§58. Synergistic Effects of Plasma and Neutron (Ion) on Plasma Facing Components in QUEST

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Tungsten (W) has many attractive properties that are never available in the other metals and is planned to be employed as the key material in PFC (Plasma Facing Components) such as the full W divertor in ITER (International Thermonuclear Experimental Reactor). Exposed to heavy thermal loads combined with irradiation with high energy neutrons, low energy ions, etc., W in PFC will suffer degradation such as intergranular embrittlement caused by recrystallization and radiation and high retention of hydrogen isotopes due to radiation induced lattice defects that may act as strong trapping sites for hydrogen isotopes.

Suppression of hydrogen isotopes retention requires a reduction in the accumulation of radiation induced lattice defects, which will also alleviate radiation embrittlement. Therefore, nanostructured W materials such as TFGR (Toughened, Fine Grained, recrystallized) W with 1.1wt%TiC addition, designated as TFGR W-1.1TiC, that contain a high density of sinks for radiation induced defects (grain boundaries (GBs) and fine TiC dispersoids) may offer the above required role. The followings are the main research activities performed in 2012:

1. Effects of nanostructure and radiation induced damage on D retention in W based materials

Two kinds of W materials of nanostructured TFGR W-1.1TiC and commercially available, fully recrystallized W (R-W) were subjected to investigation. The R-W was electrolytically polished and TFGR W-1.1TiC was mechanically mirror polished followed by degassing at 1473 K for 5 min. Both the specimens were irradiated with 2.4MeV-Cu^{2+} at room temperature up to 1 x 10^{19} ions/m^2 for R-W and 2 x 10^{19} ions/m^2 for TFGR W-1.1TiC, which correspond to 2 and 4 dpa (displacement per atom), respectively. The position of the peak damaged zone is around 400-500 nm from the surface. The damaged specimens were irradiated with 2.0keV-D^{2+} at room temperature up to 1×10^{21} D^{2+}/m^2 and subjected to TDS at temperatures from RT to 1023K in vacuum with a ramp rate of 1 K/s to obtain desorption spectra of D_2 and D-H against temperature. The main results are as follows:

1) Before Cu^{2+} irradiation the amount of D retention estimated from the D_2 and D-H desorption spectra is much higher in TFGR W-1.1TiC than in R-W. On the other hand, when irradiated with Cu^{2+}, R-W exhibits a sharp increase in D retention, whereas TFGR W-1.1TiC exhibits D retention less sensitive to the irradiation. This is likely due to the differences in sink density and resultant lattice defects between pure R-W and TFGR W-1.1TiC. As the damage level increases, a distinct peak around 700K appears at 0.2 dpa for pure R-W and 4 dpa for TFGR W-1.1TiC.

2) TEM (Transmission Electron Microscopy) observations show dislocation loops of the interstitial type (IL) and a high density of nanovoids in the damaged R-W. In view of higher thermal stability of nanovoids than IL, the peak around 700K is likely attributed to desorption from nanovoids.

3) Comparison of the desorption spectra of D_2 at 2 dpa for Cu ions (present result) and those of literature data at 3 dpafor Fe ions and at 0.025 dpa for fast neutrons shows that the temperature corresponding to the damage peak is different and higher for Cu ions than for Fe ions and the highest for neutrons. Since the peak temperatures correspond to the binding energy between trapping defects and D and the peak width is considered a reflection of the distribution of trapping defect locations from the surface, we can say that the radiation damage by neutrons causes the most serious effect on D retention. Therefore, the beneficial effects of nanostructures on D retention are expected to be greater in the neutron irradiated state than in the heavy ion irradiated state.

2. Improvements of TFGR W-1.1TiC

Domestic and international research collaboration work on TFGR W-1.1TiC has shown many satisfactory performances: Lowered DBTT (Ductile Brittle Transition Temperature; defined as nil ductility temperature) down to 240K when the oxygen content is less than 200 wppm, no surface alterations due to low-energy D plasma exposure, no cracking and no surface roughening by thermal shock loading in JUDITH-1 and thermal fatigue loading by electron beam, etc. The unsatisfactory performances of TFGR W-1.1TiC relative to pure W (R-W, stress relieved W) are as follows:

1) Insufficient thermal stability of TiC precipitates when exposed to D plasma at elevated temperatures

2) Limitations in material fabrication associated with the processing route by a multi-step powder metallurgical method of MA (Mechanical Alloying)-HIP (Hot Isostatic Pressing)-GSMM (GB Sliding based Microstructural Modification): Inferior fabrication efficiency and economy, difficulty in producing large sized samples, etc.

It has been confirmed that the above problems can be essentially solved.