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# Laboratory simulation experiments on the aerosol formation and hydrogen co-deposition in a high repetition rate inertial fusion reactor
高繰り返し慣性炉内エアロゾル形成と水素共体積の模擬実験

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In a high-repetition rate inertial fusion reactor, along with pellet implosions, the interior of a target chamber is to be exposed to high-energy, short pulses of X-ray, unburned DT and He ash particles and pellet debris. As a result, wall materials will be subject to ablation, ejecting particles in the plasma state to collide with each other in the center of volume. The interaction dynamics of ablation plasmas of lithium and lead, candidate first wall materials, has been investigated in the deposited energy density range from 3 to 10J/cm$^2$/pulse at a repetition rate of 10Hz, each 6ns long. The plasma density and electron temperature of colliding ablation plumes have been found to vary from the order of $10^8$ to $10^{13}$1/cm$^3$ and from 0.7 to 4eV, respectively. The formation of aerosol in the form of droplet has been observed with diameters between 10nm and 10μm. Hydrogen co-deposition has been found to occur particularly for colliding plumes of lithium, resulting in the H/Li atomic ratio varying from 0.15 to 0.27 in the hydrogen partial pressure range from 10 to 50Pa.

## 1. Introduction

Following the recent 192-beam experiments at the National Ignition Facility (NIF) [1], much attention has been directed towards the next step to design a DEMO ICF reactor with a reasonably high repetition rate of implosion (e.g. 10Hz [2]). However, it is required that the target chamber be cleared immediately after every implosion so as not to affect the subsequent shot, which may not readily be done for the following reason.

Along with pellet implosions, the interior of target chamber is repeatedly exposed to intense pulses of DT-fusion neutrons, X-rays, unburned fuel particles, He-ash and pellet debris, perhaps in the form of $C_xH_y$, the total power of which amounts to the order of 10J/cm$^2$/pulse [3]. As a result, wall materials will be subject to ablation, ejecting particles mostly in the plasma state. Ablated particles will either be re-deposited elsewhere on the wall or collide with each other in the center-of-symmetry region, if any, of the target chamber. Colliding ablation plasma particles may lead to the formation of clusters which can grow into aerosol, possibly floating thereafter. Also, it is predictable that tritium be incorporated into re-deposited materials, which would then affect the ICF reactor operation scenario, depending upon the on-site radiation safety regulation. Despite their critical importance, the chamber clearing and hydrogen co-deposition issues have not widely been addressed in the inertial fusion research community.

In our previous work, first-of-a-kind laboratory experiments on colliding ablation plasma plumes were conducted for selected materials in order to investigate the fundamental aspects of cluster/aerosol formation [4]. More recently, it has been reported that hydrogen can be co-deposited with colliding ablation plasma plumes of carbon up to the atomic ratio of (H/C), reaching the order of 0.1 [5]. The present work is intended to study these issues associated with lithium and lead, the eutectic alloy ($Li_{17}Pb_{83}$) of which is currently envisaged to be used as the liquid metal to protect the target chamber wall [6].

## 2. Experimental

Used in the present work is a setup, referred to as the Laboratory Experiments on Aerosol Formation by Colliding Ablation Plumes (LEAF-CAP), the details of which have already been presented elsewhere [4]. For completeness, the important features are described here again. A 3ω-converted YAG laser with a pulse length of 6ns and a repetition rate of

10Hz is split into two equal-power beams, each line-focused to an area of about 0.1cm by 1cm, to irradiate two arc-shaped targets positioned in vacuum $\leq 10^{-3}$Pa such that ablation plasma plumes collide with each other in the center-of-arc (CoA) region. The laser power density is varied between 2 and 10J/cm$^2$/pulse, relevant to the inertial fusion reactor situation [3].

