§64. Synergistic Effects of Plasma and Neutron (ion) on Plasma Facing Components in QUEST

Kurishita, H., Shikama, T., Nagata, S., Chou, M., Hatakeyama, M., Matsuo, S. (Tohoku Univ.),
Watanabe, H. (Kyushu Univ.),
Muroga, T.

Plasma facing materials (PFM) and components (PFC) will be exposed synergistically to fast neutrons, ions and plasma in the fusion environments. It is thus important to clarify the synergistic effects of neutrons, ions and plasma on changes in microstructures and physical and mechanical properties in the surface layer and bulk of PFM/PFC. However, reports on their combined effects are very limited due mainly to insufficient availability of a radiation controlled area (RCA), which is essential to handle radioactive materials. Therefore, we have initiated a study on plasma wall interaction (PWI) with tungsten (W) that is a leading candidate as PFM and PFC by using QUEST plasma and accelerator at Kyushu University, in view of inaccessibility to a RCA for a PWI study. The main research activities on PWI in 2011 are as follows:

1. Set-up of TDS (Thermal Desorption Spectrometer)

PWI studies need quantitative determination of the amounts of hydrogen isotopes retained in W materials, which is generally conducted with TDS. For this purpose, the TDS, already installed at Kyushu University, requires modifications to minimize the level of background caused by impurity gases adsorbed at the inner walls of the TDS main chamber. Therefore, a special specimen exchanging chamber with a differential evacuation system has been attached to the main chamber to minimize the amount of gaseous impurities. A test operation of the improved TDS system has demonstrated a satisfactory performance.

2. Retention and desorption of hydrogen isotopes in ion irradiated W specimens

The behavior of the retention and desorption of hydrogen isotopes in PFM/PFC is governed by the character and density of trapping sites in the microstructures developed by fabrication process (deformation and heat treatment) and subsequent ion or neutron irradiation. In order to obtain basic information regarding the effects of trapping sites on the retention and desorption behavior of deuterium (D) in ion-irradiated W materials, we have first employed commercially available pure W sheets (99.95% purity, 0.1mm in thickness) in the cold rolled state, because simple annealing of cold rolled sheets allows introductions of trapping sites with various characters and densities. The sheets were vacuum annealed at 1173~1323K and 2273K, followed by electro-polishing, and then irradiated with D ions at RT to 1×10^{21} ions/m^2 or Cu ions at RT to 0.02-2 dpa (displacement per atom) or D+Cu ions at RT-773K to 1×10^{22} ions/m^2 and subjected to TDS analyses to measure the retention and desorption of D. The main results are as follows:

1) In the case of the irradiations without Cu ions, two desorption peaks occur in the low temperature regions: "A peak" at 330~420K and "B peak" at 420~560K. The peak intensity decreases with increasing annealing temperature and the B peak is not observed for the recrystallized specimens annealed at 2273K. The observed desorption behavior indicates that a recrystallized structure is effective in suppressing D retention in W. 2) In the case of Cu-ion irradiation, the intensity of peaks A and B is larger and another peak C emerges at 660~900K. The intensity of peak C increases with increasing fluence. 3) Results on TEM observations and the specimen depth distribution of D lead to a conjecture on the trapping sites; peak A: impurity elements adsorbed to surfaces or single vacancies in W, B: dislocations and C: fine vacancy clusters or nano-sized voids.

3. Preparation of advanced W materials

Tungsten has many attractive properties as PFM and PFC, however, it undergoes serious embrittlement in recrystallization state (recrystallization embrittlement) and irradiated state (radiation embrittlement). In order to fabricate advanced W materials exhibiting much enhanced resistances to recrystallization embrittlement and radiation embrittlement, we developed a new fabrication technique, MA (Mechanical Alloying) - HIP (Hot Isostatic Pressing) – GSMM (Grain boundary Sliding-based Microstructural Modification) process. The MA-HIP-GSMM process allows us to fabricate toughness enhanced, fine grained, recrystallized W-1.1%TiC (TFGR W-1.1TiC). TFGR W-1.1TiC has been found to exhibit very high fracture strengths above 3GPa and appreciable bend ductility at room temperature. In addition, TFGR W-1.1TiC exhibits no surface roughening and no surface cracking at the grain boundaries after thermal shock loading under the ITER-ELM conditions or thermal fatigue loading.