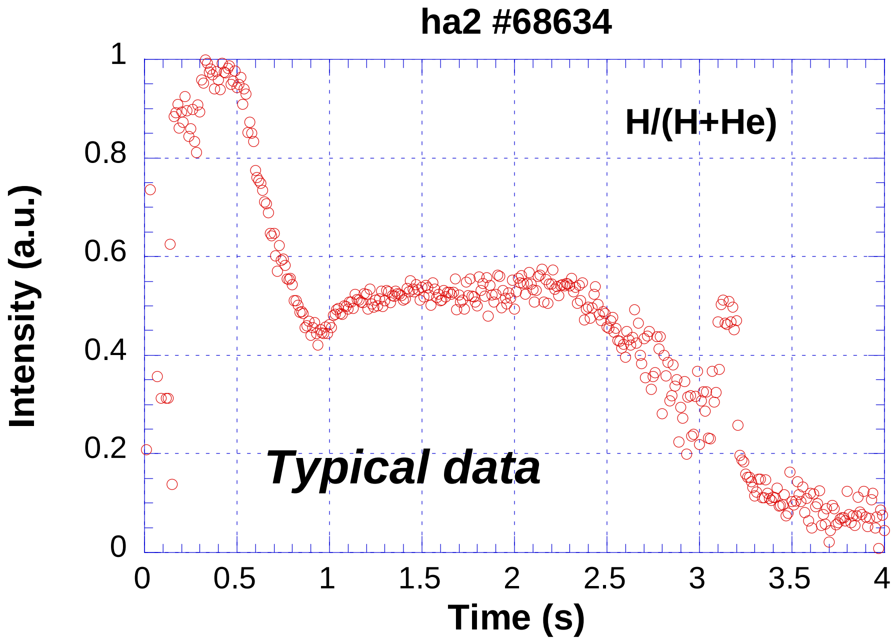
Sample holder of the material probe



Discharge Conditions (ICRF)

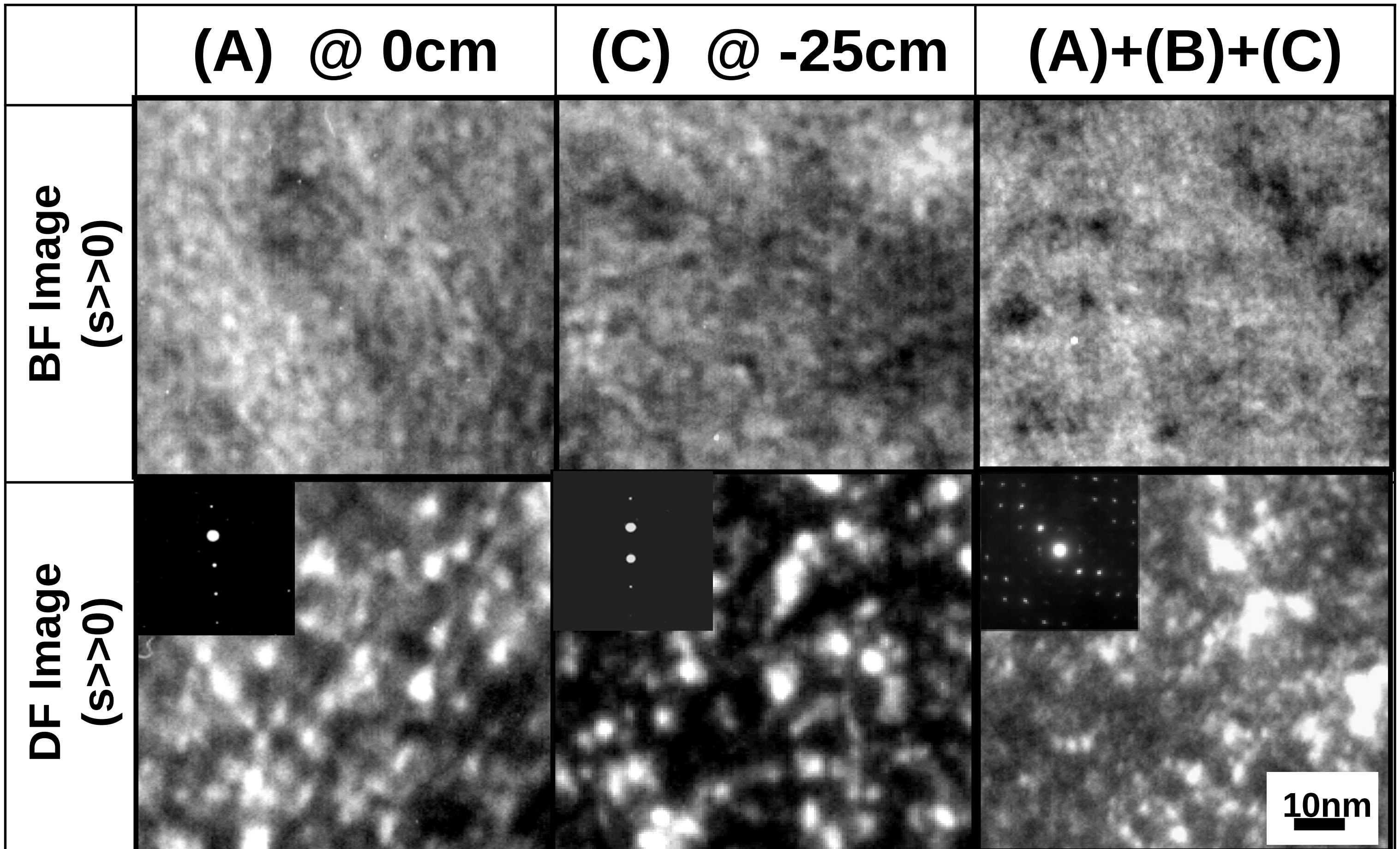
	position	No. of shots	Discharge time (s)	Ion temp. (keV)	e density ($x10^{19}m^{-3}$)	Shot #
(A)	0cm	13	408	0.5～2.0	0.25～3.6	*No.68705～68717*
(B)	-5cm	81	349.1	0.2～2.0	0.25～2.25	*No.68299～68379*
(C)	-25cm	86	351.5	0.5～2.0	0.25～3.6	*No.68618～68703*
(A)+(B)+(C)		185	1138.2	0.1～2.5	0.23～3.85	*No.68299～68383, No.68618～68718*



