Reduction in Optical Reflectivity of Tungsten Mirror by He Irradiation and Its Mitigation

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ITPA Meeting for Plasma Diagnostics @ Princeton University
26-30, March, 2007

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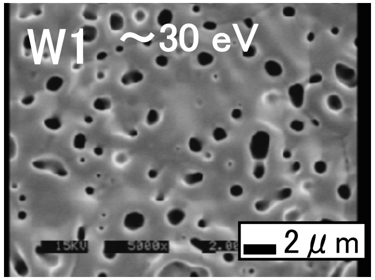
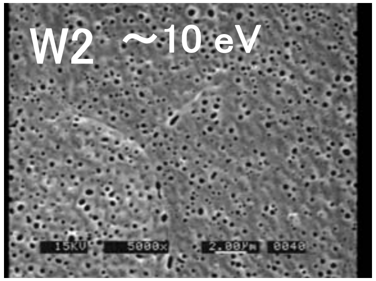
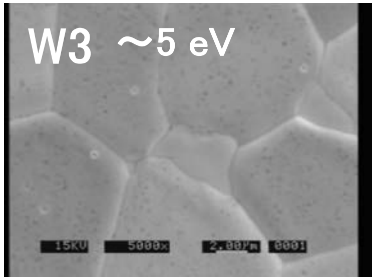
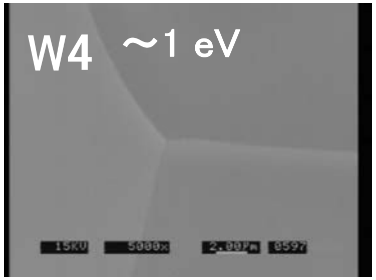
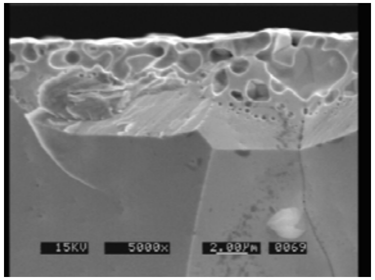
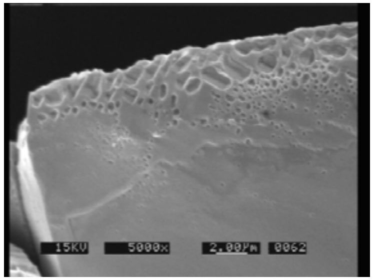
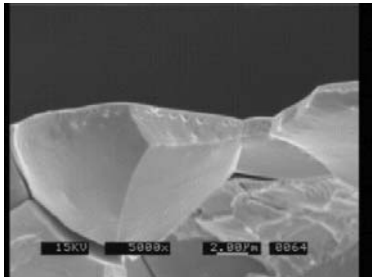
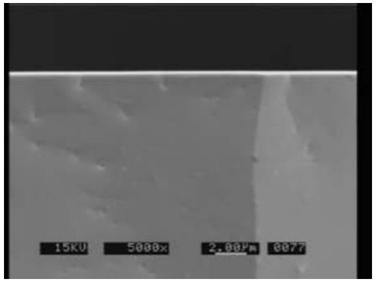
Properties of He Bubbles and Holes Formation on Bulky W Surface 1

