Ion-driven permeation of deuterium in tungsten by deuterium and carbon mixed ion irradiation

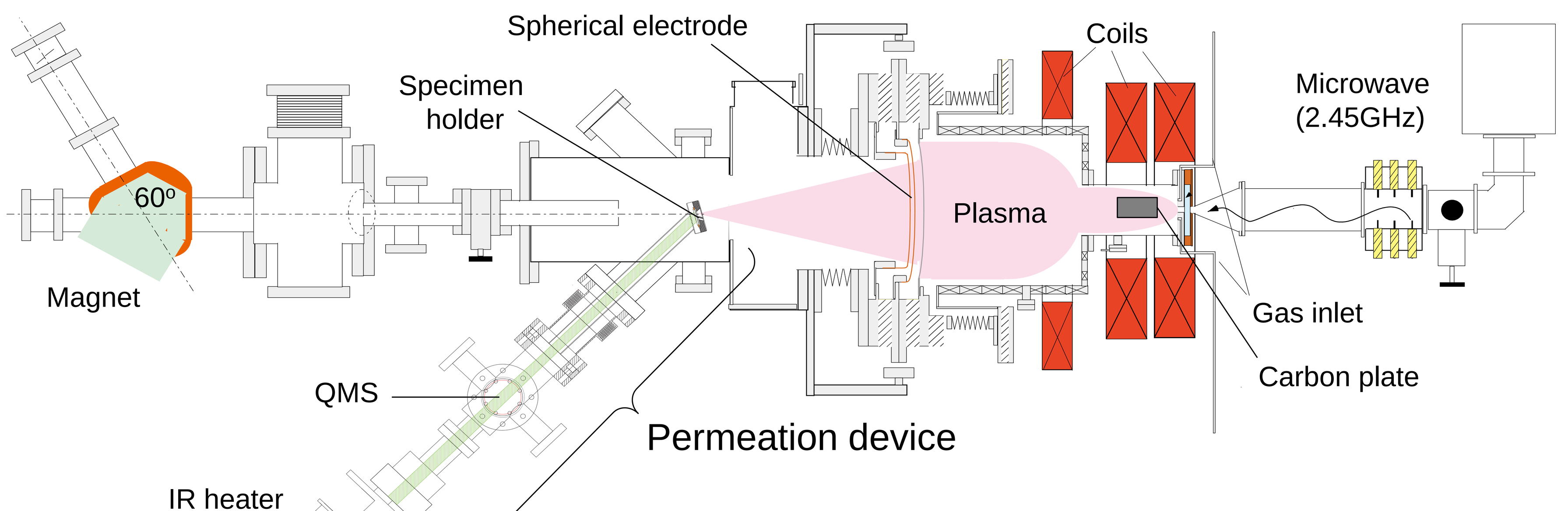
H. Y. Peng*, H. T. Lee, M. Ohmori, Y. Otsuka, Y. Ueda
Graduate School of Engineering, Osaka University, Suita, Osaka, 565-0871, Japan.

❖ Motivation

- Tungsten (W) will be exposed to hydrogen isotopes (H, D, T) and carbon (C) impurities in the initial operation stages of ITER.
- Retention study indicates that the formation of tungsten carbide at plasma facing side of the material may act as diffusion barrier increasing the inward transport of H into the W [1].
- Changes to H release and diffusion processes in W will impact on fuel recycling and retention, affecting confinement and T safety issue.

[1] V. Kh. Alimov et al J. Nucl. Mater. 375 (2008) 192.

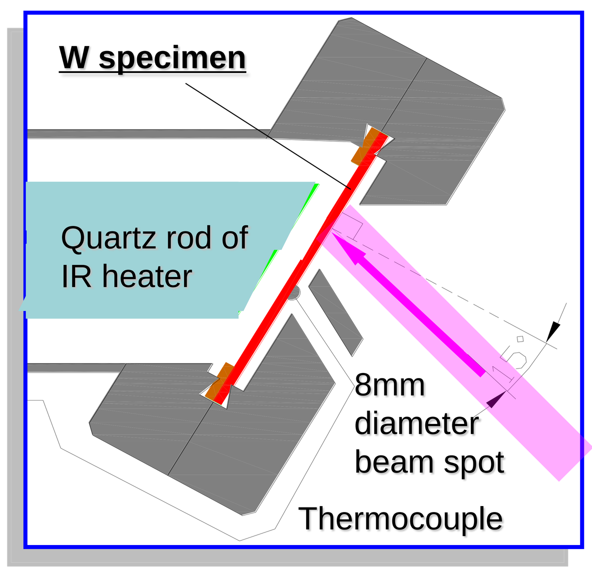
❖ Experimental



High Flux Ion irradiation Test device（HiFIT）
- Acceleration voltage: 1 keV
- Irradiation flux: 10^{20} $m^{-2}s^{-1}$

