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Deuterium and carbon accumulation in tungsten coating exposed to JT-60U divertor plasmas

JT-60Uダイバータプラズマを照射した被覆タングステン中の
重水素および炭素の蓄積

Masakatsu Fukumoto[1], Tomohide Nakano[1], Kiyoshi Itami[1],
Takaaki Wada[2], Yoshio Ueda[2] and Tetsuo Tanabe[3]
福本正勝[1]，仲野友英[1]，伊丹　潔[1]，和田隆明[2]，上田良夫[2]，田辺哲朗[3]

[1]*Japan Atomic Energy Agency, 801-1 Mukoyama, Naka, Ibaraki 311-0193, Japan*
[2]*Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*
[3]*Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka, 812-8581, Japan.*
[1]日本原子力研究開発機構 〒311-0193 茨城県那珂市向山801-1
[2]大阪大学大学院工学研究科 〒565-0871 大阪府吹田市山田丘 2-1
[3]九州大学大学院総合理工学研究院 〒812-8581 福岡県福岡市東区箱崎6-10-1

In the tungsten coating exposed to JT-60U divertor plasmas, graphitic and disordered carbon and tungsten subcarbide (W_2C) were formed within ~2 μm in depth. Retained amount of the graphitic and disordered carbon in tungsten coating exceeded the solution of carbon in tungsten lattice. These findings indicate that the irradiated carbon migrated to deep region through grain boundaries and pores in the tungsten coating, and that the carbon atoms penetrated and diffused into tungsten grains from grain boundaries and pores and formed W_2C.

1. Introduction

Tungsten coating on the blanket first wall is planned to reduce in-vessel tritium inventory and sputtering erosion of structural materials, while carbon based materials will be used for high heat load components such as the tiles facing neutral beam injection systems. In the case that the deuterium retention in the tungsten coating was increased since the carbon ions, which was simultaneously injected with deuterium ions, migrated to deep region and this carbon retained the incident deuterium ions [1,2]. Hence, carbon migration mechanisms in tungsten coating are expected to play an important role for deuterium retention. However mechanisms of carbon migration in tungsten coating are still unknown.

2. Experiment

In JT-60U, the tungsten-coated carbon fiber composite (CFC) tiles were installed in the upper part of the outer divertor plates. Tungsten with a thickness of ~50 μm was produced by vacuum plasma splaying (VPS) on the ~15 μm thick rhenium/tungsten multi-inter layer, which was deposited by physical vapor deposition on CFC tiles.

About 1100 discharge experiments were performed. Total discharge time was ~8420 sec. The maximum surface temperature during plasma discharges was ~700 K, which was evaluated by finite element methods (FEM) based on the tile temperature. After the experimental campaign, two tungsten-coated tiles were taken out from JT-60U for the present post mortem tile analysis. Samples with a size about 8 × 8 × 1 mm were cut out from the tungsten-coated tiles. Chemical state of the carbon in the tungsten coating was investigated by X-ray photoelectron spectrometer (XPS) with Mg Kα radiation. The binding energies were calibrated with the Au $4f_{7/2}$ peak at 84.0 eV. In order to investigate the depth profiles of the carbon chemical compositions in the tungsten coating, the sample surface was sputtered by a 3 keV argon ion beam.

3. Results

The C 1s spectrum measured by XPS was decomvoluted by Gauss-Lorentz functions to examine the chemical compositions of the carbon in the tungsten coating. Since the chemical state of the carbon in tungsten is expected to be graphitic and disordered carbon, tungsten carbide (WC), and tungsten subcarbide (W_2C). Hence, the C 1s spectrum was decomvoluted by four curves with the fixed peak energies with 284.2, 285.2, 283.1, and 283.6 eV for graphitic carbon, disordered carbon, WC, and W_2C, respectively [4]. Figure 1 shows the C 1s spectrum measured at the depth of

~6 μm (see Fig. 2) and the results of the decomvolution. The C 1s spectrum was best fit with three curves, disordered and graphitic carbon and W_2C. Atomic concentration of these carbon compositions based on the areal ratio of each peaks was ~11.3, ~5.8, and ~14.2% for disordered carbon, graphitic carbon, and W_2C, respectively.