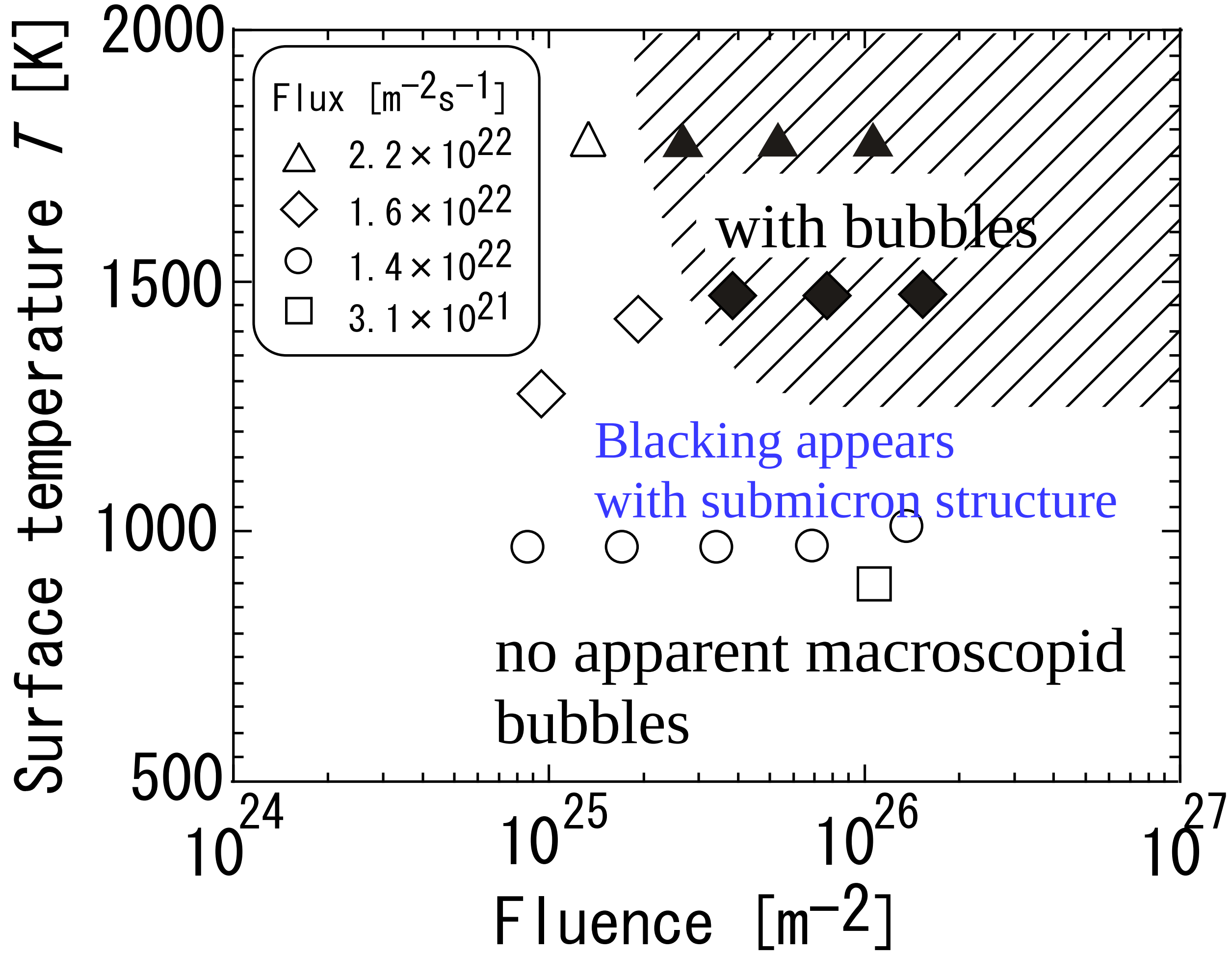
- Threshold Energy -

As low as 6 eV !

Fluence Ion Flux Time Temperature	2.6×10^{27} /m^2 3.7×10^{23} /m^{2}s 7200 s 2100 K	0.9×10^{27} /m^2 1.2×10^{23} /m^{2}s 7200 s 2600 K	0.8×10^{27} /m^2 1.1×10^{23} /m^{2}s 7200 s 2200 K	0.8×10^{27} /m^2 1.1×10^{23} /m^{2}s 7200 s 2950 K
Surface				
Cross-section				

Properties of He Bubbles and Holes Formation on Bulky W Surface 2

- Fluence & Temperature -

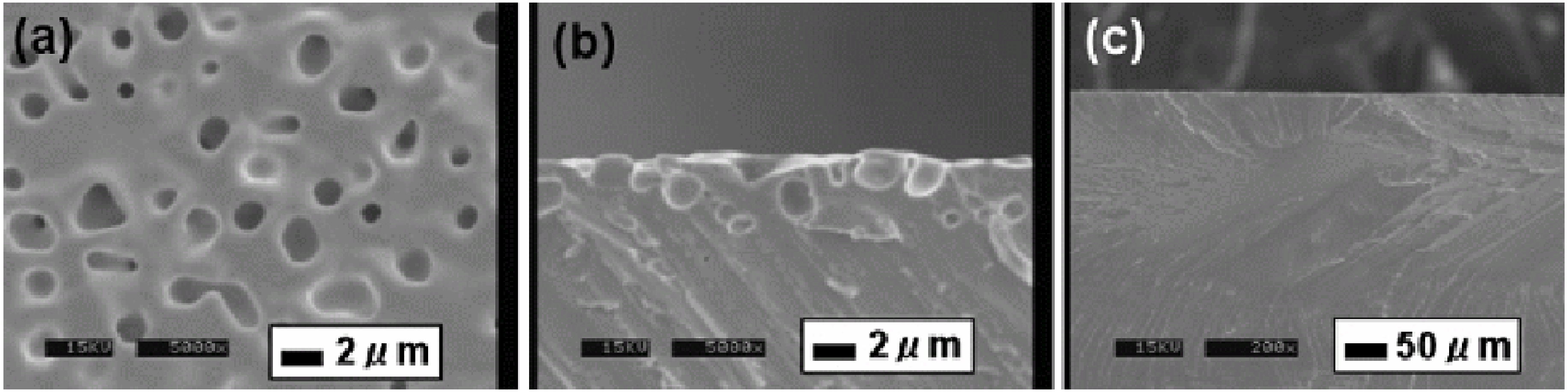


Properties of He Bubbles and Holes Formation on Bulky W Surface 3

Formation is independent of fabrication method for W material

He irradiation on single crystal tungsten makes also bubbles and holes under high surface temperature. Thermal vacancies provide trapping sites for He atoms. These mobile sites recombine to grow up to micron-size bubble.

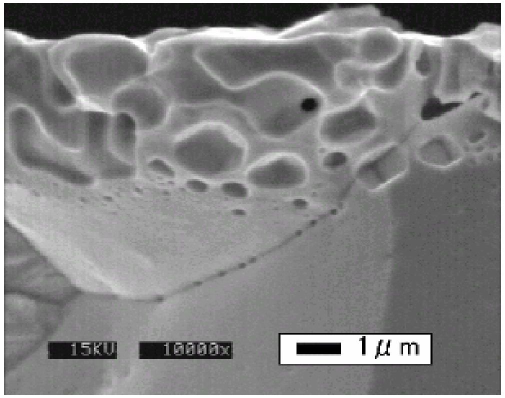
Hole structure on single crystal W sample after helium plasma exposure at 2200 K.
(a) surface, (b) cross-section near the surface (c) wide view of cross-section.