❖ Aim of this study

To examine the D permeation through W by D and C mixed ion irradiation, and compare the difference in permeation with D-only irradiation.
- To determine the effects of C on D diffusion in W.



W specimens
- 99.99 at.% pure polycrystalline W
- Stress relieved at 1573 K at 1h
- Mirror polished to Ra = 5 nm
- Thickness of 30μm and diameter of 34.8 mm

Upstream and downstream sealing in between two standard conflat flanges and a copper gasket.

Experimental parameters
- Irradiation temperature (T_w = 550-1050 K)
- C fraction in the incident flux (f_C ~ 0.9-3%)

- Mixed species ion beam (D^+, D_2^+, D_3^+, CD_x^+, $C_2D_y^+$, $C_3D_z^+$)
- D permeation flux: quadrupole mass spectrometer calibrated using D_2 leak
- Specimen was held at 1050 K and the entire permeation system was baked to 420 K for minimum 12h.

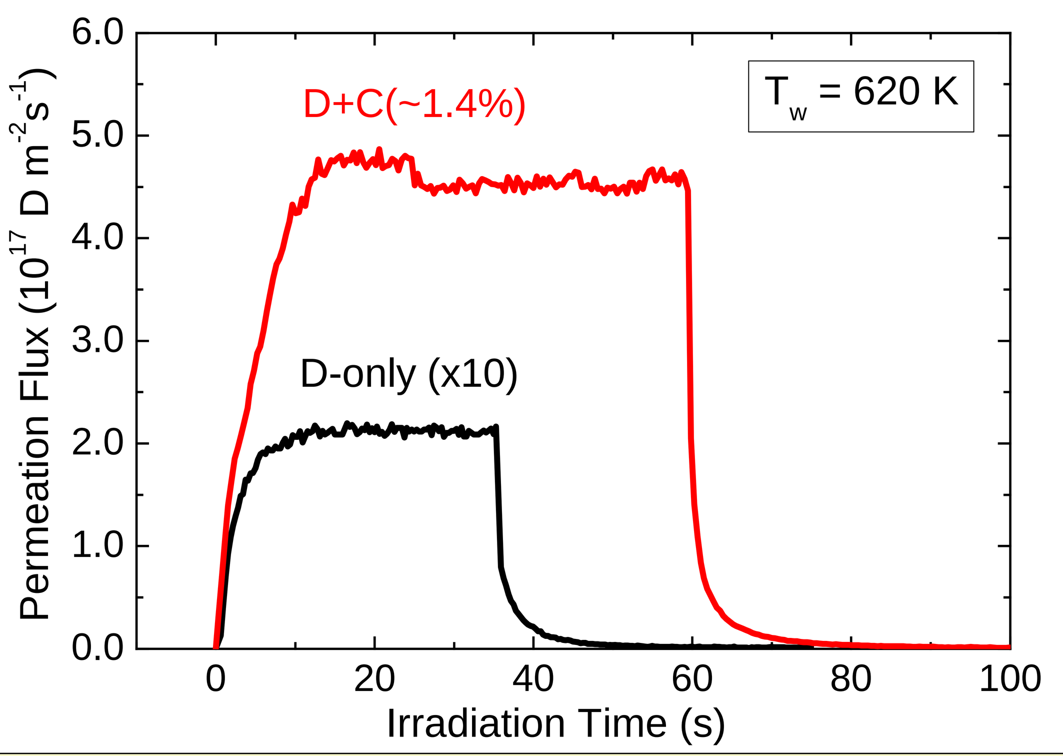
Implantation experiment to prepare the front surface modified W specimens
- Specimen size of 10 mm x 10 mm x 1 mm
- Specimen surface: optical microscope , scanning electron microscopy (SEM)
- Surface atomic composition: X-ray photo electron spectroscopy (XPS)

