In-vessel Tritium Inventory in ITER Evaluated by Deuterium Retention of Carbon Dust

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Abstracts. In order to estimate in-vessel tritium inventory of carbon dust, deuterium gas absorption and deuterium ion irradiation experiments were conducted for a carbon dust prepared by using electron beam evaporation for graphite. The retained amount of deuterium after the deuterium gas absorption was very low, D/C=10^{-3} in the atomic ratio. The retained amount of deuterium after the deuterium ion irradiation was very similar with that for graphite. The deuterium concentration becomes close to zero if the wall temperature at divertor wall region is higher than 1000K. Co-deposited carbon dust was prepared by using a deuterium arc discharge apparatus with carbon electrodes at different gas pressure and substrate temperature. The co-deposited carbon dust had a largest deuterium concentration. In the ITER condition with gas pressure of 1 Pa and wall temperature of 573K, the deuterium concentration in the atomic ratio becomes approximately D/C=0.2. In DT discharge, the tritium concentration in the atomic ratio becomes T/C=0.1. This value is presumed to be a highest concentration of carbon dust in ITER. The present result shows that the accumulation speed of in-vessel tritium inventory is lower than that predicted so far.

1. Introduction

One of major issues in ITER is an evaluation of in-vessel tritium inventory since the tritium inventory has to be controlled less than operating limits set by safety considerations [1]. In the present design of ITER, it is presumed that a carbon dust produced by erosions of CFC divertor target has a highest tritium concentration, 0.4-2 in the atomic ratio of T/C. Though this value is based on hydrogen retention data of graphite, the data of carbon dust has not been obtained systematically so far. The precise evaluation of tritium inventory of the carbon dust is required to minimize a dwell time for tritium removal operation.

In order to evaluate the tritium concentration of carbon dust, a series of experiments on deuterium or hydrogen retention of carbon dust has been conducted at both Hokkaido University and JAERI [2, 3, 4]. The carbon dust produced by erosion of graphite is exposed to molecular fuel hydrogen, fuel hydrogen atom and ion. The fuel hydrogen also co-deposits on the wall with eroded carbon. To simulate these processes, we carried our (1) deuterium molecular gas absorption experiment for carbon dust, (2) deuterium ion irradiation experiment for carbon dust, and (3) deuterium arc discharge experiment to prepare co-deposited carbon dust. The deuterium concentrations were measured after these experiments.

2. Experiments and Results

The carbon dust was prepared by using electron beam evaporation for isotropic graphite. This dust was used for the deuterium gas absorption experiments and the deuterium ion irradiation experiment. The surface morphology and crystal structure of the carbon dust prepared by electron beam evaporation were examined by using scanning microscope, SEM, and Raman spectroscopy, RS, respectively. The surface morphology and Raman spectrum are shown in **Fig. 1**. The carbon dust consisted with micron size particles and the crystal structure was amorphous carbon. In the preparation of co-deposited carbon dust, carbon electrodes were employed in deuterium arc discharge apparatus shown in **Fig. 2** to evaporate carbon atoms into the deuterium arc plasma. In the arc discharge, both the substrate temperature and discharge gas pressure were changed. The SEM photograph and the Raman spectra of the co-deposited carbon dusts are shown in **Fig. 3**. The crystal structure was amorphous for a case of low substrate temperature but the graphite like structure appeared for the case of high substrate temperature. The deuterium concentrations of the carbon dusts after the above experiments were measured by using a technique of thermal desorption spectroscopy, TDS.

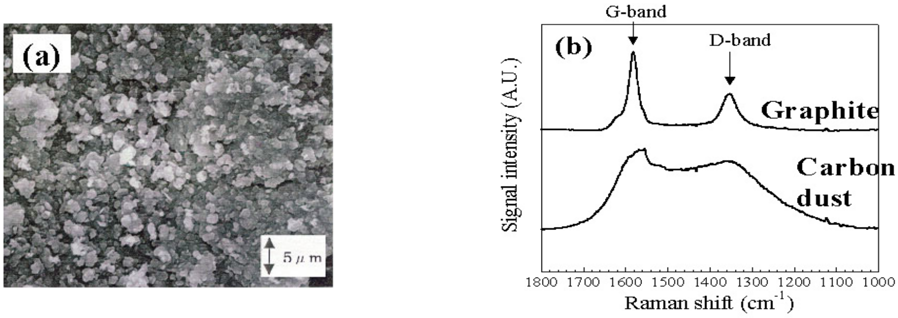


Fig. 1 *SEM photograph of carbon dust* ***(a)*** *and Raman spectra of carbon dust and isotropic graphite* ***(b)****.*

