24P096-P

Evaluation of Carbon Erosion Process in Attached and Detached Deuterium Plasmas
接触・非接触重水素プラズマ中での炭素損耗過程の評価

Masahiro Teraoka[1], Noriyasu Ohno[1], Shin Kajita[2], Atsushi M. Ito[3], and Hiroaki Nakamura[3]
寺岡正広[1], 大野哲靖[1], 梶田信[2], 伊藤篤史[3], 中村浩章[3]

[1]*Department of Engineering and Science, Nagoya University*
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
名大院工 〒464-8603 名古屋市千種区不老町
[2]*EcoTopia Science Institute, Nagoya University*
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
名大エコトピア 〒464-8603 名古屋市千種区不老町
[3]*National Institute for Fusion Science*
322-6, Oroshi-cho, Toki, Gifu, 509-5292, Japan
核融合研 〒509-5292 岐阜県土岐市下石町322-6

Carbon material, which is the candidate material of the divertor in the fusion reactor, would be damaged significantly in a detached plasma since a carbon has high reactivity with a hydrogen isotope. It is of importance in the investigation of the fundamental characteristics of carbon-hydrogen interaction. In this study, Highly Oriented Pyrolytic Graphite (HOPG) was exposed to the attached and detached deuterium plasmas in the NAGDIS-T. By surface analysis using scanning electron microscopy (SEM) and Raman spectroscopy, it was found that the HOPG irradiated with the detached plasma has anisotropic damages. The anisotropic characteristics of graphite erosion are discussed on the basis of the results of the comparison with molecular dynamics (MD) simulation.

1. Introduction

The interaction between carbon and hydrogen is one of the most important issues for nuclear fusion research. Carbon materials are well known to be beneficial for fusion device walls, such as divertor plates. Because carbon has a high reactivity to a hydrogen isotope, carbon materials also would be damaged heavily even in the low-temperature plasma, so-called “detached plasma”. It is of significant to investigate the fundamental characteristics of carbon erosion. Thus, we focused the orientation of the graphite structure and used HOPG, which has a multilayer of graphene structure. HOPG was irradiated with the attached and detached deuterium plasmas in the toroidal plasma divertor simulator NAGDIS-T and analyzed by SEM and Raman spectroscopy to investigate the surface features. the light from the plasma was measured by spectroscopy. We focused on the difference between the effect of the attached and detached plasmas in this study.

2. Experimental Methods

HOPG, which reflects the two-dimensional anisotropy of the graphene sheet strongly was exposed to the attached and detached deuterium plasmas in the NAGDIS-T and the light of CD radicals was measured by spectroscopy to investigate amount of the carbon erosion. In the attached plasma, the typical electron density n_e is 10^{18} m^{-3} and the temperature T_e is 2-5 eV. On the other hand, n_e and T_e are typically 1.5×10^{18} m^{-3} and less than 0.1 eV, respectively in the detached plasma. After the plasma irradiation, the graphite targets were analyzed by SEM and Raman spectroscopy.

3. Results

Figures 1(a)-(f) were SEM micrographs of the central and edge ares of the HOPG samples before irradiation and after the attached and detached plasma irradiation, respectively. It was found that, after the irradiation with the detached plasma, the center of the HOPG target had no damage and the peripheral region of the target was damaged and showed a staircase pattern, as shown in Figs. 1(e) and 1(f). This suggested that the edge area of the HOPG target was mainly damaged when the incident ion energy was low. The edge of the graphene sheet is thought to be weaker than the central area for low-temperature deuterium plasma irradiation. Figure 2 shows the Raman spectral analysis results for the nonirradiated and irradiated HOPG samples in terms of I_D/I_G and FWHM$_G$[1]. A part of surface of the HOPG sample irradiated with the attached plasma became visually darker than its margin and seemed to have more in-plane defects than isotropic graphite. The dark area seemed to be protrusion-like structure, as seen in the SEM micrograph in Fig. 2.

