10. International Collaboration

Plasma Wall Interaction (PWI) Collaboration

This collaboration is based on the IEA Technical Collaboration Programme (TCP) of the "Development and Research on Plasma Wall Interaction Facilities for Fusion Reactors" (in short, PWI TCP). The objective of this TCP 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, collaborations on PWI experiment, tritium retention analysis, plasma diagnostics, and edge plasma simulation were conducted. All the collaborations are listed in Table I. Highlight of each activity is described in this report.

Microstructure and hydrogen retention property in Beryllium exposed to high density plasma: This study was conducted in collaboration with University of California at San Diego (UCSD). Beryllium (Be) samples were exposed to deuterium (D), D - 10% helium (He) mixture, and He plasmas, respectively, at the temperature of 573 K in the PISCES-B divertor plasma simulator. After the exposures, surface microstructure analysis with scanning electron microscopy (SEM) and transmission electron microscopy (TEM) was conducted. Cross-sectional observation revealed the formation of peculiar cone structure on the surface for each Be sample exposed to the plasma at the various conditions. Especially, remarkable change was obtained from the sample exposed to helium seeding plasma at high ion energy of ~100 eV. The analysis of crystal structure of the cones and the mass loss caused by the plasma exposure implied that the cones were formed by sputtering mechanism.

Impact of crystal orientation on radiation damage formation in helium plasma exposed tungsten: This study was conducted in collaboration with Forschungszentrum Jülich (FZJ). PSI-2 linear plasma device was utilized for this study. High-purity recrystallized tungsten (W) was exposed to He plasma at ~800 K, which is lower than the threshold temperature of the fuzz formation. The incident He particles is monoenergetic 75 eV, and this energy is slightly below the sputtering threshold energy. Surface structure morphology with He plasma exposure was observed using SEM, TEM, and electron backscattered diffraction pattern analysis (EBSD) and confocal microscopy (CM). A nanoscale undulating surface structure begin to form at fluence above 10^{24} m^{-2}, and its development is almost saturated at fluence above 10^{25} m^{-2}. The difference in elevation among grains is formed at a fluence of 3.0×10^{26} /m^2, and it reaches to 140 nm from the cross-sectional observation. Results of the analysis using EBSD and CM shows that the surface erosion rate varies depending on the crystal orientation of the grain (see Fig. 1).

Collaboration of plasma diagnostic study on Magnum-PSI and Pilot-PSI: This study was conducted in collaboration with Dutch Institute for Fundamental Energy Research (DIFFER). To find a way to stabilize the detached plasma, the plasma detachment experiments in the MAGNUM-PSI linear plasma device was planned with a focus on plasma fluctuation measurement.

Hydrogen de-trapping dynamics in damaged tungsten: This study was conducted in collaboration with Max-Planck-Institut für Plasmaphysik (IPP) Garching. D - hydrogen (H) isotope exchange in W was investigated by using the dual ion beam device. The device is equipped with a mass-analyzed D/H ion implantation source and is capable of in-vacuo ion beam analysis. Results indicate that the D loss is proportional to the square root of the implanted H fluence. This indicates that the rate-limiting step of D loss from D-H isotope exchange measured in experiments may be diffusion-limited.

A study about effects of high heat flux on surface morphology induced by He ion irradiation: This study was conducted in collaboration with FZJ. This study is focused on the effects of pre-melting with thermal pulses on the W surface morphologies induced by He ion irradiations. High heat pulses were applied to the W samples in ACT2 electron beam device in NIFS. The melted W samples were exposed to He plasma in the PSI-2 at FZJ.

Measurement of tritium (T) distributions in JET-ILW divertor tiles using β-ray induced X-ray spectrometry: This study was conducted in collaboration with VTT Technical Research Centre of Finland. The analysis of the W-coated carbon divertor tiles used in the JET ITER-Like Wall (ILW) campaigns were performed in VTT. Because of a shallow escape depth of β-rays from T, the 2-dimensional distributions of β-ray intensity obtained by using Imaging Plate technique provided the T distributions near the tile surfaces. The distribution

indicated the co-deposition of T thermalized in the plasma with Be sputtered from the main chamber wall. β-ray Induced X-ray Spectrometry (BIXS) provided information on T implanted at high energy (~MeV) into deeper regions of the W layers due to far larger escape depth of X-rays induced in the materials by β-rays. The concentration and penetration depth of T in the W layers showed systematic correlation with poloidal location of the tile in the vacuum vessel.

