Neutron Irradiation Effects in Graphite for Fusion Reactor Applications -Hydrogen Absorption, Diffusion and Annealing Effects-

Bulk hydrogen retention and absorption kinetics have been studied on graphite, which is one of the candidate materials for plasma facing walls in a fusion reactor. It is ascertained in this study that two kinds of hydrogen trapping sites exist and be additionally produced during neutron irradiation. The creation and annealing of these two trapping sites show quite different behavior.

Graphite and carbon fiber/carbon composites (CFCs) are principal materials for current fusion experimental devices due to high thermal conductivity and thermal shock resistivity. However, these materials degrade such various advantages by irradiation of neutrons originated from the fusion reaction of deuterium and tritium. Moreover, since carbon has a chemical affinity to hydrogen, it may cause high tritium inventory in plasma facing walls and a large amount of fuel gas recycling between fusion plasma and wall materials. The authors also have found out that neutron irradiation significantly raised hydrogen retention in graphite in previous studies. From the viewpoint of plasma density control and reducing the radioactive tritium inventory in plasma facing components, it is important to clarify the hydrogen behavior in these materials.

Fig.1 shows a model of hydrogen trapping and transport in graphite proposed by the authors. In an absorption process, hydrogen molecules penetrate easily through open pores and grain boundaries of graphite filler grains and reach the surface of the grain. Then, hydrogen will migrate into the filler grain apparently as molecule (in practice, sequence of dissociation and recombination) controlled by the diffusion process with an activation energy of 1.3 eV. The hydrogen will be trapped at outside edge surface of crystallites by a covalent bond with the adsorption enthalpy of 2.6 eV. This site has been named as trap 2. If the trap 2 sites are sufficiently fulfilled with hydrogen atoms, hydrogen can permeate into the crystallite along the graphite intercalations. The hydrogen absorption, or atmospheric hydrogen pressure decrease, in this stage is controlled by first-ordered chemical reaction, which caused by dissociation at a surface or detrapping from trap 2. Inside a crystallite, there are interstitial cluster loops or zigzag structures, and they should be the other trapping site for hydrogen (trap 1). The trap binding energy for hydrogen was estimated to be 4.4 eV. In the case of unirradiated samples, the number of trap 1 is below 10 % of the total number of trapping sites, and trap 2 is the major sites for hydrogen.

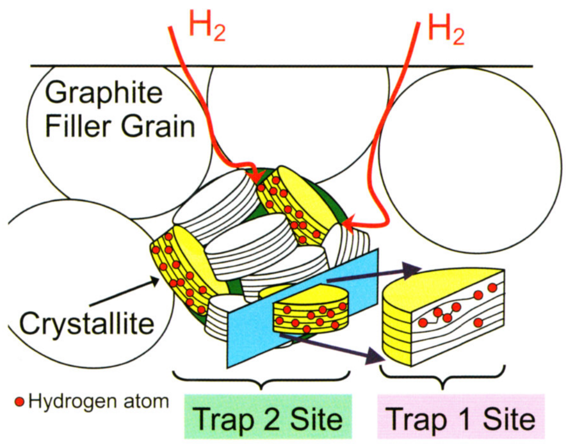

Fig. 1 Schematic illustration of hydrogen trapping sites and hydrogen transport in a graphite material.

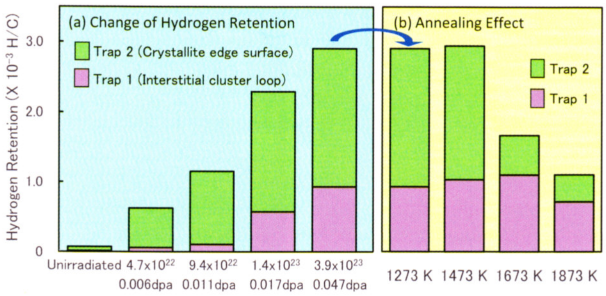

Fig. 2 Change of hydrogen retention and the pre-annealing effect in neutron-irradiated graphite shown for each trapping site (absorption temperature: 1273 K, Equilibrium pressure: ~ 10 kPa).

Graphite and CFC samples were irradiated in the Japan Materials Testing Reactor (JMTR) at various fluences up to 5.4 x 10^{24} n/m^2 (>1 MeV), which corresponded to 0.65 dpa, below 473 K. Hydrogen retention in neutron-irradiated graphite determined for each trapping site is shown for different neutron fluences in Fig. 2 (a). The total retention increases with the irradiation fluence. At lower neutron fluences below 0.011 dpa, the increase is mainly due to the increase of trapping in trap 2, while trap 1 retention is clearly increased at higher fluences above 0.017 dpa. At the highest fluence of 0.65 dpa, the total retention became 6.3 times as large as that for 0.047dpa, and the retention consisted of nearly the same quantity of trap 1 and trap 2 retention.

The retention obtained for the samples which were annealed before hydrogen absorption is shown in Fig. 2 (b). The retention which corresponds to trap 2 tends to decrease with the increase of pre-annealing temperature. This indicates that most of the trap 2 sites induced by neutron irradiation will be annealed out at high temperatures. However, the trap 2 sites may not be completely annealed out, since the retention was still larger than the amount obtained for the unirradiated samples, which was also pre-annealed at 1873 K. On the other hand, retention in trap 1 tends to remain relatively high even after the heat treatment at 1873 K. One can conclude the trap 1 sites should be thermally more stable than trap 2.

Although it is not mentioned in the article, hydrogen diffusion coefficients and reaction rate constants at trap 2 in neutron-irradiated graphite and their pre-annealing effects have been investigated. These results are described in refs [1] and [2].

References

[1] H. Atsumi, A. Muhaimin, T. Tanabe and T. Shikama, J. Nucl. Mater. **386-388**, 379 (2009).

[2] H. Atsumi, T. Tanabe and T. Shikama, J. Nucl. Mater. **390-391**, 581 (2009).

Key Words

Fusion Reactor Materials, Graphite, Irradiation Effects

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