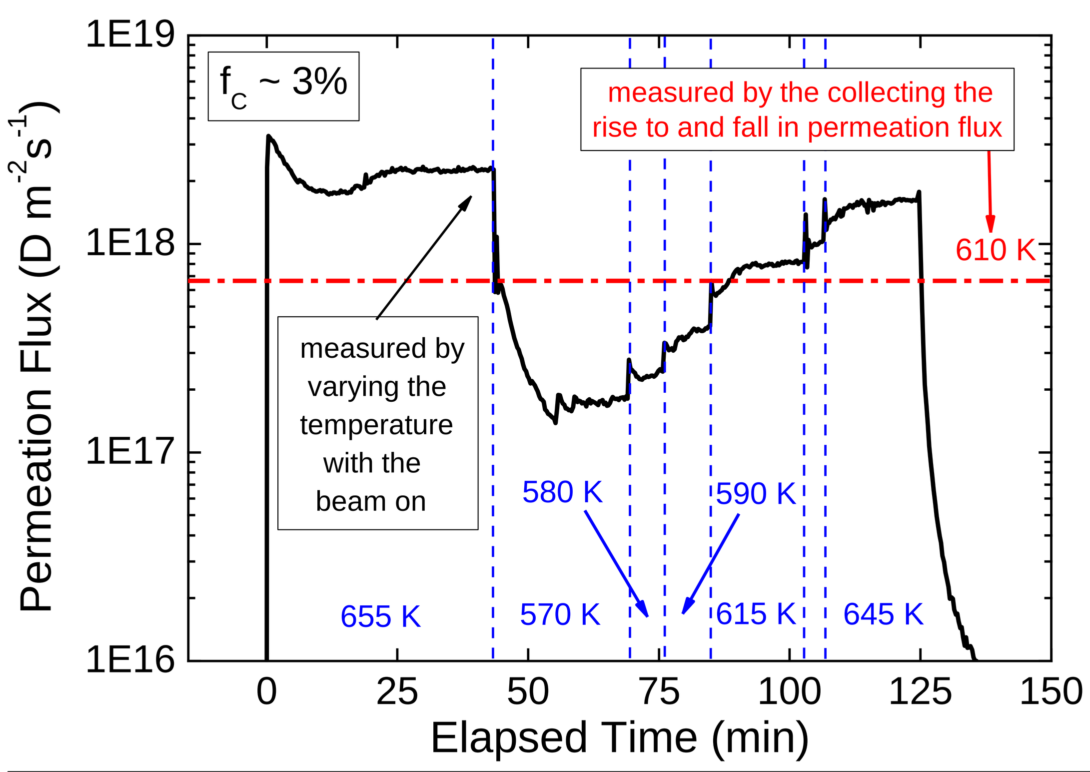
❖ Summary

⇒ Clear increase in steady state D permeation flux under D+C mixed ion irradiation.
⇒ The increase in steady state D permeation flux is temperature dependent with a maximum (200 times larger than D-only case) at temperature around 700-800 K.
⇒ The irradiated surface is a mixed composition of C and W that is temperature independent (C/W ratio near unity for all irradiation temperatures).
⇒ Correlation between the increase in permeation flux and the increase in blisters size formed on W surface.
⇒ A rise in divertor temperature under certain off normal conditions may result in unacceptable level of H permeation, giving significant impact on fuel recycling as well as T handling and recovery.