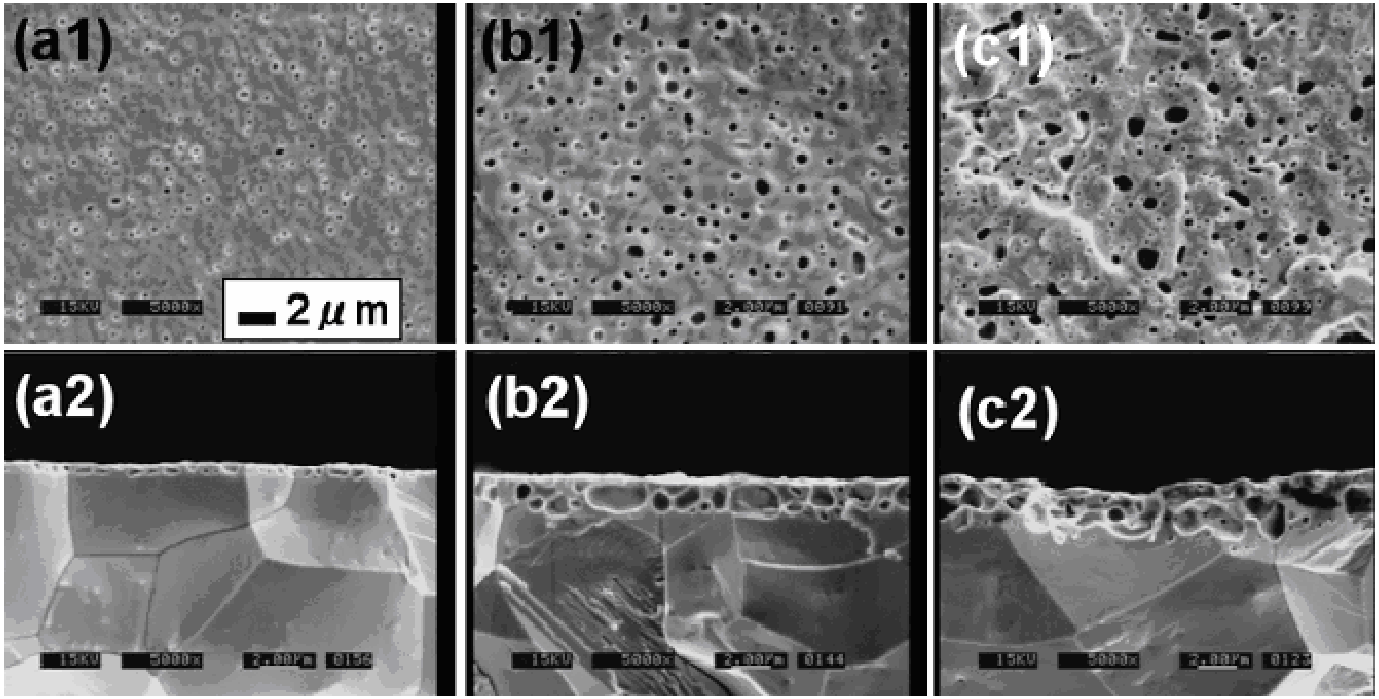


Heavy Irradiation of He Ions

Figure shows the dependence of the fluence for the hole/bubble growth on PM-W samples exposed to He plasma at 2200 K with 25 eV He ions at a flux of 8×10^{22} $m^{-2}s^{-1}$. (a)Submicron-sized Hole/Bubble already appeared on the sample after only 1000 seconds exposure to a fluence of 8×10^{25} m^{-2}. (b)They grew up to micron-sized hole/bubble after 10000 s (~ 170 min) exposure to a flunece of 8×10^{26} m^{-2}. (c)The surface became rough and ragged after 75000 s (~ 21 h) exposure.

