§16. Development of CT Injection and Neutralization Technology towards Pulse Heat Flux Material Tests

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Plasma facing materials (PFMs) in large fusion devices like ITER are exposed to not only steady state heat loads of up to 20 MWm^{-2} but also transient heat loads of up to $1GWm^{-2}$ especially in the divertor region. Transient heat flux tests for performance of ITER tungsten (W) are required to be investigated 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 in ITER are expected to be 0.2–2 MJ/m^2 during 0.1–0.2 ms on the divertor plate during each event. The conditions typical for their transient events are difficult to achieve in electron/ion beams and plasma simulators which are used as static heat flux sources for the damage tests. The Compact Toroid (CT) injector is applicable as powerful transient heat load simulators satisfied ITER requirements for material damage tests. The high pulsed heat flux produced by coaxial plasma guns will damage the divertor materials leading to surface evaporation, cracking, melting, boiling and droplet ejection. The ablation rate is much lower than that found using lasers and electron beams due to the vapor shielding effect. Thus, when compared with laser or electron beams facilities, the plasma guns have suitable facilities to incorporate the shielding effect into erosion simulation of the ELMs/disruptions. Earlier tests with the magnetized coaxial plasma gun at University of Hyogo showed enough test capacity to simulate for the ITER relevant high heat flux conditions.

We have recently performed ELM transient W melting experiments by using SPICA (SPheromak Injector using Conical Accelerator) plasma gun device which is located in NIFS as shown by Fig.1. In this experiment, we have tested pure tungsten plate samples (thickness 2 mm and 3 mm) and the vacuum plasma spray (VPS) W coated graphite plate used at the divertor in LHD. These test samples in the target chamber are placed at the axial distance of z=5 mm or 12 mm away from the tip of accelerator inner electrode.

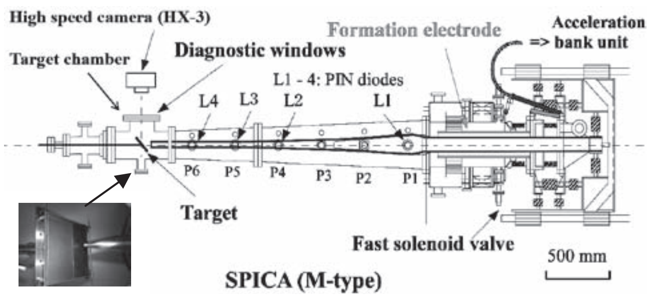

Fig.1 Schematic view of the ELM-PWI simulator by SPICA.

The exposure duration is ~0.016 ms and the peak gun current is 200-300 kA at the charging voltage of 15-23 kV. The peaked absorbed energy density is 1.9 MJ/m^2 at z=30 mm which is measured with a graphite calorimeter. In this experiment, the external magnetic fields are not applied.

Figure 2 shows a damaged area (spot size 30x40 mm) on the W plate surface after the plasma exposure with 68 pulses. W can see traces of coagulation of meting W and bridging of gaps due to melt motion. Figure 3 shows the first observation of W droplet splashing (ejection) on the W target by using a high speed camera (NAC Image Tech.: HX-3). Note that the pattern of white lines on the pictures indicates that the droplet is flying toward the left side during and after the plasma impact. The droplet speed is about 28 m/s. Figure 4 shows dynamics of the surface damage of the VPS-W. We can see that the W layer heaves at t=200 μs and then cracking occurs by t=300 μs. FE-SEM analysis shows that there are many flaking spots on the highly heated area of the damaged W layer. Thus, it is found that the surface temperature increases up to 2000-3000℃.

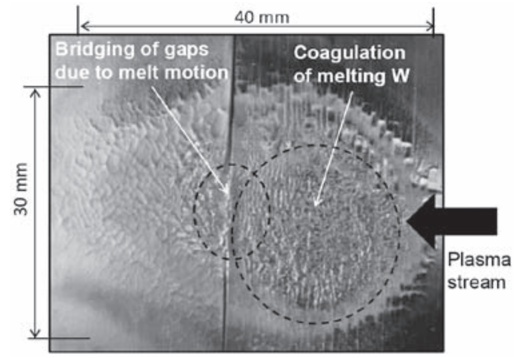

Fig. 2. Surface morphology of melting W sample.

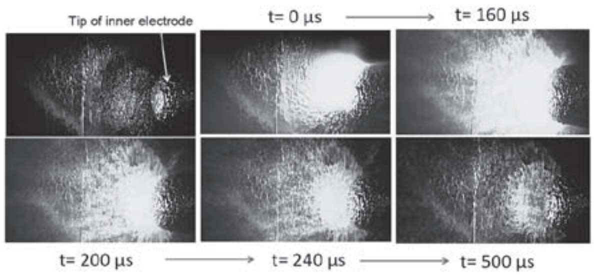

Fig. 3. Fast camera images shows W droplet ejection.

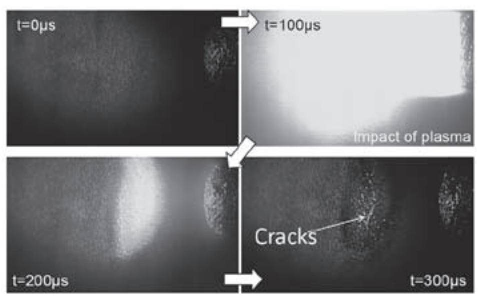

Fig. 4. Fast camera images shows occurrence of heave and crack of the VPS-W layer after plasma impact.