24C02

Revival of Arcing Issue in Fusion Reactors
核融合炉内でのアーキング問題の再来

Shin Kajita, Noriyasu Ohno, Shuichi Takamura, Masayuki Tokitani, Suguru Masuzaki, Naoaki Yoshida, Takaki Hatae, Masakatsu Fukumoto, Kiyoshi Itami, Tomohide Nakano, Yoshio Ueda
梶田信 [1], 大野哲靖 [2], 高村秀一 [3], 時谷政行 [4], 増崎貴 [4], 吉田直亮 [5],
波多江仰紀 [6], 福本正勝 [6], 伊丹潔 [6], 仲野友英 [6], 上田良夫 [7]

[1] *EcoTopia Science Institute, Nagoya University, Nagoya 464-8603, Japan*
[2] *Graduate School of Engineering, Nagoya University, Nagoya 464-8603,*
[3] *Aichi Institute of Technology, Toyota 470-0392, Japan*
[4] *National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu 509-5292, Japan*
[5] *Research Institute for Applied Mechanics, Kyushu University, Fukuoka 816-8580, Japan*
[6] *Japan Atomic Energy Agency, Ibaraki 801-1, Japan*
[7] *Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*
[1] 名古屋大学エコトピア科学研究所　〒464-8603　名古屋市千種区不老町
[2] 名古屋大学工学研究科エネルギー理工学専攻　〒464-8603　名古屋市千種区不老町
[3] 愛知工業大学　〒470-0392　豊田市八草八千草1247
[4] 自然科学研究機構　核融合科学研究所　〒509-5292　岐阜県土岐市下石町322-6
[5] 九州大学応用力学研究所　〒816-8580　福岡県春日市春日公園 6-1
[6] 日本原子力研究開発機構　〒311-0193 茨城県那珂市向山 801-1
[7] 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

Arcing is a long standing plasma-surface interaction issue in nuclear fusion research, and the issue is being revived recently from new points of view. In the linear plasma device NAGDIS-II, the demonstration experiments of arcing/unipolar arcing have been conducted by mimicking the transient heat load using a pulsed laser. The ignition condition of arcing and erosion rate of tungsten accompanied with the arcing are investigated. It is shown that the helium irradiation significantly makes it easier to initiate arcing by the surface morphology change. Actually, in LHD, arcing was initiated on helium irradiated tungsten surface even without transients. From JT-60U, arcing phenomena occurred on baffle plate inside the vacuum vessel and diagnostic mirror outside the vessel are presented.

1. Introduction

After divertor configuration was regarded as a plausible option, arcing phenomena have not been paid attention in fusion research so much, because they were thought to be avoidable and sputtering of material was regarded as the major impurity source. However, recently, arcing issue has been revived from new different points of view: the effects of transient heat loads such as ELMs and disruptions and surface morphology changes caused by plasma irradiation [1]. Indeed, arcs in several tokamaks including ASDEX-U [2] and D-IIID [3] have been reported recently. These observations suggested that arcing could be an important topic in ITER or future fusion devices like DEMO, because the transient heat load will be greater than those in present devices when ELMs occur and irradiation of helium, which will be produced by the nuclear fusion process, may contribute to morphology changes as suggested in many literatures [4-6].

In this paper, we present the Japanese arcing activities in fusion research from a linear divertor simulator, LHD and JT-60U. First, arc tracks observed in the buffle tiles and a diagnostic mirror in JT-60U are presented. Then, the arcing exponents conducted in the linear plasma device NAGDIS-II and LHD are shown in detail.

2. Arc trails observed in JT-60U

Figure 1(a) shows a laser scanning microscope micrograph of the baffle time of JT-60U. It was found that there are many trails that run vertical direction, which is vertical to the magnetic field. From the depth analysis of the surface using the laser microscope, it was found that eroded depth was several tens of micrometers in some parts. It was suspected that massive amount of impurities has been released when the arc was initiated.

Another arcing issue in JT-60U is discharge trails recorded on the diagnostics mirror for laser Thomson scattering. Because the damages were so fatal that the mirror had to be replaced after the breakdown. Details of the characteristics of the damage are investigated from the observation of the trails. It is thought that surface discharge was initiated on the mirror. The phenomena issue warning on the components to be installed in ITER and future fusion devices both inside and outside the vacuum vessel.