❖ Results

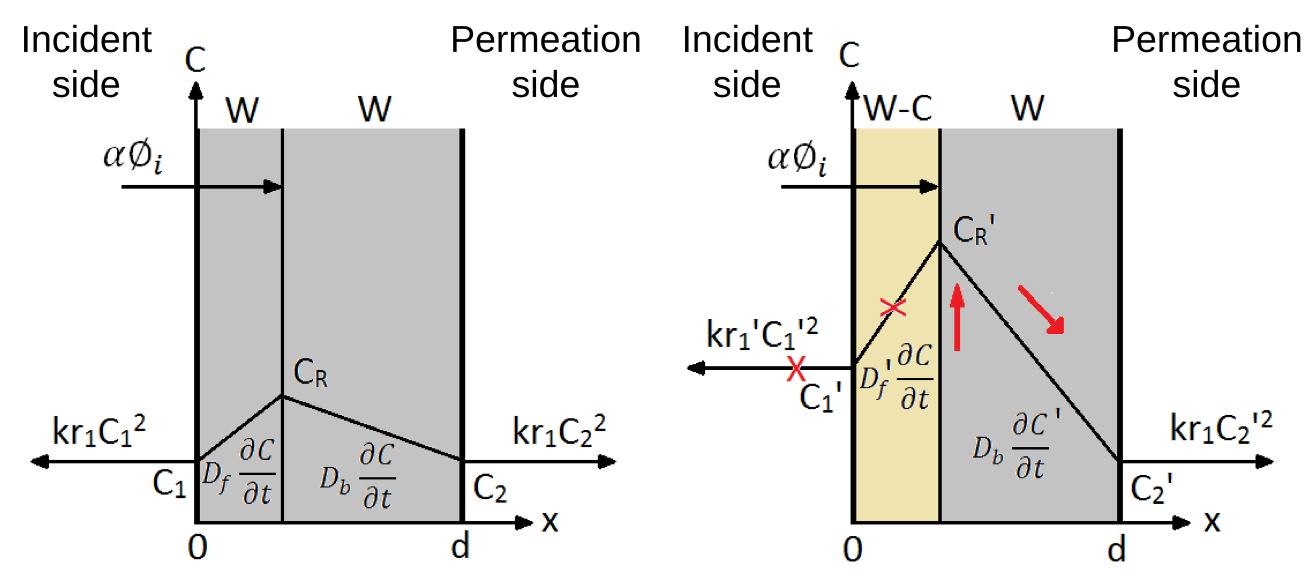
(1) Transient Permeation Curves





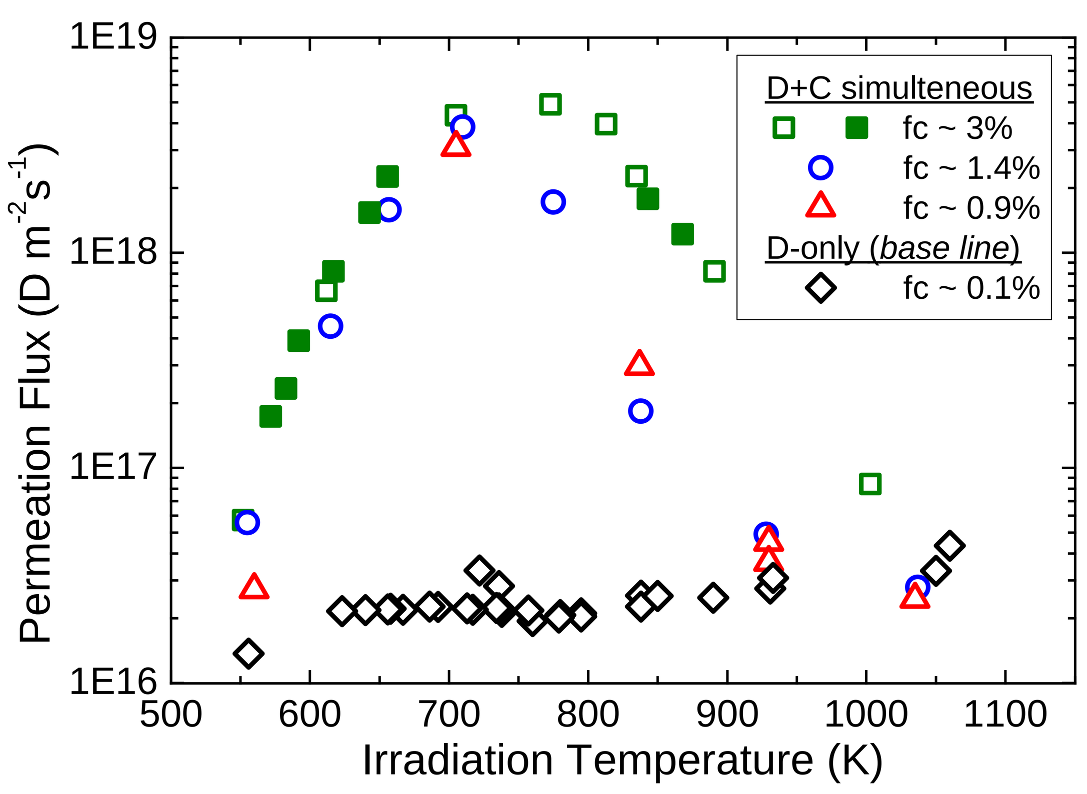
- The steady state D permeation flux for simultaneous D+C case is 20 times larger than that of D-only case.
- The lag time for simultaneous D+C case is 1.5 times larger than that of D-only case