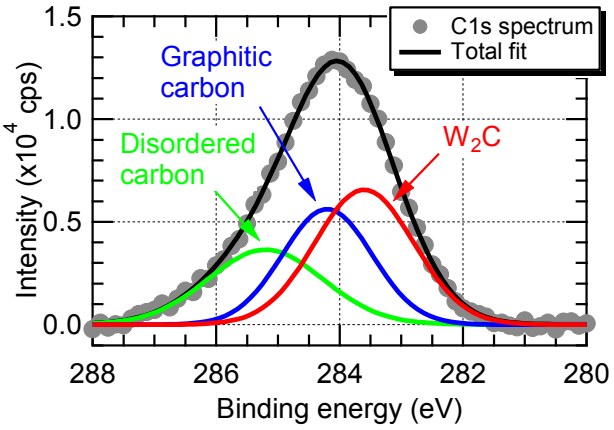

Fig.1. Carbon 1s spectrum in the tungsten coating measured by XPS with the best fits for the measured spectrum. The gray points show C 1s measured spectrum. The three colored lines represent the curves deconvoluted by Gauss-Lorentz functions. The black line shows total fit of the deconvolution curves.

Figure 2 shows depth profiles of chemical compositions of the carbon in the tungsten coating measured by XPS. The carbon composition for each depth was investigated by the methods mentioned above. Atomic concentration of the graphitic and the disordered carbon increased with depth and reached ~10 % at ~0.6 μm in depth. After that, the atomic concentration of these carbon compositions was decreased with increasing depth to ~1 % at the depth of ~2.2 μm. The W_2C concentration was

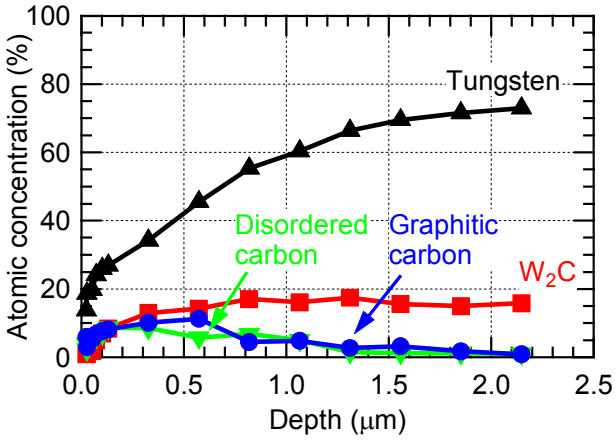

Fig.2. Depth profiles of chemical compositions of the carbon in the tungsten coating measured by XPS.

increased with depth and saturated at the depth deeper than ~1 μm (16-17 %).

4. Discussion

According to the carbon diffusion coefficient for polycrystalline tungsten obtained from the ^{14}C diffusion experiments [4], the calculated carbon diffusion length in tungsten lattice was less than 10 nm provided that the surface temperature and the discharge duration were 700 K and 8420 s, respectively. As shown in Fig. 2, the migration length of the injected carbon atoms was much deeper than this calculated diffusion length. This discrepancy suggested that the dominant mechanisms of carbon migration in the tungsten coating are different from diffusion of carbon atoms in the tungsten lattice.

As shown in Fig. 2, more than one percent of the graphitic and the disordered carbon were accumulated in the tungsten coating within the depth of ~2 μm. This indicates that most of the graphitic and the disordered carbon existed at grain boundaries and pores, since the solubility of carbon in tungsten grains is less than 0.3 at.% [5].

From above findings, the carbon migration mechanism in tungsten coating is expected as follows. The injected carbon migrated to deep region through tungsten grain boundaries and pores as a form of carbon atoms or gaseous molecules such as CDx. The carbon atoms penetrated from grain boundaries and pores and diffused into tungsten grains, and most of the carbon reacted with tungsten atoms, forming W_2C

5. Conclusion

Carbon migration mechanisms in tungsten coating irradiated by JT-60U divertor plasmas were discussed based on the chemical composition of the carbon. The injected carbon migrated to deep region through grain boundaries and pores. After that, the carbon atoms were penetrated and diffused into tungsten grains and formed W_2C.

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