A variety of techniques are employed to diagnose colliding plasma plumes in real-time, including CCD and ICCD cameras, quadrupole mass analyzer, visible spectrometer, Langmuir probe, and quartz crystal film thickness monitor. Also, ablated material deposits are analyzed after-the-fact with optical microscopy for surface characterizations, and with thermal desorption spectrometry (TDS) for hydrogen retention measurements in a separate system. Selected up to present in the LEAF-CAP series of experiments as the target materials have been copper, aluminum, tungsten, carbon (isotropic graphite), lead, and lithium. In the present paper, unless it is for a comparative purpose, the results from lithium and lead experiments will be described in detail.

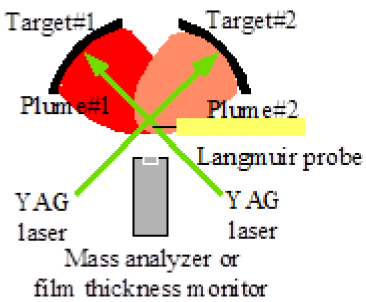


Fig. 1 A schematic diagram of the LEAF-CAP setup [4].

## 3. Results and discussion

Shown in Fig. 2 are aerosol particles collected for about 1 hour, i.e. ~3.6 x $10^4$ pulses, on Pyrex glass substrates replacing the mass analyzer in the LEAF-CAP setup (see Fig. 1). As can be seen, aerosol particles are generally in the form of droplet, the diameter of which ranges from the order of 100nm to 10μm. Colliding Li-Pb plumes appear to have produced droplets with the smallest diameter.

Similar aerosol formation experiments have been conducted at hydrogen partial pressures from 10 to 50Pa, relevant to reactor conditions. Selected thermal desorption spectra, taken from Li-Li+H co-deposits, are shown in Fig. 3. The atomic ratio of H/Li has been found to reach ~0.3, close to that of H/C measured under the identical conditions in the LEAF-CAP setup in our recent work [5].

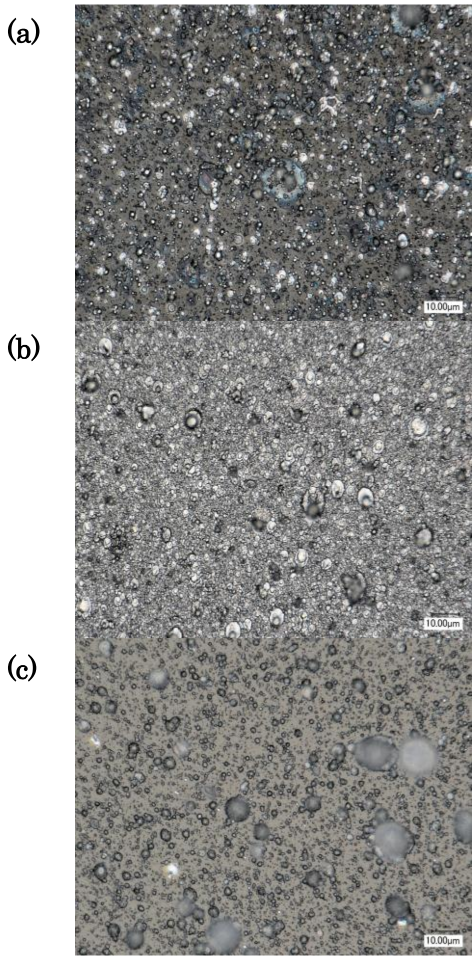


Fig. 2 Aerosol particles generated by colliding ablation plumes for (a) Li-Pb, (b) Pb-Pb and (c) Li-Li target combinations on Pyrex glass substrates.

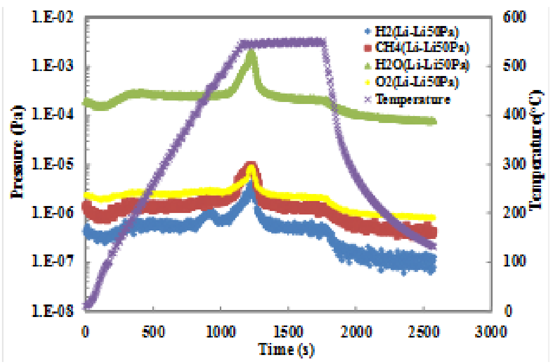


Fig. 3 TDS data taken from Li-Li+H codeposits.

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