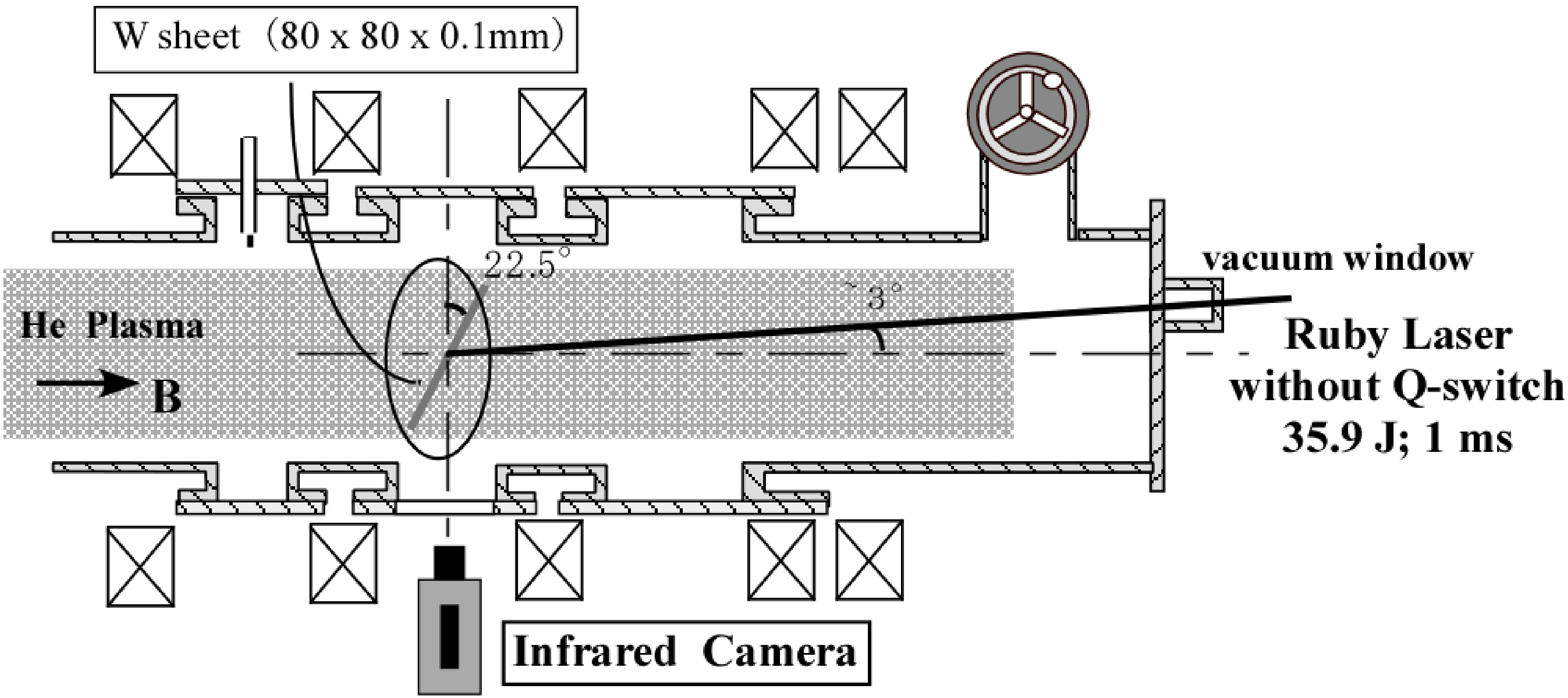
Although holes/bubbles did not so much grew in vertical direction, bubble coalescence spreads in a transverse direction and creates a labyrinth-like structure as indicated in Fig. (c2).





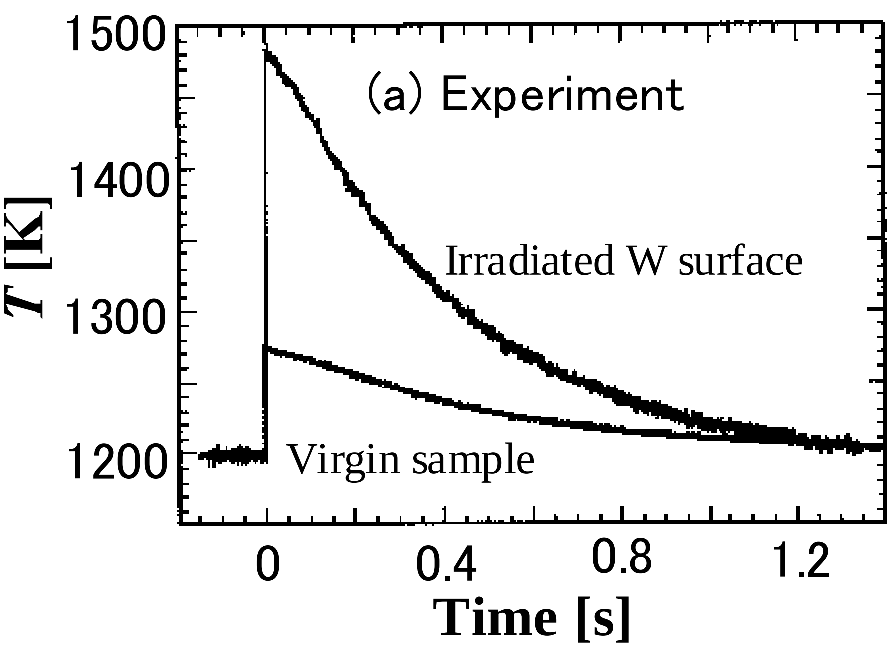
Effects of He Bubbles & Holes on Power Reflectivity for High-Power Laser Light

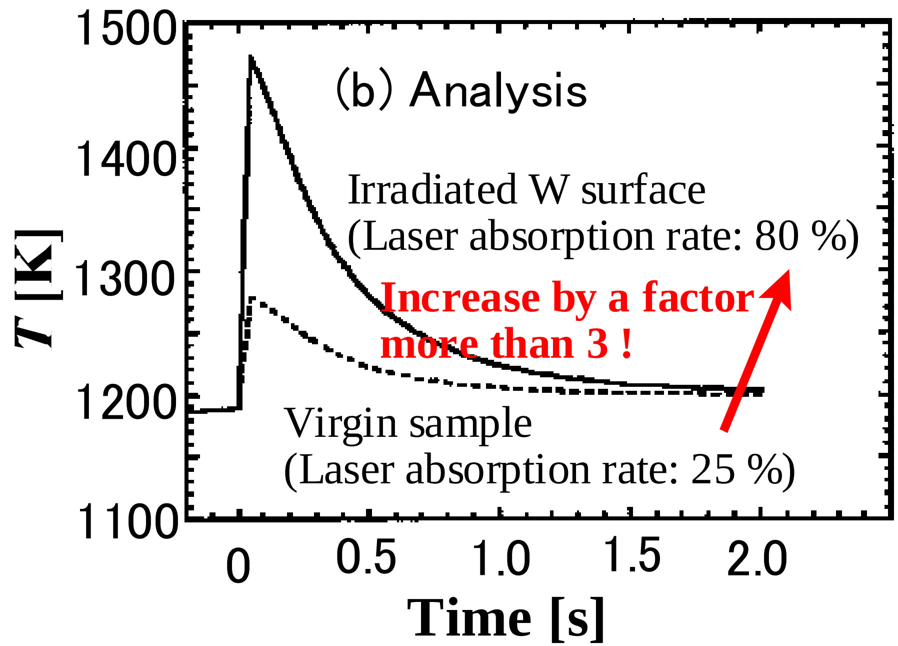
Power reflectivity has been measured by reflecting ruby laser light after irradiating He plasma on the W surface and rotating the tungsten target.