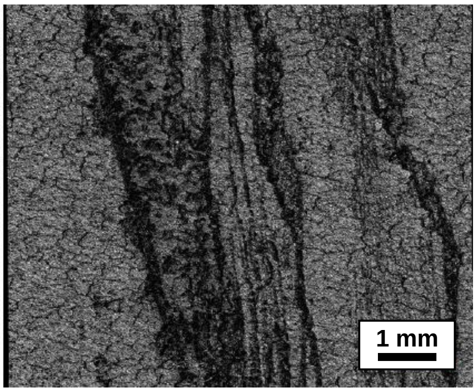

Figure 1: A laser scanning microscope micrograph of carbon baffle plate of JT-60U.

3. Arc demonstration experiments

3.1 In LHD

A tungsten sample was exposed to helium plasma in NAGDIS and the nanostructured sample exposed to the Large Helical Device (LHD) divertor plasma for 2 s. After the exposure to the LHD plasma, arc trails were observed on the surface, as shown in Fig. 2 [7]. Interestingly, the arcing was initiated even without any transients. Because the magnetic field direction was almost normal to the surface, the fractality measured using a box-counting method was almost two, indicating that the motion was similar to the Brownian motion. This results support the fact that the arcing is easily initiated on the nanostructured tungsten surface.

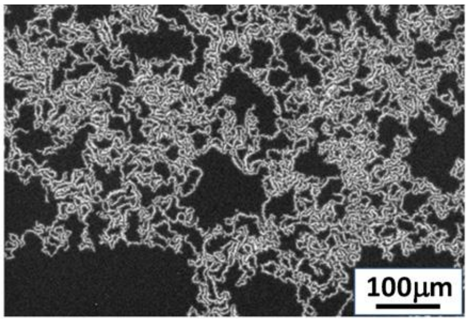

Figure 2: A laser microscope image exposed to the LHD plasma. From ref. [7].

3.2 In linear device NAGDIS-II

The initiation condition and behavior of arc spot was demonstrated in detail in the linear divertor simulator NAGIS-II. To simulate the transient heat load, a pulsed laser with the pulse width of ~0.6 ms irradiates the sample. A W sample was used for the experiments.

Ignition condition of arcing was investigated systematically by changing the laser power, plasma conditions, surface nature, and so on. Arcing was never ignited unless the target was sufficiently biased negatively, say less than -50 V, and one could say that the target voltage is one of the key parameters to control arcing. The helium irradiation changes the surface morphology and makes the ignition of arcing much easier. When the nanostructure was formed on the surface, necessary laser pulse energy to ignite arcing was approximately 0.01 MJm^{-2}, which was several orders of magnitude lower than the heat load accompanied with type-I ELMs in ITER. Thus, it raises a concern that the arcings are also triggered in response to type-II or type-III ELMs in ITER if the nanostructures are formed on the surface.

The cross section of unipolar arc trail recorded on the surface was analyzed with transmission electron microscopy (TEM) using focused ion beam (FIB) milling.

From the cross sectional image, it was found that 33-46% of nanostructured tungsten layer was still remained on the surface for single spot. Roughly, with some assumptions for the spot velocity and mass density of nanostructured tungsten, the eroded tungsten by arcing per second is estimated to be 10 mg. The value will provide a benchmark to assess the influence of arcing in fusion devices. When the spots form a group, the damages were more significant, indicating that the erosion rate would be increased. Detailed investigation of erosion of grouped spots will be a issue for future study.

Acknowledgments

This work was performed as a part of the collaborative research with RIAM Kyushu University. This work was supported in part by a Grant-in-Aid for Young Scientists (A) 23686133.

References

[1] S. Kajita, S. Takamura and N. Ohno 2009 Nucl. Fusion **49** 032002.
[2] V. Rohde, N. Endstrasser, U. Toussaint, M. Balden, T. Lunt, R. Neu, A. Hakola and J. Bucalossi 2011 J. Nucl. Mater. (*in press*).
[3] D. L. Rudakov, *et al.* 2009 LLNL-PROC-410679.
[4] S. Takamura, N. Ohno, D. Nishijima, and S. Kajita 2006 Plasma Fusion Research **1** 51.
[5] M. Baldwin and R. Doerner 2008 Nucl. Fusion **48** 035001.
[6] S. Kajita, W. Sakaguchi, N. Ohno, N. Yoshida and T. Saeki 2009 Nucl. Fusion **49** 095005.
[7] M. Tokitani, S. Kajita, S. Masuzaki, Y. Hirahata, N. Ohno, T. Tanabe and L. E. Group 2011 Nucl. Fusion **51** 102001.