2. PWI Collaboration

This collaboration is based on the IEA Implementing Agreement of the “Development and Research on Plasma Wall Interaction Facilities for Fusion Reactors” (in short, PWI IA), which is former TEXTOR IA. The objective of this Agreement is to advance physics and technologies of the plasma-wall interaction research by strengthening co-operation among plasma–wall interaction facilities (in particular, by using dedicated linear plasma devices), to enhance the research and development effort related to the first wall materials and components for fusion reactor. In this fiscal year, collaboration on PWI studies and plasma diagnostics were carried out. All the collaboration activities are summarized in Table. I. Highlights in individual activities are described in this report.

Plasma diagnostic study on Magnum-PSI and Pilot-PSI

In this collaboration program, electron density and its fluctuation in the divertor simulation device of Pilot-PSI were studied by using a microwave interferometer and reflectometry system. The one channel 70 GHz microwave interferometer system, which can also be used as a reflectometer, was installed to Pilot-PSI to measure electron line density, its fluctuation, and density fluctuation. These measurements were carried out in the low magnetic field condition and higher hydrogen gas pressure. Hydrogen plasma with magnetic field of 0.8 T and plasma duration of 7 s was used. The line density was about 4.0×10^{17} m^{-2}. The FFT analysis of the line density shows the low frequency fluctuation of about 13.2 kHz. Moreover, the Hα line emission was measured by using a photo detector and a high speed camera. By using FFT analysis of Hα emission intensity, the same fluctuation frequency as the line density measurements was observed.

Temperature impact on radiation damage development in helium plasma exposed tungsten

Impact of temperature on radiation damage formation in helium plasma exposed tungsten has been investigated on the linear plasma device, PSI-2, in FZJ. A nanoscale undulating surface structure, which shows a periodic arrangement, is formed under low-temperature conditions below 1073 K, in contrast to the fuzz nanostructure formation in high-temperature range. The crest of the undulation aligns with <100> direction. The interval of the undulation is the narrowest at the crystal grain of {110} surface. The interval becomes wider as crystal grain surface tilting away from the {110} surface. The cross-sectional TEM observation shows that the height of undulation is ~8 nm independently of the interval of the undulation, and it is almost the same as the depth of the heavily damaged layer with helium plasma exposure.

Non-destructive tritium analysis of divertor tiles used in JET ITER-like wall campaigns by means of β-ray induced X-ray spectrometry

The present ITER design uses tungsten as the divertor material and beryllium as the main chamber wall material because the usage of carbon is expected to result in an unacceptable level of in-vessel tritium inventory. To test the combination of these reference materials in a large tokamak,

Table. I List of Japanese Participations

Subject	Participants	Term	Key persons *etc.*
Collaboration of plasma diagnostic study on Magnum-PSI and Pilot-PSI	Masashi Yoshikawa (Univ. Tsukuba)	9 - 14 Aug. 2015	H. V. Meiden (DIFFER)
Temperature impact on radiation damage developmentin helium plasma exposed tungsten	Ryuichi Sakamoto (NIFS)	16 - 23 Aug. 2015	A. Kreter (FZJ)
Non-destructive tritium analysis of divertor tiles used in JET ITER-like wall campaigns by means of β-ray induced X-ray spectrometry	Yuji Hatano (Univ. Toyama)	26 Aug. - 3 Sep. 2015	J. Likonen (VTT) A. Widdowson (JET)
Experimental investigation of effects of material vapor on incoming plasma heat flux under steady-state and pulsed plasma irradiation on Pilot-PSI	Ikko Sakuma (Univ. Hyogo)	19 – 26 Sep. 2015	T. Morgan (DIFFER)
Influence of surface melting on deuterium retention behaviour in tungsten	Heun Tae Lee (Osaka Univ.)	6 – 12 Dec. 2015	A. Kreter (FZJ)
Tritium loading study of tungsten pre-irradiated to TEXTOR D-plasmas	Yukinori Hamaji (NIFS) Yuji Torikai (Univ. Toyama)	17 – 24 Jan. 2016	A. Kreter (FZJ)

***DIFFER**: Dutch Institute for Fundamental Energy Research, **FZJ**: Forschungszentrum Jülich (Germany), **VTT** (Finland)*