- The temperature increment of 10-20 K results in corresponding rise in permeation flux, and vice versa.
- The permeation flux obtained at 615 K was within the experimental error with the value measured at 610 K.

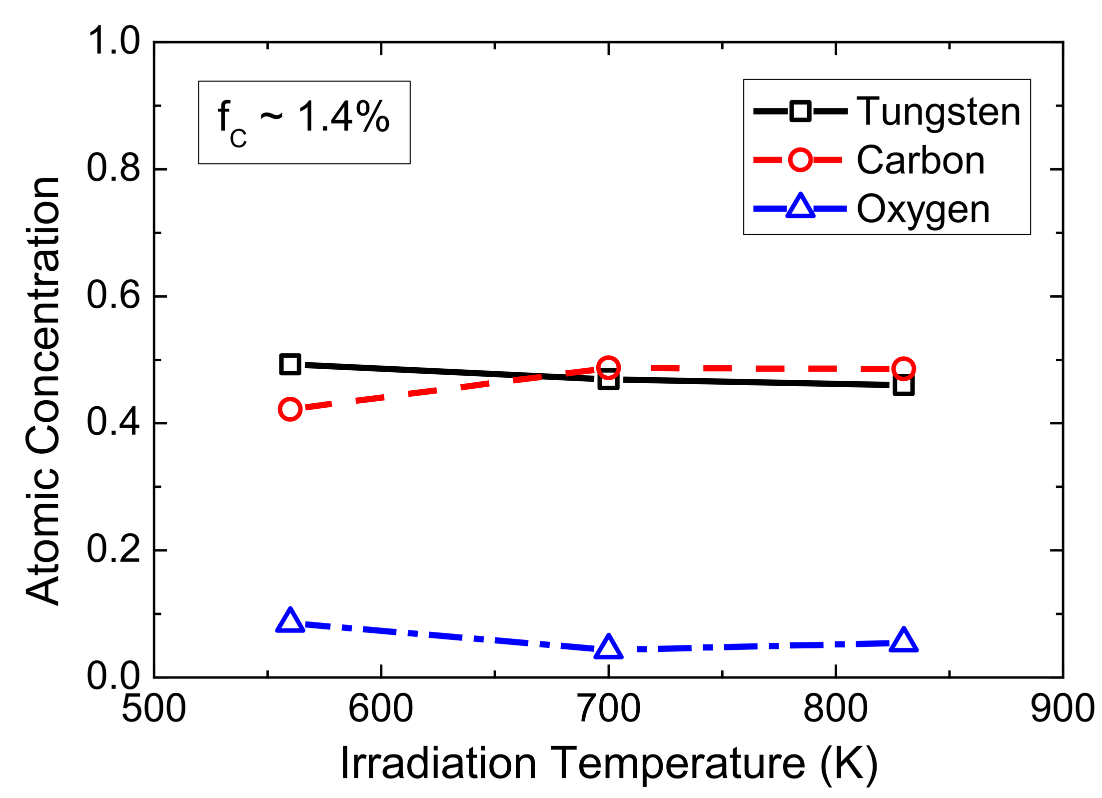


- The formation of tungsten carbide layer may results in the decrease in either recombination coefficient or diffusivity, depending on the D transport regime.
- The tungsten carbide layer decreases the outward release of D from the surface of the incident side, leading to the increase of the concentration of D in W

