EX/P3-12 Control of fuel particle balance with the wall temperature modification and particle condensation in the hot wall on all-metal plasma facing wall in QUEST

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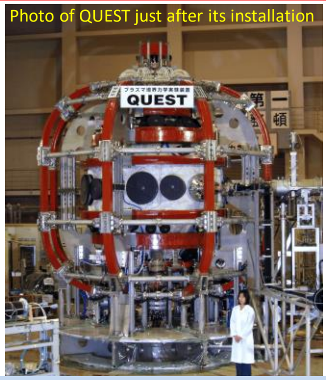
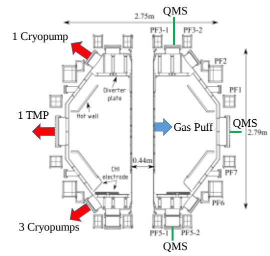
Abstract

QUEST (Q-shu University experiments with Steady-state Spherical Tokamak) has been promoting to study on integrated understanding particle balance including plasma, scrape-off layer, and plasma-facing walls (PFWs) with the equipped hot wall. The microscopic observations for plasma-exposed specimens provide the physical constants of the plasma exposed surface, such as diffusion coefficient, surface recombination, trapping energy and so on. There are three typical surfaces on QUEST such as deposition and oxide layers and atmospheric plasma sprayed tungsten and their physical constants are obtained. The time for wall saturation is derived from the physical constants and the wall temperature dependence of achieved plasma durations can be expressed by the time for wall saturation of plasma induced deposition layer. Two 6 h discharges have been achieved. Water cooling of the top side hot wall induced the wall temperature reduction by 30K (0.5K/min) and consequently gives rise to taking a preferable particle balance. The direction of ion grad-B drift plays a role in the extension of plasma duration through the effective particle pumping and condensation.

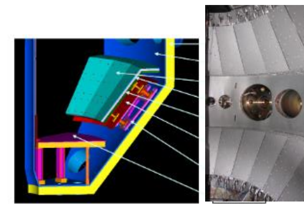
Photo of QUEST just after its installation





Conceptual cross-sectional view of QUEST. PF1-7 denote the position of poloidal field coils. A QMS located behind the CHI electrode was installed before 2018 spring/summer campaign. Three QMSs located on top, plasma chamber, and bottom are set up in 2018 spring/summer campaign. It should be noted that the coils located inside the center-stack are not drawn in the figure.

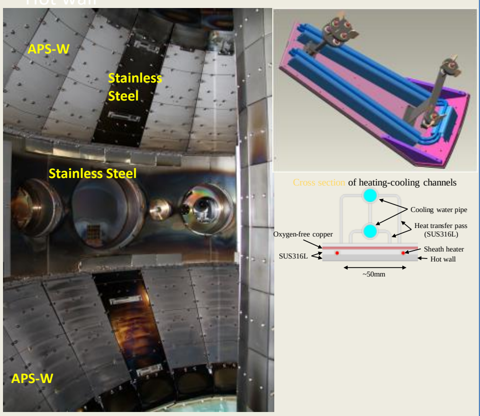
Hot wall



Left: Cross-sectional view of the hot wall, which are composed of heater-cooling panels and a trifarious radiation shield, is shown. Right: Present status of the hot wall. There are some holes for plasma heating devices and diagnostics on the midplane. The surface of the hot wall is covered with APS-W of 100 mm in thickness.

Present Status of QUEST wall

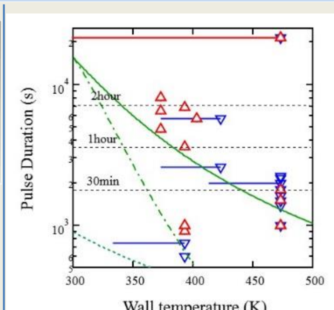
Hot wall

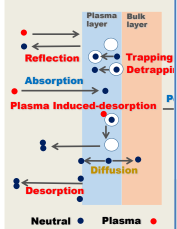


	Material	Area (m²)
Center stack Cover panel	Stainless Steel type 316L	3.06
Top divertor plate	APS-W	2.01
Top HW with water cooling	APS-W	3.58+ 0.97
Mid-plane HW (passive)	Stainless Steel type 316L	5.71
Down HW w/o water cooling	APS-W	3.58+ 0.97
Ports	Stainless Steel type 316L	2.5
Conical Vessel	Stainless Steel type 316L	1.6
Down divertor plate	Stainless Steel type 316L	2.01
Total		14.9(SS) 11.1(W)