Helium bubbles & holes increase power absorption of high-power laser light by a factor more than three !

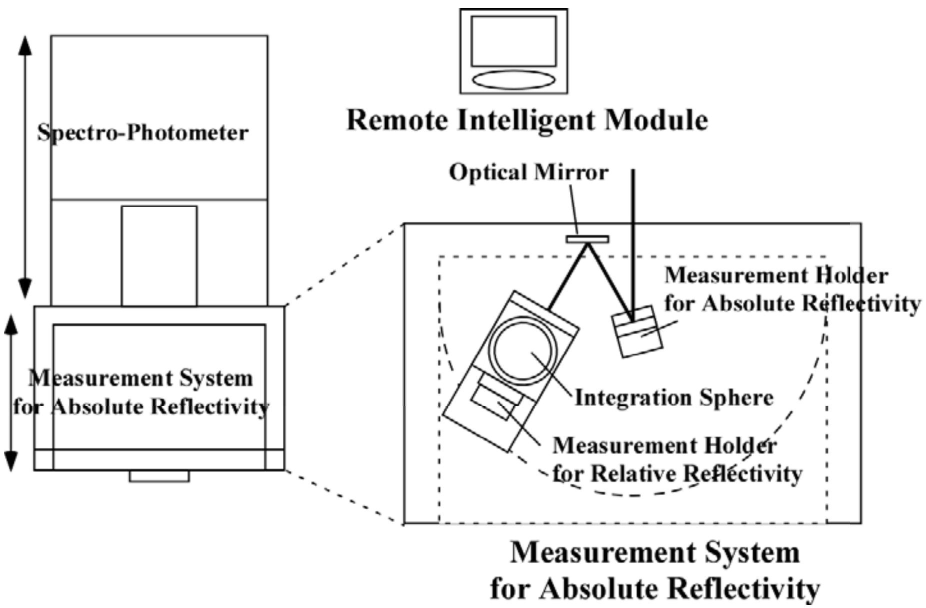
High-power laser light for plasma diagnostics might ablate tungsten surface due to a low thermal conductivity and a high absorption coefficient due to bubbles and holes.

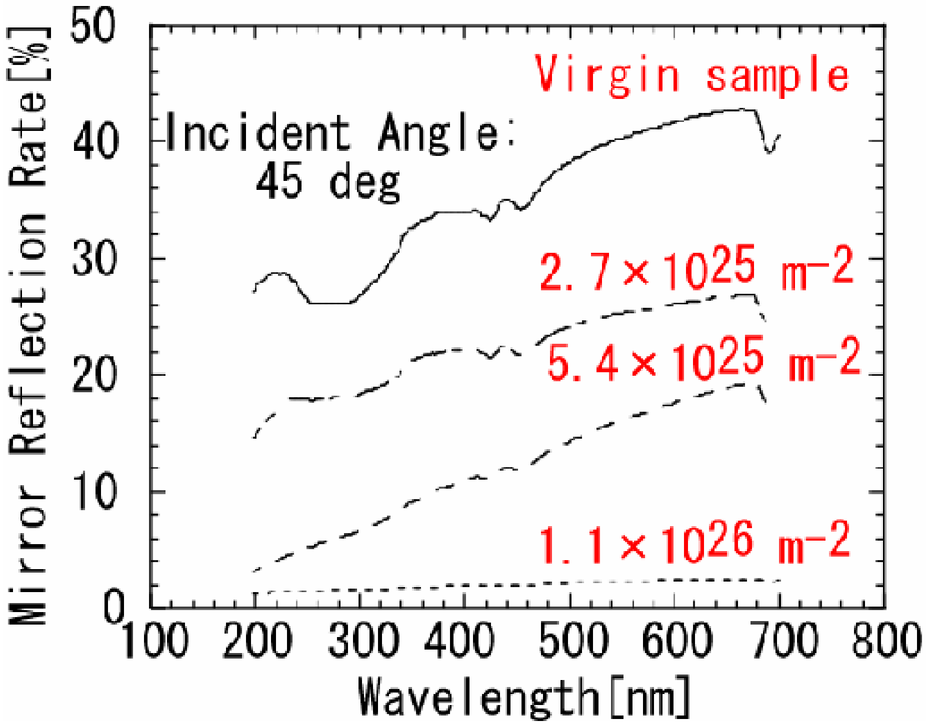




M.Y. Ye, S. Fukuta, N. Ohno & S. Takamura et al.:
J. Plasma Fusion Res. SERIES 3 (2000) 265.

