§29. Study on Surface Modification of Tungsten Plasma Facing Materials

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It is of importance to clarify phenomena of implantation, retention, diffusion and permeation of tritium on surface of the armor materials of the first wall/blanket and the divertor from a viewpoint of precise control of fuel particles, reduction of tritium inventory and safe waste management of materials contaminated with tritium. In addition, it is well known that re-deposited layer, which includes the first wall components emitted by sputtering and residual gases such as oxygen, is formed. On the other hand, tungsten would be used as armor material of the first wall and divetor in DEMO reactor. Therefore, clarification of behavior of tritium on surface exposed by plasma in all metallic first wall and divertor needs to be made. In the present work, surface analyses have been carried out for long term installed samples on first wall in spherical tokamak QUEST, which is an all metallic first wall device.

Samples have been installed on the vacuum chamber of spherical tokamak QUEST in Kyushu University. After the plasma discharge experiments, the samples have been examined using XPS, RBS and ERD. Quantitative analyses of depth profiles of the composition and the implanted H in the materials deposited on sample have been carried out by means of Rutherford back scattering (RBS) and elastic recoil detection (ERD). Depth profiles of H were measured by using an $^4He^{2+}$ analyzing beam ERD technique with an energy of 2.8 MeV. The incident angle of the analyzing beam was 72° from the surface normal to the specimen. The scattered ^4He atoms were detected with the RBS detector placed at an angle of 170° to the incidence direction. The recoiled H atoms were detected by the ERD detector at an angle of 30° to the analyzing beam direction. An Al film 12 μm thick was placed in front of the ERD detector to absorb the He ions scattered from the specimen surface. In this fiscal year, W installed on vacuum chamber of spherical tokamak has been investigated [1]. In addition, tritium (T) exposure experiments have been carried out using a T exposure device in the condition which temperatures of pre-heating and T exposures were 400 °C and 350 °C, respectively.

XPS analyses showed that re-deposited layer was formed on W installed in the 9th cycle (from 2012/11 to 2013/3) and main composition was Fe, O, W and Cr. Fe and Cr are considered to be sputtered on the vacuum vessel made by SUS316L. On the other hand, W is considered to be emitted from the divertor armor, the center stack and W protector. In addition, O, which is residual gas, was co-deposited in the re-deposited layer. H is also detected on the W surface by ERD analyses and is considered to be also co-deposited in the re-deposited layer. The thickness of re-deposited layer is thinner than that of the third cycle which main composition was C, and 6 times thicker than that of the seventh cycle, which main composition was Fe. These composition and thickness of the re-deposited layers are considered to be reflected the plasma parameter and the surface condition of the plasma facing components and the vacuum vessel.

The results from the IP measurement indicated that amount of T on W installed in the 9th cycle (from 2012/11 to 2013/3) which temperatures of pre-heating and T exposures were 400 °C and 350 °C was 11.3 times higher than that of non-exposure sample. On the other hand, T in the area of W which was sputtered by Ar for XPS analyses was 3.7 times higher than that of non-exposure sample. These results indicate that the formation of the re-deposited layer enhances T retention on the surface area, and radiation damage and surface modification by Ar sputtering on W surface also increases T retention on W.

BIXS measurement of W which temperatures of pre-heating and T exposures were 400 °C and 350 °C, respectively showed that W(M_α), W(L_α), Fe(K_α) and Cr (K_α) peaks originated from composition of W, Fe and Cr in addition to Ar(K_α) peak, originated from β ray on T near surface of W, were detected. Peaks of Fe(K_α) and Cr (K_α) were small and originated from Fe and Cr which were re-deposited on W surface. In addition, bremsstrahlung X ray originated from T which exists in deeper area of W was also detected. This result means that T diffused to the deeper area from the re-deposited area on W surface.

It is considered that property, structure and composition of the re-deposited layer influences T retention and diffusion. In addition, in the case which metallic materials are used as the vacuum and the first wall, the metallic elements as well as H, O and C, which are residual gases in vacuum are co-deposited on the vacuum and the first wall. As a results, the re-deposited layer enhances T retention on the surface. Microstructure dependence of W and effect of irradiation of hydrogen/ helium particles and high energy electrons such as the runaway electron on T retention will be also investigated in addition to the effect of the re-deposited layer.

[1] K. Tokunaga, M. Matsuyama, S. Abe, S. Nagata, B. Tsuchiya, M. Tokitani, K. Araki, T. Fujiwara, Y. Miyamoto, M. Hasegawa, K. Nakamura, K. Hanada, H. Zushi、Effects of plasma exposure on tritium behavior of long term installed samples on first wall in spherical tokamak QUEST、21th International Conference on Plasma Surface Interaction, 26-30, May, 2014, Kanazawa, Japan