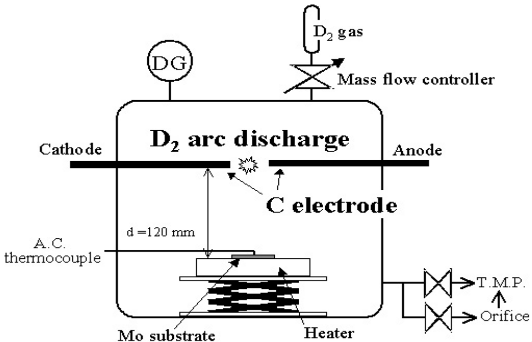


Fig. 2 *D_2 arc discharge apparatus with carbon electrodes.*

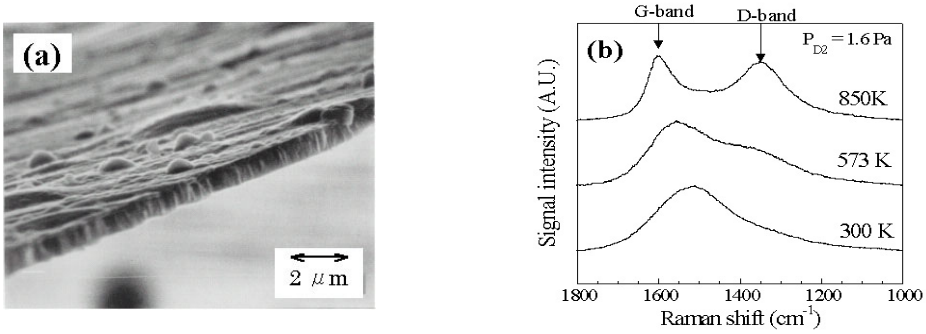


Fig. 3 SEM photograph of co-deposited carbon dust ***(a)*** *and Raman spectra of several co-deposited carbon dusts* ***(b)****.*

The carbon dust was exposed to D_2 gas atmosphere in gas absorption apparatus at Hokkaido University. The equilibrium deuterium concentration after the deuterium gas absorption was measured. In this experiment, the gas pressure and the sample temperature were varied. For comparison, the concentrations of bulk graphite and the graphite powder with a size of 1μm were similarly measured. The absorption amount of carbon dust was much larger than that of bulk graphite or graphite powders as shown in **Fig. 4.** The effective surface areas of these samples were measured using BET method. The absorption amount was roughly proportional with the effective surface area. The absorption of molecular fuel hydrogen takes place at the shadow of plasma facing wall. For the condition with a temperature of 573K and gas pressure of 1Pa, i.e. the ITER vacuum wall condition, the deuterium concentration became approximately 10^{-3} in the atomic ratio of D/C. Thus, the absorption of fuel hydrogen molecular into the carbon dust can be ignored.

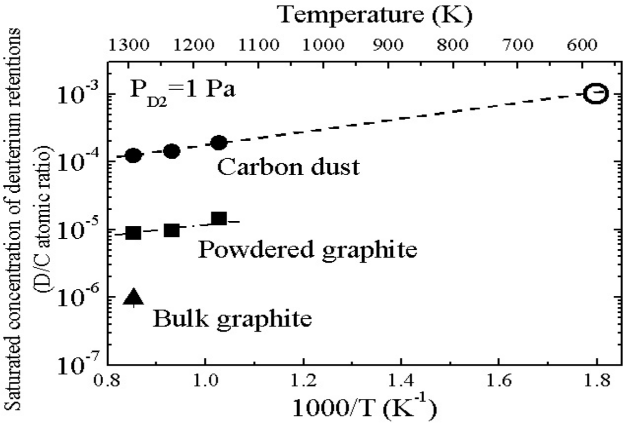


Fig. 4 Equilibrium concentrations of carbon dust, powdered graphite and bulk graphite versus inverse of absorption temperature.

The carbon dust was irradiated by deuterium ions with energy of 1.7keV at RT in ECR ion irradiation apparatus at Hokkaido University. For comparison, isotropic graphite was similarly irradiated. **Fig.5** shows the deuterium concentrations of carbon dust and graphite versus deuterium ion fluence. The fluence dependence of carbon dust shown in Fig.5 and the behavior of the thermal desorption were quite similar with those of graphite. In the deuterium ion irradiation, the structure in the implantation depth becomes amorphous in both the graphite and the carbon dust, and then the trapping behavior becomes the same. This is a possible reason for the concentration of carbon dust to be the same as that of graphite. For graphite, the temperature dependence of hydrogen concentration has been already obtained by several authors [5], and thus this result can be applied for the case of carbon dust. The divertor target region receives fuel hydrogen ion flux. The steady state wall temperature is approximately 1000K. The fuel hydrogen concentration of carbon dust becomes approximately zero, again negligible small.