Effects of He Irradiation on Optical Reflectivity





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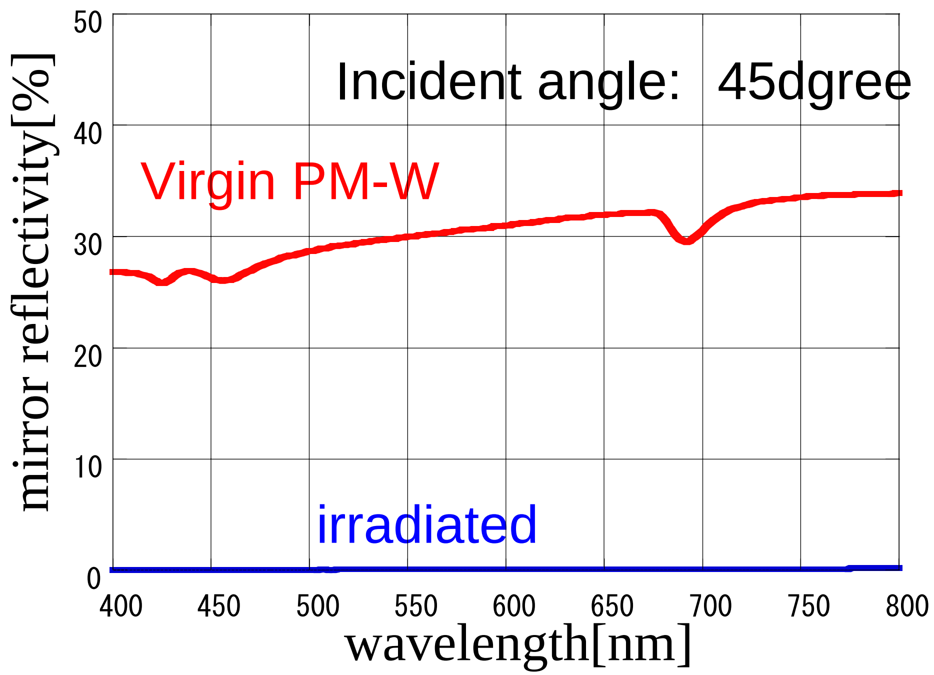
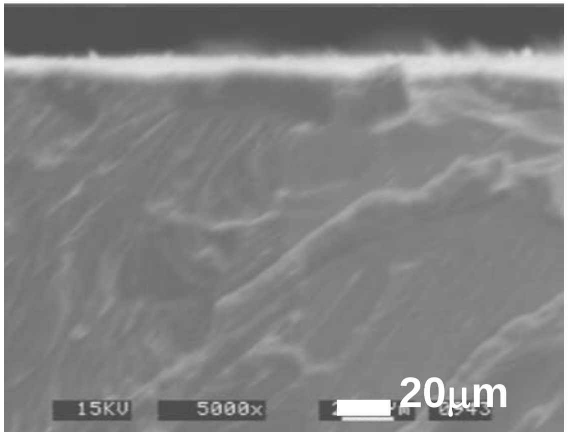
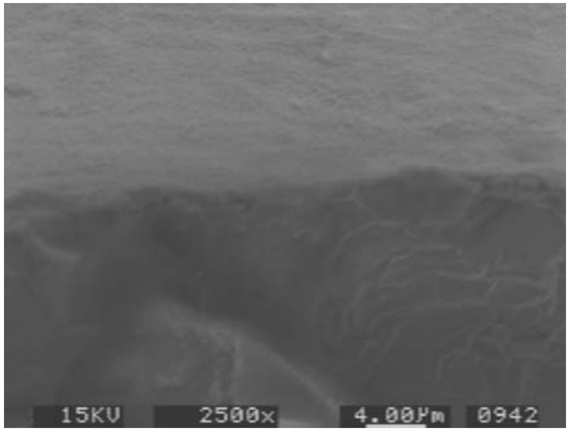
SEM photograph also shows submicron-size powders on the PM-W surface which destroys the optical reflectivity. They are not sticky, but easily wiped out.

In low temperature bulky W, helium does not diffuse deep inside so that spinous projection type structure may appear.

In VPS W coated graphite, an interface between neighboring two layers may play a role of diffusion barrier ?



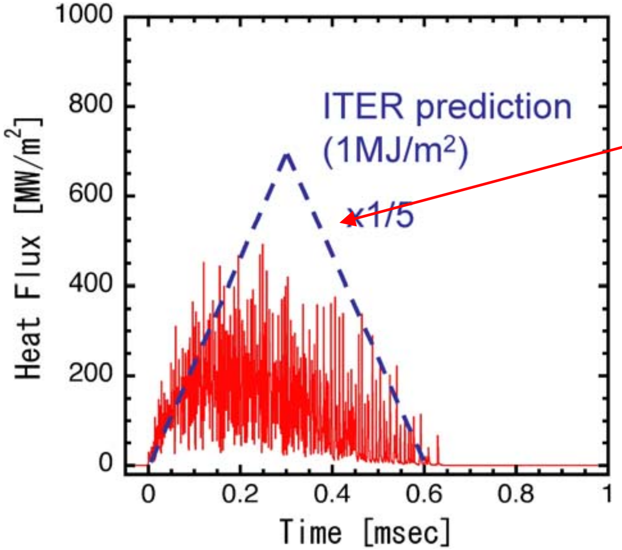




He:1200 K, 10 h, 2.1×10^{27} m^{-2}, 80 eV

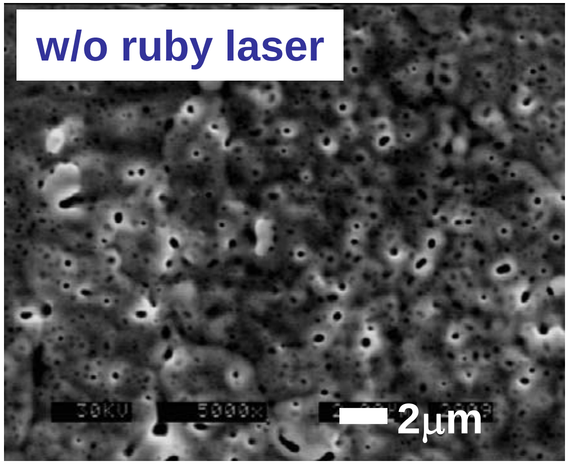
ELM-like heat pulse to PM-W exposed by He plasma