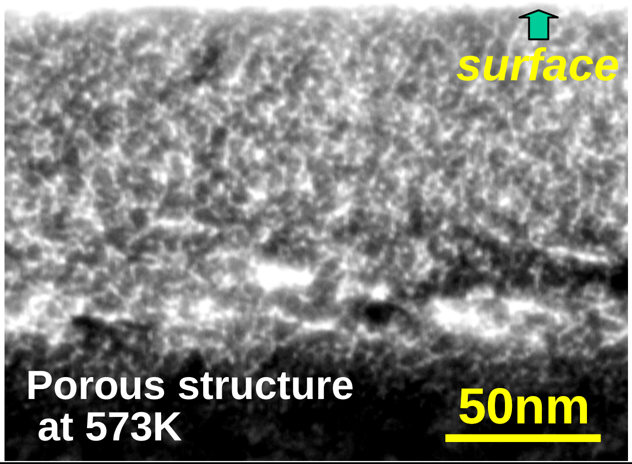
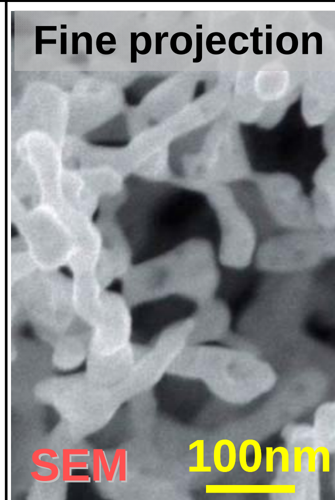


Damage in Mo Exposed to ICRF-He Plasma

- Even at the position of **-25cm**, serious damage (He bubbles, dislocation loops) occurred like wall position. (exposure time~350s, T_i~2keV, n_L~$2x10^{19}m^{-3}$). Similar damage was also observed in NBI case.
- This is the damage caused by **CX-He** with energy of about **1keV**. The flux is estimated to be **10^{18}~$10^{19}He^0/m^2s$**.



Studies on He Irr. Effects on Optical Reflec.

	1st Wall Relevant Conditions	Divertor Relevant Conditions
Research G.	Yoshida Lab. (Kyushu U.)	Takamura Lab. (Nagoya Univ.)
Material	Mo	W
Irr. Temps.	R.Temp.~873K	1250K~3000K
Ion Energy	1.2keV, 8keV, 14keV	10eV~100eV
Ion Fluence	≲ $3 \times 10^{22} He^{+}/m^{2}$	≲ $4 \times 10^{27} He^{+}/m^{2}$
Mechanism of Blacking	• Blistering • Porous structure by nm-size He bubbles	• Fine projections (a few 10nmϕ) at 1250K • Projections (a few 100nmϕ) and pin holes (~1μmϕ) above 1500K
Micro-structure	Cross sectional view 	Fine projection at 1250K  

Behavior of He bubbles determines these variety of microstructures and resulting optical properties.