	Stainless Steel Type316L	APS-W	Deposition Layer
D_0[m²/s]	4.7×10^{-7}	4.3×10^{-10}	1.5×10^{-7}
E_D[eV]	0.57	0.48	0.41
R_0[m⁴/s]	3.8×10^{-28}	1.0×10^{-15}	4.0×10^{-36}
E_R[eV]	0.55	1.08	0.25
E_{det} [eV]	0.7	1.05	0.5
H_{T0}[m^{-2}]	2×10^{21}	4.5×10^{19}	3×10^{21}
Thickness[nm]	20	30	30

QUEST experiments





Green dotted line indicates time for wall saturation using hydrogen barrier model w/o trap, de-trap effect.

$$\tau_{WS} = \left(\frac{d_{dep}^2}{\Gamma_W k_{rec}}\right)^{1/2}$$

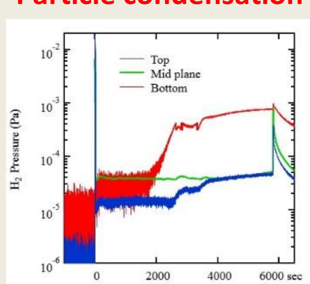
d_{dep}; thickness of deposition layer
Γ_W; Hydrogen flux to PFWs
k_{rec}; surface recombination coefficient

Green solid and chain lines represent time for wall saturation of the deposition layer and sus316L with trap, de-trap effect.

$$\frac{dH_W(t)}{dt} = S_W \Gamma_W - \frac{k_{rec}}{S_W d_{dep}^2} H_W^2(t) - \frac{dH_T(t)}{dt}$$

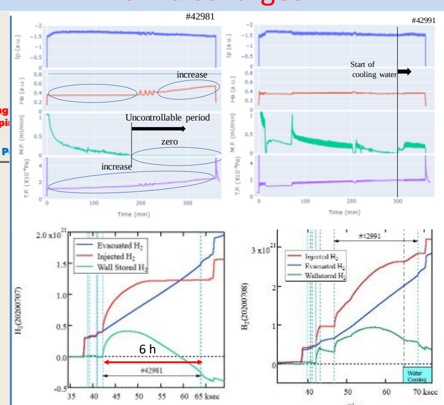
$$\frac{dH_T(t)}{dt} = \frac{D}{d_{dep}^2} H_W(t)\left(1 - \frac{H_T(t)}{H_{T0}}\right) - \nu_0 Exp\left(-\frac{E_T}{T}\right) H_T(t)$$

Particle condensation



Time evolution of partial pressure of H_2 during the 1h36m discharge behind the top divertor plates (blue line), the vacuum vessel mid-plane (green line), and behind the bottom divertor plates (red line). The ion drift direction was down. The background pressure was subtracted from each signal as an offset.

6 h discharges



A pre-programed 6 h discharge could be achieved by local parts (center stack cover panels) cool down of PFWs at T_{HW}=473K.
The injected H_2 is 1.5 times larger than that before local cool down. This indicates wall-pumping is more active and it is helpful for plasma surviving.
The number of wall stored H_2 got to negative. This suggests unexpected outgas could make up for a fuel deficit. The outgas frequently give rise to density runaway that prevents from SSO.

A pre-programed 6 h discharge could be achieved by hot wall cooling down from T_{HW}=473K to 443K with the speed of 0.5K/min.
The injected H_2 is 2 times larger than that before local cool down. This indicates wall-pumping is more active and it is helpful for plasma surviving.
After starting water cooling of the top hot wall, fuel particle can balance including wall stored H. This situation is preferable to obtain SSO.