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Particle Simulations for Plasma-Plasma Intersecting Experiments
粒子シミュレーションを用いたプラズマ交差実験の挙動解析

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Experiment is conducted on the intersections of two plasma plumes created by laser ablation. In our experiments, a clear material dependence has been found clearly in the visible light emission from the intersecting plumes. Two carbon plumes merge each other after the intersection. However, tungsten plume just passes through in another tungsten plume. We have developed a particle simulation code to understand the physics of the plume intersections. The results show that the plume collisions strongly depend on the plasma density, ionization fraction and material mass.

1. Introduction

Walls in a laser fusion reactor could be ablated by exposure of high energy materials such as x-rays and pellet debris from fuel DT-pellet implosions. Ablated plasma plumes from reactor walls may expand toward the center of the reactor and may collide or stagnate with each other.

To study the behavior of these plasma plumes, we have conducted experiments on the intersections of two plasma plumes created by laser ablation[1, 2]. Figure 1 shows the experimental setup. A laser beam from one Nd: YAG laser (3ω, 355 ns, 6 ns, 10 Hz) is split into two separate beams with an equal power. Line-focused two laser beams irradiate solid targets. We have observed the temporal evolution of plasma emission with an intensified CCD (ICCD) camera. Figure 2 shows the results of ICCD observations. The behavior of plasma emission after the intersection of two plasma plumes changes between tungsten and carbon. We have developed a particle simulation code to understand the physics of the plasma plume intersections.

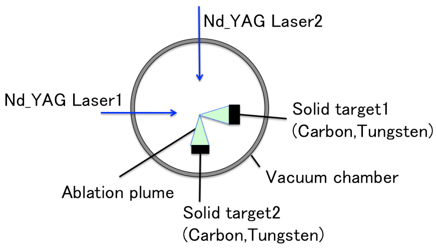

Fig.1 A schematic diagram of the experimental setup [1].

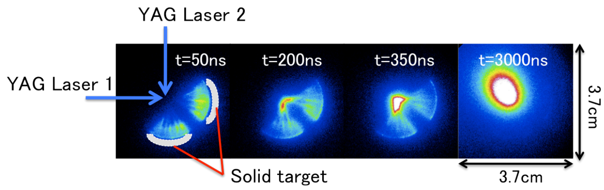

Fig.2 Examples of the ICCD observations from the top of the vacuum chamber. Emission of plasma plumes moves to the synthetic diagonal direction after the intersection[3].

2. Particle Simulation Code

The code developed in this study uses the direct simulation Monte-Carlo (DSMC) method and coulomb collision model[4, 5] to simulate the plume intersections. The plume plasma density is estimated to be 10^{13}~10^{15} cm^{-3} at the intersection point from measurements with a Langmuir probe and also results of hydrodynamics calculations. Since the density is low, the intersecting phenomena can be simulated with a particle code. In our code, neutral-neutral, neutral-ion and ion-ion collisions are considered. All collisions are completely elastic collisions. We conducted simulations with various initial particle densities (from 10^{13} cm^{-3} to 10^{15} cm^{-3}) to compare with our experimental results. The initial temperature of ion and neutral particles was changed from 0.1 eV to 1 eV. The fraction of ion species was estimated based on the corona equilibrium[6, 7].

Figure 3 shows the simulation setup. Two groups of particles mimic the two intersecting plasma plumes. The plume intersections of carbon plumes and tungsten plumes were considered. The velocity of plumes is given by the summation of the thermal velocity and a drift velocity. The drift velocities, which are determined by ICCD observations, are 2.9×10^6 cm/s in the carbon case and 1.1×10^6 cm/s in the tungsten case. Our simulations are in three dimension and the particles groups have 0.5 cm thickness in z direction. We set two observation areas(A1 and A2) to count the number of particles that come through the areas.

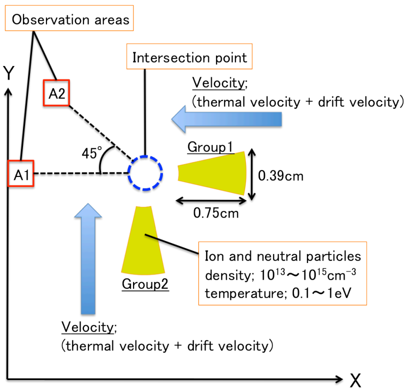

Fig.3 Simulation setup

3. Results and Discussion

Examples of simulation results are shown in Figs.4(a) and 4(b). In Fig.4(a), most tungsten particles do not collide with each other at the intersection point and two particles groups go through without changing their directionality. In Fig.4(b), two carbon particles collide with each other at the intersection point. After the intersection, the directionality of two particles groups are changed and they move to the synthetic diagonal direction. Table 1 summarizes simulation results. The values shown in table 1 are the ratio of the number of particles that come through the area A1 and A2 in calculation time. When the value is beyond 1, it means that the particles go to the A2 direction are more than that of the A1 directions.

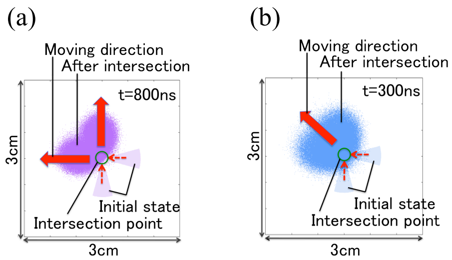

Fig.4 (a)Tungsten case (b)Carbon case, (the particle density is 10^{15} cm^{-3}, the temperature is 1 eV)

Table.1 Result table

(a)Te=0.1eV (=Ti)	Particle density(cm^{-3})			Ionization fraction
	10^{13}	10^{14}	10^{15}	
Tungsten	0.0017	0.021	**1.36**	0(neutral)
Carbon	0.0010	0.020	0.91	0(neutral)

(b)Te=1eV (=Ti)	Particle density(cm^{-3})			Ionization fraction
	10^{13}	10^{14}	10^{15}	
Tungsten	0	0	0.19	1
Carbon	0.0011	0.0056	**1.40**	0.8

The results show that the plume collisions strongly depend on the density, ionization fraction and material mass. Comparison of the results with ICCD images shows that the experimental plasma densities are considered 10^{15} cm^{-3} in carbon case by neutral-neutral or ion-ion elastic collision. In tungsten case, plasma plumes may collide with the density more than 10^{15} cm^{-3} by neutral-neutral elastic collision.

4.Summary

Particle simulations about plasma intersecting experiments have been performed. The result shows that the plume collisions strongly depend on the density, ionization fraction and material mass. From the elastic collision model, the experimental plasma densities are considered 10^{15} cm^{-3} in carbon case, and plumes may collide with the density more than 10^{15} cm^{-3} in tungsten case.

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Reference

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