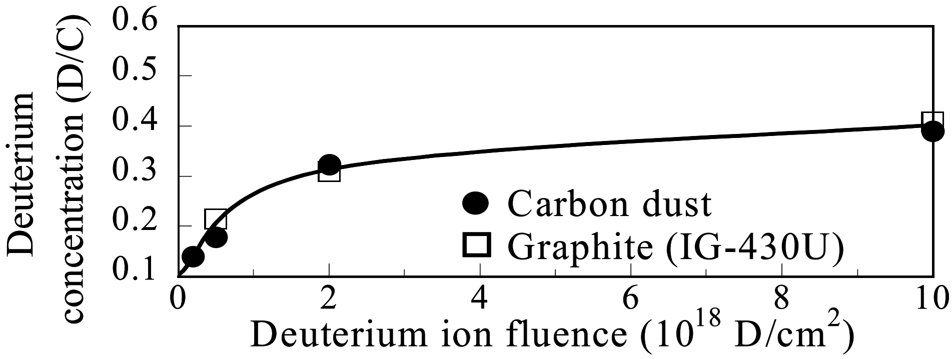
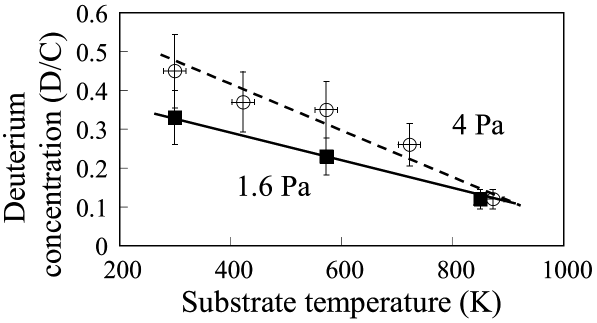


Fig. 5 *Amount of retained deuterium of carbon dust vs deuterium ion fluence.*

The co-deposited carbon dust is produced by the deposition of fuel hydrogen on the carbon dust in the formation process of carbon dust. The co-deposited carbon dust deposits on the wall in the vicinity of CFC target. The fuel hydrogen concentration may become large since the reactive species, i.e. fuel hydrogen atom or ion deposits on the carbon dust. The co-deposited carbon dust was prepared on the substrate in the deuterium arc discharge by changing the substrate temperature and the discharge pressure. **Fig. 6** shows the deuterium concentration of co-deposited carbon dust versus the substrate temperature for discharge pressures of 1.6Pa and 4Pa. **Fig. 7** shows the deuterium concentration versus the discharge pressure for the substrate temperature of 573K. In ITER, the highest concentration becomes 0.2 in the atomic ratio of D/C for the condition at wall temperature of 573K and discharge gas pressure of 1Pa. The co-deposited carbon dust had a highest deuterium concentration. For DT discharges, the tritium concentration becomes 0.1 in the atomic ratio of T/C. This value may be recognized as the highest tritium concentration of carbon dust in ITER. We now estimate the number of main discharge shot which accumulates the in-vessel tritium inventory of 500g. For the in-vessel inventory to reach 500g, the shot number becomes 400 if the erosion rate of CFC is 50g/shot and all the eroded carbon becomes co-deposited carbon dust.



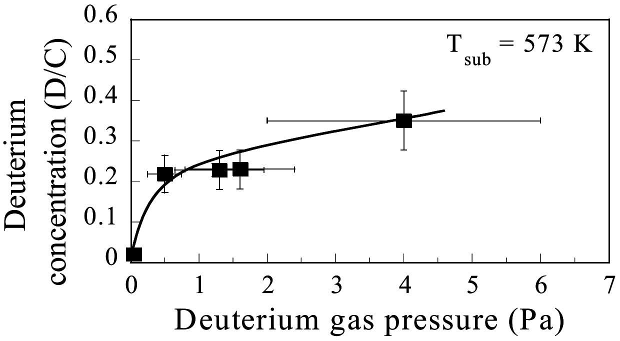


Fig. 6 *Deuterium concentration of co-deposited carbon dust versus substrate temperature.*

Fig. *7 Deuterium concentration of co-deposited carbon dust versus deuterium gas pressure.*

In the deuterium arc discharge, tungsten and carbon electrodes were employed for the anode and cathode, respectively, for the preparation of tungsten mixed carbon dust [6]. The deuterium concentration was observed to be higher than that of co-deposited carbon dust. The structure of the tungsten mixed carbon dust was more amorphous compared with that of co-deposited carbon dust. Thus, the deuterium might have been more trapped. However, the evaporation amount of tungsten is very small, and thus this contribution may be ignored for the in-vessel tritium inventory.

3. **Summary and Conclusion**

The deuterium concentration of carbon dust was measured after deuterium gas absorption and deuterium ion irradiation. The deuterium concentration after the deuterium gas absorption was very low, D/C=10^{-3} in the atomic ratio. The deuterium concentration of carbon dust after the deuterium ion irradiation was similar with that for graphite. The deuterium concentration becomes close to zero when the wall temperature is higher than 1000K. This contribution was also very small. The co-deposited carbon dust had a highest deuterium concentration. The deuterium concentration was D/C=0.2 in the atomic ratio when the deuterium gas pressure of 1Pa and substrate temperature of 573K. For DT plasma, the tritium concentration becomes 0.1 in the atomic ratio of T/C. For the in-vessel tritium inventory of carbon dust to reach 500g, the number of plasma discharge shot becomes 400.

The carbon dust is produced mainly in the disruption phase. In the disruptions, the major erosion of CFC takes place by the emission of carbon particles with a size of μm. The tritium retention of the carbon particle may be much smaller than that of carbon atom or cluster. In addition, the tritium concentration significantly depends on the wall temperature.

The actual wall temperature becomes higher than 573K during the plasma discharge. The tritium concentration decreased by the elevated temperature. Hence, the tritium concentration of carbon dust may be smaller than T/C=0.1. Hence, the period required for dust cleaning is furthermore lengthened.

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