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Formation of W droplets splashing by pulsed heat flux irradiation using the SPICA plasma gun

SPICAプラズマガンを使ったパルス高熱負荷照射によるW材料の溶融と飛散

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Compact Toroid (CT) injector can eject a high-dense CT plasmoid at a speed up to a few hundred km/s. By taking the advantage of CT injector, the SPICA injector has been employed as a plasma simulator for heat flux tests on R&D of ITER plasma facing components. SPICA accelerates a CT plasmoid to 100 km/s with a density up to 1×10^{22} m^{-3} at the muzzle. In the plasma exposure test on a pure tungsten plate, W melting and droplet splashing has been successfully generated.

1. Introduction

On R&D of ITER plasma facing components (PFCs), Heat flux tests of PFCs should be conducted under realistic plasma parameters and conditions simulating transient events such as Type I edge localized modes (ELMs) and disruptions events in ITER. The ELM heat loads on the divertor plate in ITER are estimated to be 0.2–2 MJ/m^2 for each event during 0.1–0.2 ms. It is difficult to achieve the typical conditions for the transient events by using electron/ion beams for the damage tests and also plasma simulators as static heat flux sources.

We have proposed to employ a magnetized coaxial plasma gun (MCPG) as a plasma simulator for material damage tests. A MCPG has been developed as a Compact Toroid (CT) injector for advanced fueling in fusion reactors since the late 1980s. It has high performance to produce a CT plasmoid at a speed of a few hundred km/s and a density up to the order of 10^{22} m^{-3}. The CT injector can be employed as a powerful transient heat load simulator for material damage tests required in ITER [1,2]. The high pulsed heat flux will damage the divertor materials leading to surface evaporation, cracking, melting, boiling and droplet splashing. The ablation rate is much lower than that on the laser- or electron-beam irradiated materials because of the vapor shielding effect [3]. The CT injector thus has suitable ability to incorporate the resultant shielding effect in erosion simulation of ELMs/disruptions, compared with laser- or electron-beam facilities. In preliminary tests at University of Hyogo, the MCPG has been found to have enough performance to simulate for the ITER relevant high heat flux conditions.

We have recently employed the CT injector of SPICA (SPheromak Injector using Conical Accelerator), which is developed for advanced fueling in LHD, as a plasma simulator. In the experiment, we have tested pure tungsten samples (cold-rolled W plate: 2 mm and 3 mm in thickness) and the vacuum plasma spray (VPS) W coated graphite for the divertor in LHD.

2. Experiment setup

We have exposed a test sample to a CT plasmoid ejected from the SPICA injector as shown in Fig.1. The original SPICA had two-stage coaxial electrodes for CT formation and acceleration. It has, however, been operated as a single-stage CT injector with connecting only the acceleration bank unit to the outer and both inner electrodes for easy operation and maintenance of the injector and its power supplies. In the electrode configuration, SPICA accelerates a CT plasmoid to 100 km/s with a density up to 1×10^{22} m^{-3} at the muzzle. Test samples are placed at the axial distance of z=5 mm or 12 mm away from the tip of the accelerator inner electrode in the target chamber. The exposure duration is ~0.016

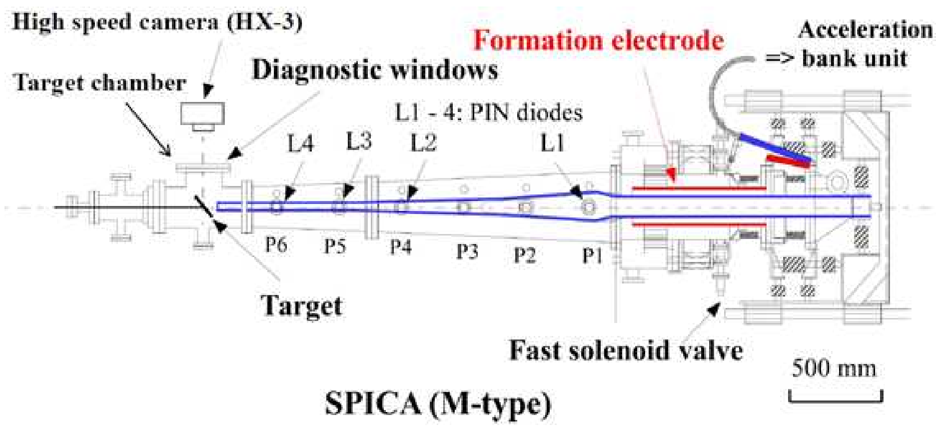

Fig.1 Schematic view of the SPICA injector as a plasma simulator.

ms and the peak current for CT acceleration is 200-300 kA at the charging voltage of 15-23 kV. The peaked absorbed energy density at z=30 mm is 1.9 MJ/m^2, which is measured with a graphite calorimeter.

3. Experimental results

In the plasma exposure test for pure W plates, W droplet splashing/ejection on the target plate has been observed by using high speed cameras (NAC Image Tech.: HX-3 and Photron: FASTCAM SA4). Figure 2 shows a single flame in a movie of W droplet splashing. The white pattern in the picture indicates that droplets are splashing and some of them are flying toward the left side during and after the plasma impact. The droplet speed is about 28 m/s. On the W plate surface after the plasma exposure with 68 pulses, the spot size of a damaged area becomes roughly 30mm x 40 mm. Traces of coagulation of melting W and bridging of gaps due to melt motion are confirmed.

In the test for a VPS-W, the surface damage has been observed. The thin W layer partially exfoliates and then upheaves, ultimately cracks due to plasma attack. FE-SEM analysis indicates that many flaking spots occur on the highly heated area. This leads to the surface temperature up to 2000-3000℃.

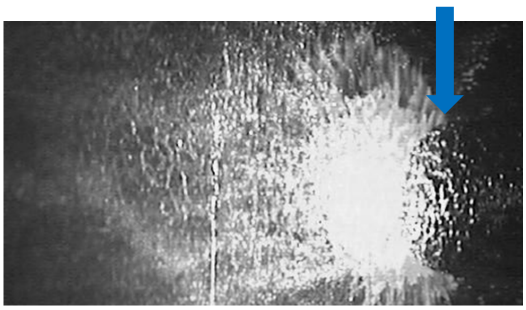

Fig. 2. W droplet splashing on a W plate.
(a single flame in a movie taken by using the high speed camera (HX-3))

4. Conclusions

Hear flux test has been carried out by using the CT injector of SPICA. In the test W melting and droplet splashing has been successfully generated. It is experimentally proven that SPICA can be employed as a high-performance pulsed plasma simulator on R&D of ITER PFCs. We have prepared to survey specifications of SPICA as a plasma simulator and current fed into a target plate from the tip of the inner electrode, and have designed the equipment to apply an external magnetic field on the target plate. We intend to investigate behavior of W melting and droplet splashing in a magnetic field. In the conference, we will also report about the new result and the future work.

Acknowledgments

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