SI-5

慣性炉チェンバーに於けるPWIと高繰り返しペレット爆縮
PWI & High Repetition Pellet Implosions in IFE chamber

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In IFE reactors, the inner wall surface could be exposed to a rather high thermal flux stemming from nuclear fusion reactions. The thermal flux consists of high energy (several 100 keV to MeV) H, C, He ions as well as neutrons. Since these particles come onto the wall within a micro second order, the thermal flux intensity can be as high as 10^9 W/cm^2. This intensity is close or beyond the material ablation threshold resulting in the wall surface melting or ablation. Testing this whole process is essential to understand the mechanisms and characteristics of ablation and subsequent plasma plume and possibly aerosol formation. If we replace this ion thermal flux to laser flux, laser system can deliver almost any level of intensity and energy densities from 100 W/cm^2 to 10^{14} W/cm2 or 10^{-3} J/cm^2 to 1 kJ/cm^2. These numbers can be controlled relatively easily to test the ablation and evaporation processes of basically any target wall materials. Using ultra-intense laser system, we can even create 10 MeV proton beam with a psec pulse duration which can be used to test the material damage with ion beam[1]

In our study, 1J blue laser beam is split into two beams with equal energy to irradiate two concave shape solid targets with a mm wide line focusing (0.1 mm width). The laser wave length is 351 nm, repetition rate is 10 Hz, and pulse width is 6 nsec. The focused laser intensity can cover 10^7 W/cm2 to 10^{12} W/cm^2 while the energy density varies from 0.1 J/cm2 to 50 J/cm^2. When carbon targets are used the plumes show temperature around 1 to 10 eV and plasma density around 10^{11} to 10^{12}/c.c. for single and double plumes measured at 1.3 cm away from the target surface. Only one laser beam is used for the single plume case while the two laser beams are used for the double plume cases. The experimental configuration is shown in Fig. 1. The double plumes collide and stagnate at the crossing point at 1.3 cm away from the target.
The plume moving speed is 10 km/sec.
The process appears to be led by Carbon ion collisions based on our particle simulation [2].

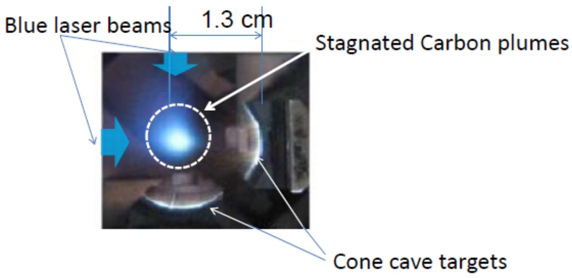

Fig. 1 Experimental Configuration
Two soli targets with cone cave shape are irradiated with two blue laser beams. The ablated plumes cross each other at 1.3 cm.

The simulation has been conducted using a Direct Simulation Monte Carlo method. The model simulation has assumed 10^6 cells with 5x 10^5 particles of ions or neutral particles within a 3 cm cubic box.

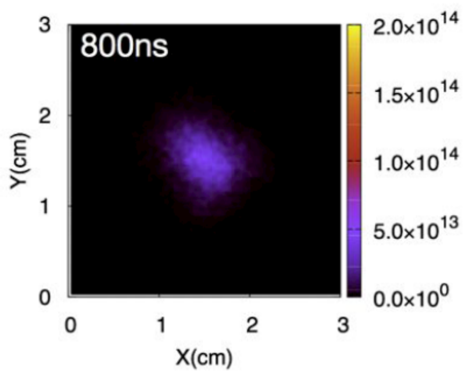

Fig. 2 DSMS simulation shows close similarity to the observation.

The stagnated carbon plumes result in carbon large molecules such as nano tube formation [3]. Actually created are onion, carbon nano-tubes, etc. as shown in Fig. 3. These created carbon products actually aviate much longer than the plasma plume life time which has been measured with another laser probe beam using a scattering techniques.

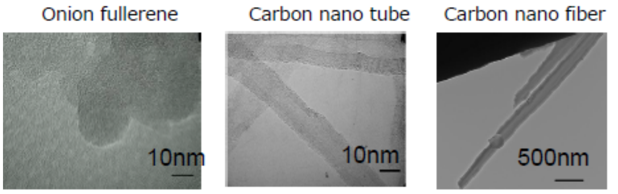

Fig.3 Carbon molecular products recovered from the plasma plume collision and stagnation.

The life time of these products are peaked at 3 micro seconds with roughly 2 microsecond life time after the laser pulse irradiation while the plasma plume peak emission comes at around 2 microseconds.

The collision and stagnation has been tested for other materials such as W, Al, and Mo.

If we take into account the fraction of ionization, average Coulomb collision frequency is,

$$\overline{\nu_{\alpha\beta}} \propto \frac{\overline{Z_\alpha^2 Z_\beta^2} n_\mathrm{L} \ln \Lambda}{m_{\alpha\beta}^2 u_{\alpha\beta}^3}$$

The efficiency of collision can be expressed as "Shield rate". The shield rate is defined as the ratio of transmitted particles of one plasma plume through the second plume crossing normal to the first one to the particles directly counted without the secondary plume (namely single plume). The shield rate is plotted for Carbon, Aluminum, Mlybdenum, and Tungsten materials in Fig. 4.

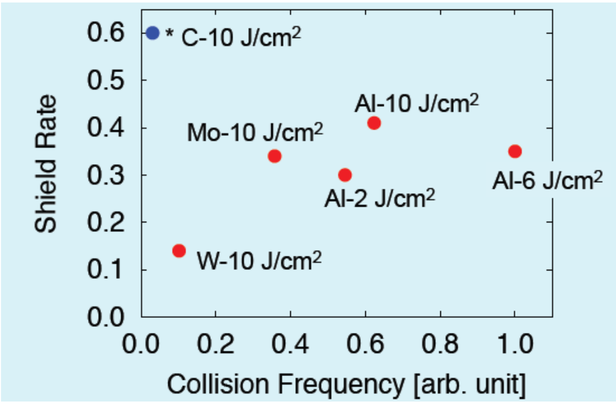

Fig. 4. Shield rate vs. collision frequency Target materials are Aluminum, Carbon, Mlybdenum, and Tungsten. The number/cm^2 indicates the laser energy density.

Figure 4 indicates that the collision efficiency is linearly proportional to the collision frequency. The carbon is an exception showing 60 % of shield rate. This high number of C should be related to the molecular formation processes which are not applicable to the metal materials.

In recent theoretical study, another possible issue is indicated as afterglow plasma evolution in IFE chamber [4]. The averaged residual gas densities from the target reactions only could reach as high as 10^{15} /cm^3. Cryogenic targets could survive from the black body radiation heating only if the gas density is below 3 x 10^{13} /cm^3. This new issue could be studied in an independent experimental platform as proposed here.

In a summary, experimental platform based on laser systems can be a versatile tool[5] to study the ablation or evaporation from the inner wall surface of IFE reactors. Our recent studies show ablated plasma plumes can collide and stagnate at the crossing point. In the carbon plasma case, the collision is effective more than the other metal targets. As a result of collision and stagnation, the carbon case shows efficient molecular formation such as carbon-nano tubes etc.

Reference

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