§39. Irradiation Study of the W-fuzz Structure in the LHD Divertor Plasma

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Tungsten is a potential candidate for the divertor armor materials However, serious radiation effects, due to helium irradiation have been reported In particular, growth of a nanometre-sized fibreform structure (W-fuzz) which is easily formed when the temperature is in the range 1000–2000 K, and the incident ion energy of helium is higher than 20 eV [1], would cause undesired problems for fusion plasma. In addition, it was reported that such a fine fibreform structure could make it significantly easier to trigger unipolar arcing and exfoliate some areas of the W-fuzz structure itself [2].

In this study, therefore, a mechanically polished recrystallized tungsten specimen of $20\times10\times1\text{mm}^3$ (A.L.M.T. Corp., Ltd) was pre-exposed to a low-energy helium plasma in the linear divertor simulator (NAGDIS) for creating the W-fuzz structure on the specimen surface. The created W-fuzz specimen was inserted into the divertor leg position through the retractable material probe system, and then, were exposed to the neutral beam injection (NBI) heated hydrogen plasma for 2 s (1shot). T_e, T_i, n_e and the heat flux in the divertor region and the ion flux to the specimens were estimated to be $T_e \sim T_i \sim 20$ eV, $n_e \sim 10^{18}$ m^{-3}, $q \sim 4.2$ MW/m^2 and $\sim 10^{23}$ H/m^{2}s, respectively. The incident ion energy distribution to the specimens must be a shifted-Maxwellian (sheath potential + Ti). Therefore, it was expected that the effective incident energy of hydrogen ions to the specimens was of the order of 100–200 eV. The maximum temperature of the embedded thermocouple was raised up to 421 K. After the exposure, surface morphologies of the W-fuzz layer were observed using a laser microscope, digital microscope and scanning electron microscope (SEM). And then, fractal analysis for the arc trails was conducted using a box-counting method in order to identify the directivity of the arc trails [3].

Fig. 1 shows the laser microscope image. Very fine and complicated arc trails were clearly observed. Such arc trails were observed at least at the area of 6×10 mm^2 on the W-fuzz specimen. This means that arcing was initiated due to the heat flux from the divertor plasma, and then, large scale exfoliation of the W-fuzz layer was caused by sweeping of the arcing spot [4]. It is clear that the arc spot migrated in random motion on the micrometer scale resulting in remarkable erosion of the fuzzy tungsten layer. The typical width and depth of each arc trail were about 8 μm and 1 μm, respectively. If arcing were initiated on the W-fuzz layer, it would be difficult to prevent the large scale erosion and subsequent emission of tungsten to the bulk plasma.

To investigate the characteristics of the migration of an arc spot, the fractal dimension (D) from the arc trails was deduced using a box-counting method [3]. In the case of Fig, 1, D was estimated to be $D \approx 1.922$. It was very close to $D = 2$. A fractal dimension of $D = 2$ corresponds to the value of Brownian motion, indicating no effect of the magnetic field, while $D = 1$ corresponds to the linear motion, indicating the effect of the magnetic field. Therefore, Fig. 1 indicates that the arc spot motion was Brownian like motion (not linear motion). Since the magnetic field lines to the divertor leg were completely normal to the surface of the specimen, the arc spot motion was not influenced by the magnetic field. While, when the case of the magnetic field line to the surface was shallow (5°), the spot moved with the quite linear motion as shown in Fig. 2.

When an arc spot moves like Brownian motion and the lifetime of the arc spot becomes sufficiently long, the exfoliation area of the W-fuzz may become larger than that of the linear motion.

[1] S. Kajita et al 2009 Nucl. Fusion 49 095005
[2] S. Kajita et al 2009 Nucl. Fusion 49 032002
[3] S. Kajita et al 2010 J. Phys. Soc. Japan 79 054501
[4] S. Kajita et al 2009 Phys. Lett. A 373 4723–277

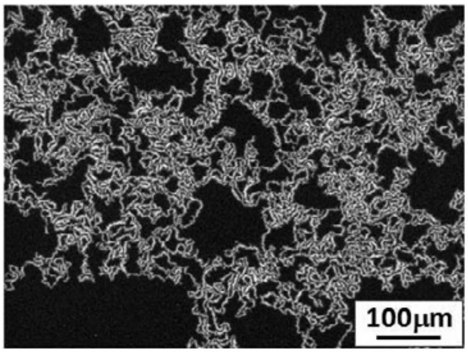

Fig. 1. Laser microscope image of the W-fuzz surface after exposed to the LHD divertor plasma.

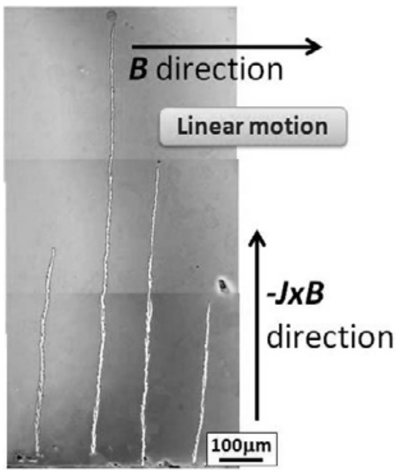

Fig. 2. Digital microscope image of the unipolar arc trail exposed to the LHD divertor plasma. The incident angle of the magnetic field line to the specimen surface was 5°.