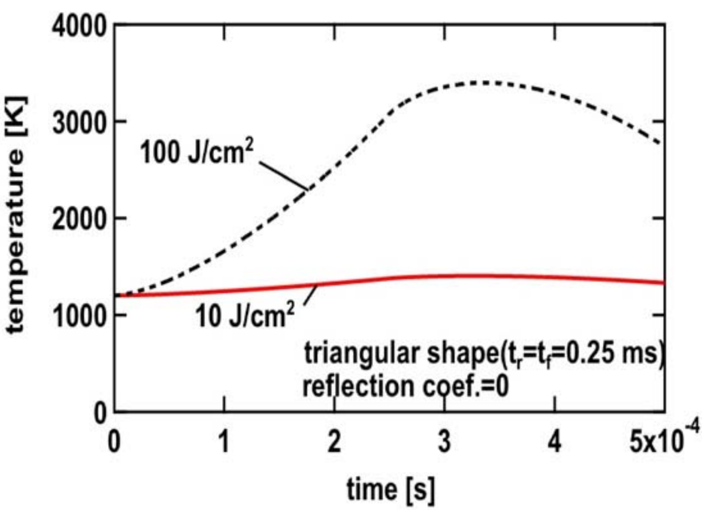
Timescale of transient heat flux by ruby laser without Q switch is quite similar to that of ELMs.



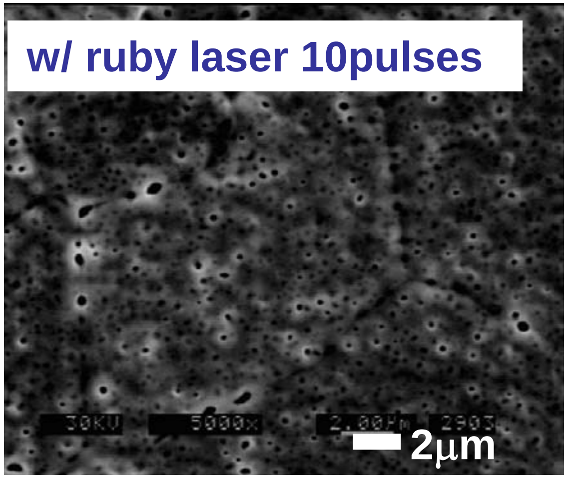
Ruby laser:
60kJ /m², 0.6ms

ELM(ITER):
1MJ/m², 0.6ms





No significant modification of W surface w/ and w/o ruby laser pulse
→ Temp. change is small because of insufficient heat flux.
Need to focus the laser light to PM-W