Analysis of detached plasmas of linear devices by using a plasma fluid model with anisotropic ion temperature: This study was conducted in collaboration with FZJ. The magnitude of the magnetic field changes along the scrape-off layer (SOL) - divertor region can affect the divertor detachment formation. A numerical study of the mirror effect of simple mirror magnetic field configurations on the plasma parameters and generation of the detached plasmas was conducted by using B2-EIRENE code. The mirror effect was added to the plasma fluid model, known as the Braginskii equations in B2 code.

(S. Masuzaki)

Table I. List of collaborations

Subject	Participants	Term	Key persons
Microstructure and hydrogen retention property in Beryllium exposed to high density plasma	Mitsuki Miyamoto (Shimane Univ.)	15 Aug. – 7 Sep. 2016	D. Nishijima (UCSD)
Impact of crystal orientation on radiation damage formation in helium plasma exposed tungsten	Ryuichi Sakamoto (NIFS)	4 - 10 Sep. 2016	A. Kreter (FZJ)
Collaboration of plasma diagnostic study on Magnum-PSI and Pilot-PSI	Masayuki Yoshikawa (Univ. Tsukuba)	25 Sep. - 1 Oct. 2016	H. V. Meiden (DIFFER)
Hydrogen de-trapping dynamics in damaged tungsten	Heun Tae Lee (Osaka Univ.)	6 – 12 Nov. 2015	Thomas Schwarz-Selinger (IPP Garching)
A study about effects of high heat flux on surface morphology induced by He ion irradiation	Yukinori Hamaji (NIFS)	10 – 18 Dec. 2016	A. Kreter (FZJ)
Measurement of tritium distributions in JET-ILW divertor tiles using β-ray induced X-ray spectrometry	Yuji Hatano (Univ. Toyama)	11 – 15 Jan. 2017	Jari Likonen (VTT)
Analysis of detached plasmas of linear devices by using a plasma fluid model with anisotropic ion temperature	Satoshi Togo (Univ. Tsukuba)	19 – 26 March 2017	B. Unterberg, M. Tokar, D. Reiter (FZJ)

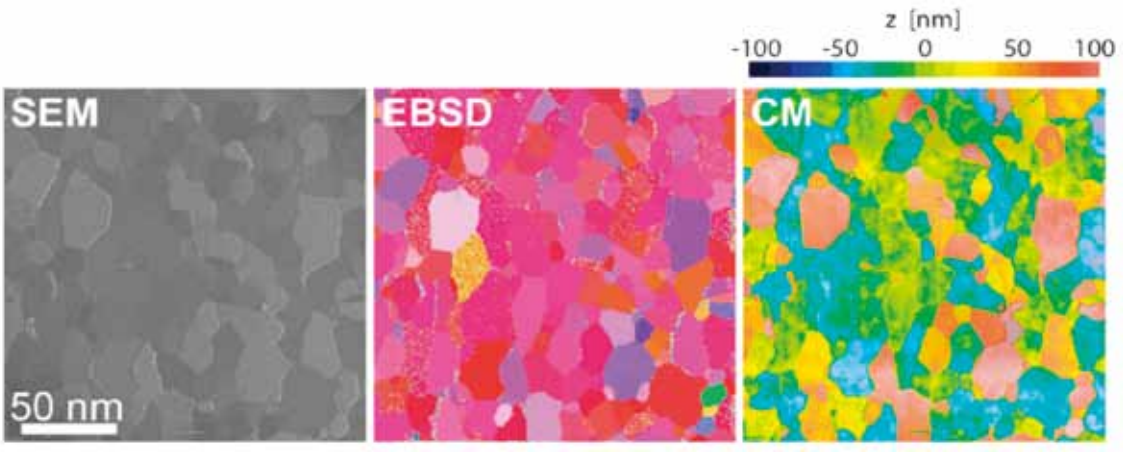

Fig. 1 Comparison of SEM image, crystal orientation, and difference of elevation of helium plasma exposed tungsten surface (3.0×10^{26} m^{-2}).