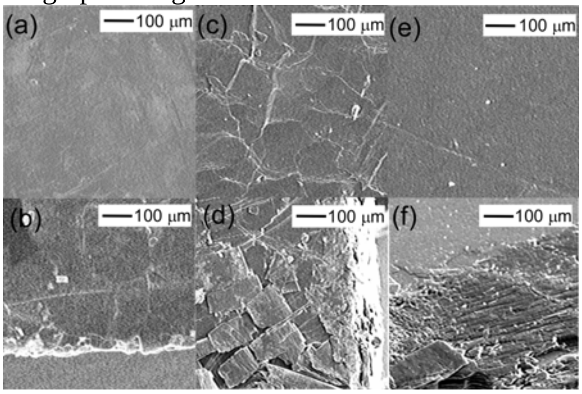

Fig.1. SEM photographs of the surface of HOPG target. (a) and (b) show the nonirradiated target in the central and edge parts, (c) and (d) show the irradiated target with the attached plasma in the central and edge parts, and (e) and (f) show the irradiated target with the detached plasma in the central and edge parts.

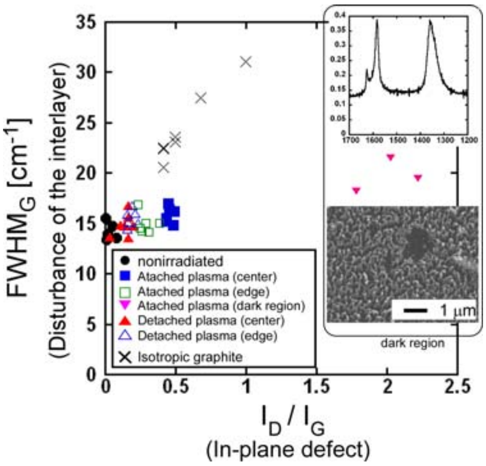

Fig.2. FWHM$_G$, which corresponds to disturbance of the interlayer, as a function of the intensity ratio (I_D /I_G), which corresponds to in-plane defects of nonirradiated, and irradiated HOPG targets.

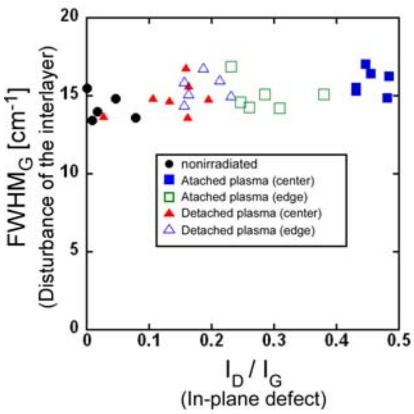

Fig.3. Enlarged diagram of Fig. 5 except for the results of visually dark region and isotropic graphite.

Thus, the dark area seemed to be severely damaged by irradiation with the attached plasma comparing with its margin. Figure 3 shows the enlarged diagram of Fig. 2 excluding the results of the dark area and isotropic graphite. The HOPG irradiated with the attached plasma was observed to have more in-plane defects than that irradiated with the detached plasma. As for the irradiation with the detached plasma, the edge region had particularly in-plane defects. In the same manner as the results from SEM photograph, the HOPG target is likely to be damaged from the edge of a graphene sheet at a low ion incident energy.

4. Discussion

The analysis of hydrogen-carbon interaction has been conducted by MD simulation [3]. It was found that there is an energy barrier of 0.4 eV in the (0001) plane of graphene sheet, while there is no such potential barrier in the edge region of graphene sheet by the energy potential calculation with an MD simulation for a hydrogen atom to be adsorbed onto the graphene sheet. In the attached plasma, the incident ion energy is much higher than the energy barrier. However, the incident ion energy is lower than 0.4 eV in the detached plasma. Thus, in the attached plasma, the incident deuterium ions can pass through the barrier, and most of the deuterium ions might have been reflected before reaching the surface in the detached plasma.

5. Conclusion

We have exposed HOPG specimens to attached and detached plasma and measured by spectroscopy and SEM and Raman spectroscopy. From SEM and Raman spectral analysis results, it was found that the edge region of HOPG was severely damaged, while damages were not observed in the central part. From the results of MD simulation, it was found that there is the energy barrier in (0001) plane. It was suggested that the prediction from the MD simulation results qualitatively agrees with the experimental results for the detached plasma.

Acknowledgments

This work was supported in part by a grant of Knowledge Cluster Initiative (Tokai region) Implemented by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and by the NINS Program for Cross-Disciplinary Study.

References

[1] T. Tanabe, T. Maruyama, M. Iseki, K. Niwase, and H. Atsumi: Fusion Eng. Des. 29(1995) 428.

[2] A. Ito, Y, Wang, S, Irle, K. Morokuma, and H. Nakamura: J. Nucl. Mater. 390-391(2009) 183.