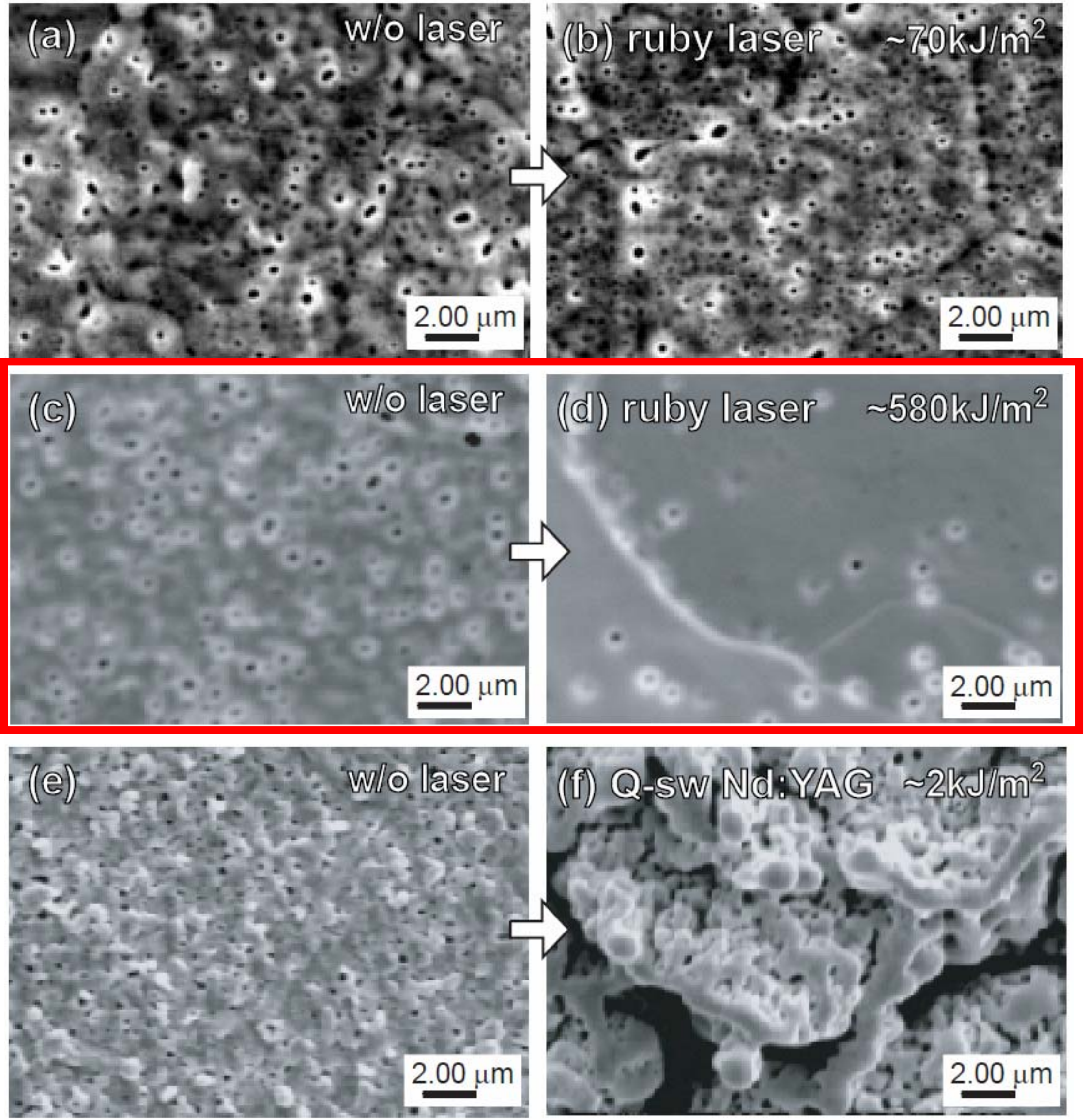
He:1600 K, 3.0×10^{27} m^{-2}, 27 eV

Mitigation or Avoidance of He Bubbles & Holes

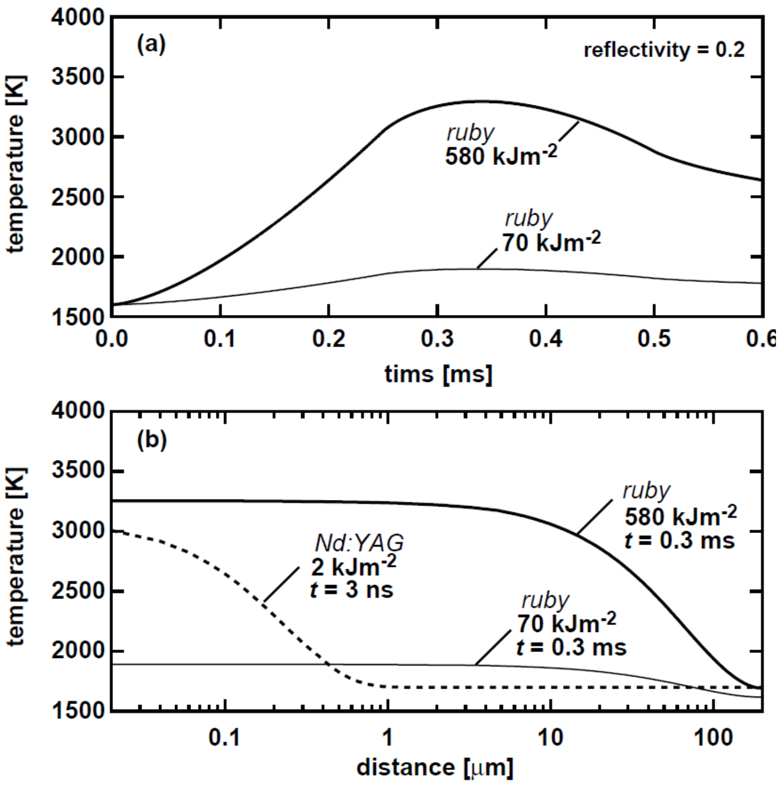
Tungsten has a great potential for Optical Mirror and should be tested in ITER burning plasma with SSO. We have to find out a mitigation method or even a new tungsten material with substantially reduced damage due to He :

- **Thermal annealing by appropriate heat pulse**
- **A new material – Ultra-Fine Grained W-TiC (not shown at this time, maybe at next Meeting)**

Thermal Annealing by Appropriate Heat Pulse



Ruby laser irradiation with 580 kJ/m^2 substatially decreases the number of bubbles and holes !



SUMMARY

- (1) When the W surface temperature becomes higher than about 1600K, many small bubbles and holes with the size less than 10 micrometers appear, of course, with the presence of fuel ions (hydrogen, deuterium and possibly tritium). The phenomenon is very fundamental because it is inevitable even for monocrystal W due to the thermally excited defects. The threshold He ion energy for the formation of these holes and bubbles seems to be as low as 6 eV !

- (2) The optical reflectivity of helium irradiated tungsten surface would be dropped down due to the growth of bubbles and holes.

- (3) Preliminary experiments show a reduction of visible light reflectivity of tungsten surface even under a lower temperature of 1200-1300 K without any bubbles and holes on the SEM image, in which, however, nano-scale bubbles would contribute to this phenomena.

- (4) When many small bubbles and holes are formed on the surface, the thermal conduction of the surface to the deep bulk decreases very much and the power absorption dramatically increases so that a high-power diagnostic laser light might ablate the tungsten surface.

- (5) A mitigation or an avoidance of He bubbles and holes formation is discussed. Ruby laser light irradiation without Q-switch seems appropriate for mitigation, and this technique maybe applied also to an amelioration of reflectivity reduction due to hydrocarbon deposition on mirrors.