JET has performed ITER-like wall (JET-ILW) campaigns. In this study, tritium distributions in tungsten-coated CFC divertor tiles used in the JET-ILW campaigns were examined non-destructively by measuring X-rays induced by β-rays from tritium. The energy spectra of X-rays were measured using a semiconductor detector under argon atmosphere. The escape depth of β-rays in tungsten is several tens nm, while that of X-rays is several μm; the range of 1.01 MeV tritium ions, which are generated by deuterium fusion reaction, in tungsten is 4.3 μm. Characteristic X-rays of argon are induced by tritium at the surface and subsurface, while those of tungsten and molybdenum and bremsstrahlung X-rays are mainly generated by β-rays from tritium in the bulk. Two tiles, which were at torus inboard-side were analyzed. The spectra obtained for the horizontal part (apron) of Tile 1, which was at the top of the inboard-side divertor tiles, were characterized by strong bremsstrahlung X-rays accompanied with weak characteristic X-rays of tungsten and argon, indicating that majority of tritium was present in deposited beryllium layers. In contrast, the spectra observed for the vertical part of Tile 1 showed very large tungsten Mα X-ray peak and relatively strong bremsstrahlung X-rays in high energy region (≥ 6 keV) together with small argon Kα X-ray peak. Those are typical spectra when tritium penetrates deep (at least several μm) in tungsten; tritium in this part of the tile is considered to be high energy tritium, which is generated by deuterium fusion reaction.

Experimental investigation of effects of material vapor on incoming plasma heat flux under steady-state and pulsed plasma irradiation on Pilot-PSI

In fusion reactor, plasma-facing components were exposed to thermal transient events such as type-I edge localized modes (ELMs). The simultaneous irradiations of steady-state and pulsed plasmas to an aluminum block, which simulated the ELM situation, was carried out on Pilot-PSI in DIFFER in 2014. In that experiment, the surface temperature of the block reached the melting point of aluminum, and droplet splashing and evaporation were observed, and the thermal barrier effect of aluminum vapor was confirmed. On the other hand, in realistic situation, the incident ion energy and flux during ELMs can be high enough to produce a particle cloud in front of plasma facing components, caused by sputtering ejection of plasma facing materials. To investigate the influence of the sputtered particle cloud, the simultaneous irradiation of steady-state and pulsed plasmas to an aluminum block were conducted with keeping the surface temperature to be lower than the melting point of aluminum. The aluminum distribution on the vacuum vessel of Pilot-PSI was investigated with material probe method to know the sputtered aluminum atoms behavior. The analysis is in progress.

Influence of surface melting on deuterium retention behaviour in tungsten

We examined the modification to tungsten surface topology, surface/bulk microstructural modifications, and corresponding deuterium retention behavior following vertical displacement event-like thermal transient loads (190/230 MW/m^2; 0.04-0.16 seconds) in the electron beam device, ACT-2 in NIFS. Increase in grain growth size and cracking are observed with increased power load or time. Following deuterium plasma exposure at PSI-2 in FZJ, uniform blister sizes (0.5-1 μm diameter) on the surface were observed regardless of surface topology or grain growth due to heat load. However, the distribution of such blisters greatly increases in regions of large surface topology changes with/without significant grain growth. These observations support the notion that hydrogen isotope retention increases in regions with high residual stresses caused by permanent (i.e. plastic) deformation rather than microstructural transformations and grain growth. Deuterium concentrations measured by Nuclear Reaction Analysis (NRA) show deuterium retention increases with exposure time to the heat load. However, the absolute levels are within a factor of two in comparison to reference tungsten. We conclude that despite large changes to surface morphology and bulk microstructure, the effect of heat load on deuterium retention is minimal in comparison to mixed material layer formation at the surface due to impurities (e.g. carbon, nitrogen, helium).

Tritium loading study of tungsten pre-irradiated to TEXTOR D-plasmas

Re-crystalized tungsten specimens manufactured by A.L.M.T. Corp. were irradiated to PSI-2 deuterium plasma and deuterium plasma with impurities, such as argon, nitrogen, helium and neon, respectively, to a fluence of 1×10^{26} D/m^2 at the temperature of the tungsten surface about 493 K or 700 K, and were irradiated deuterium with 2.5% helium + 2.5%-argon plasma at the temperature of 493 K. After these irradiations, specimens were shipped to Univ. of Toyama and measured hydrogen isotope trapping on their surfaces by tritium loading method. Tritium trapping amount on the specimen, which was irradiated to pure deuterium plasma is two times higher than that of non-irradiated tungsten specimen. It follows that tritium trapping sites are created on the tungsten specimen surface by the deuterium plasma irradiation. Tritium trapping amount on the specimen, which was irradiated to deuterium plasma with helium is two times higher than pure deuterium plasma irradiated specimen, and 4 times higher than that of non-irradiated specimen. On the other hand, in spite of having irradiation to deuterium plasma, tritium trapping amount on the specimen, which was exposed to the deuterium plasma with 2.5% argon is lower than that of pure deuterium plasma irradiated specimen, and is almost same as that on non-irradiated specimen. Tritium trapping amount on the specimen, which was exposed to the deuterium plasma with 2.5% helium is highest, followed by the case of deuterium + nitrogen plasma, then pure deuterium. The specimen exposed to deuterium + argon plasma and deuterium + neon plasma showed the lowest tritium trapping, close to the unexposed reference specimen.

(Masuzaki, S.)