(2) Temperature / C fraction dependence

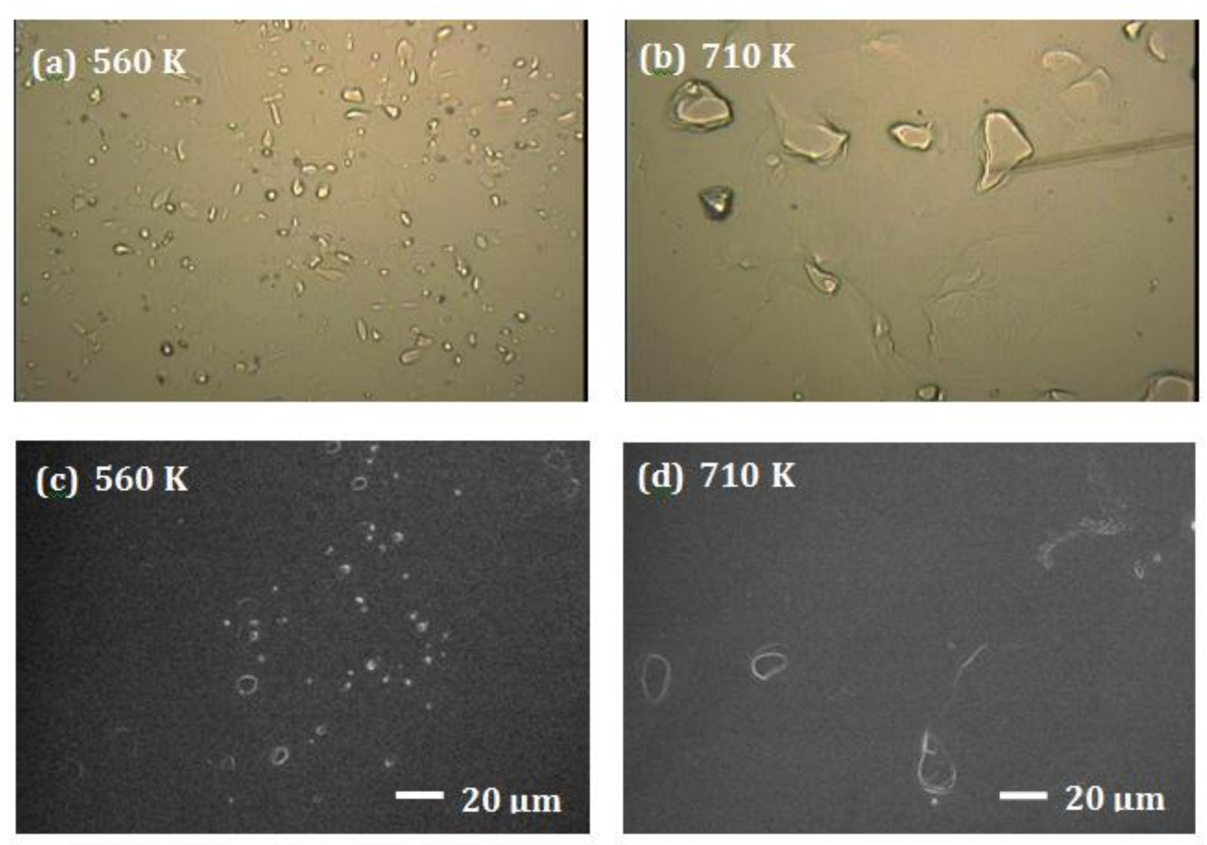


(3) Surface atomic composition (by XPS)



- For f_C ~ 0.9% and f_C ~ 1.4%, the steady state D permeation flux value reached maximum at T_w = 710 K, which was 200 times larger than that of D-only case.
- When the C fraction got increased to f_C ~ 3%, the peak shifted to 770 K, and the D permeation flux values for high temperature region (T_w > 710 K) were 2 times to 10 times larger than f_C ~ 0.9% and f_C ~ 1.4%
- The C/W ratio is near unity indicating no observable temperature dependence on surface composition.

(4) Blisters formation on W surface



- The sizes of the blisters formed on the surfaces of W specimens show temperature dependence.
- Small blisters (1-8 μm) at T_w = 560 K, larger blisters (10-30 μm) at T_w = 560 K, no blister at T_w = 560 K.

Corresponding email: penghanyee_8388@st.eie.eng.osaka-u.ac.jp
13th PFMC Workshop / 1st FEMaS Conference, Rosenheim, Germany, May 9 - 13, 2011.