IMPACT-INDUCED MELT DROPLETS CREATED BY HYPERVELOCITY IMPACT EXPERIMENTS USING A LASER GUN.
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Introduction: A hypervelocity impact at large impact velocities generates an impact-induced vapor cloud and melt droplets [e.g., 1]. The impact-induced melt droplets had played important roles in topics of planetary science. Spherule layers, such as K/Pg boundary layer, are thought to be made from the impact-induced melt droplets and work as a good geological indicator of impacts [e.g., 2]. Previous studies show that the impact-induced melt droplets are tightly related to impact-induced environmental perturbations and the K/Pg mass extinction: severe atmospheric heating during reentering [e.g., 3], sunlight blockage as atmospheric aerosol [e.g., 4], scavenging sulfuric acid aerosols which results in rapid falling of sulfuric acid rain and ocean acidification [5], contribution to chemical reactions in the impact-induced vapor plume [6], and neutralizing of acid rain in fresh water and shallow sea [7]. Additionally, the size and condition of impacts can be estimated from the properties of spherule layers [8]. Melt droplets created by giant impacts are considered as a candidate of the origin of chondrules [9] and have been observed outside the solar system [10].

However, the physics and chemistry of the formation of impact-induced melt droplets are poorly understood. Although some previous studies propose theoretical modeling of the formation of impact-induced melt droplets for large-size natural impacts [e.g., 1], the models have not been confirmed by actual impact experiments in laboratories. Impact-induced melt droplets have not been created and analyzed in laboratory experiments, because of experimental difficulties. Here, we introduce a new experimental method to create impact-induced melt droplets by actual impacts in the laboratory using a laser gun. We also show the initial results of the analysis: the size distributions and chemical composition of impact-induced melt droplets.

Experimental Methods: Figure 1 shows the experimental setup of this study. We accelerate Ta flyer foil using a large powered and high speed laser gun (GEKKO XII-HIPER facility of Institute of Laser Engineering of Osaka University. Details of the flyer acceleration method are shown in Kadono et al. [11].). The flyer and the target sample are set in a large vacuum chamber and on a low pressure condition ($<10^{-3}$ mbar) before the shot. We irradiated a laser pulse (1054nm, 10-20ns, ~2 kJ) on a 50 μm-thick plastic ablator, which is set in front of a 30 μm-thick tantalum flyer. The ablator is vaporized by the laser pulse and the generated high temperature vapor accelerates the flyer to the target. Then the flyer impacts on a pressed powder pellet target. We pressed a mixture of $CaCO_3$ and $MgSO_4$ powder samples tightly to form the powder pellet target. A 200 μm-thick gold spacer is set between the flyer and the tightly pressed powder pellet target.

The created impact-induced melt droplets are collected on glass witness plates, which are set in a hollow aluminum sphere. The impact-induced melt droplets collected on the glass witness plates are observed using a scanning electron microscope (SEM) to analyze the size distributions and chemical compositions. The chemical compositions of the impact-induced vapor plumes were also measured directly using a quadrupole mass spectrometer (QMS). We introduce the released gasses to the QMS through a SUS inhalation tube. We use a hollow aluminum sphere in order to avoid dispersion of the released gas to the vacuum chamber and to improve the S/N ratio of the QMS analysis. Details of the experimental system of gas analysis are described by Ohno et al. [5].

Results and Discussion: Figure 2 shows an example of the SEM image of the impact-induced melt droplets collected on the glass witness plate. We found a lot of various sized melt droplets, which collided and adhered on the glass witness plate.

We counted the number and measure the area of the melt droplets in SEM images to generate size distributions of the impact-induced melt droplets. Figure 3 shows an example of the size distribution: the cumulative numbers of the melt droplets are plotted as a function of the area in the SEM image. The size distributions of the impact-induced melt droplets may be different from the exponential distribution, which is created by breaking up of liquid droplets in high velocity gas flow [12]. The size distributions obtained in this study can be fitted as power functions with a bend around 100 μm^2 in area in the SEM image. The numbers of the melt droplets are small at the sizes of smaller than 1μm. This decrease can be related to the formation mechanism of the droplets, although this would be affected by the detection limit and prevention of impaction on the witness plate by impact-induced vapor.

We also analyzed the elemental compositions of the melt droplets. The chemical compositions of melt droplets are not uniform, but the most of the melt droplets are dominated by mixtures of MgO and CaO and not abundant in sulfur. It indicates that the majority of the sulfur of $MgSO_4$ in the initial target have been devolatilized and released as SO_3. We also observe SO_3 gas directly using the QMS measurements in the same experimental run, indicating devolatilization of $MgSO_4$ and SO_3 release. On the other hand, we found some melt droplets which have almost pure $CaSO_4$ composition. These melt droplets indicate that chemical reaction of SO_3 gas with CaO would have been partially occurred and formed $CaSO_4$ in the impact-induced vapor plume, because the starting material (a mixture of $CaCO_3$ and $MgSO_4$) does not contain $CaSO_4$.

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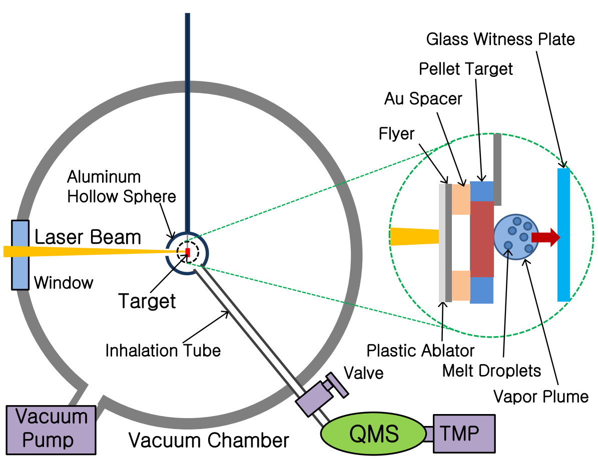

Figure 1: A schematic diagram of the experimental system. Details of the flyer acceleration method are shown in Kadono et al. [XX] and details of the experimental system of gas analysis are shown in Ohno et al. [2014a].

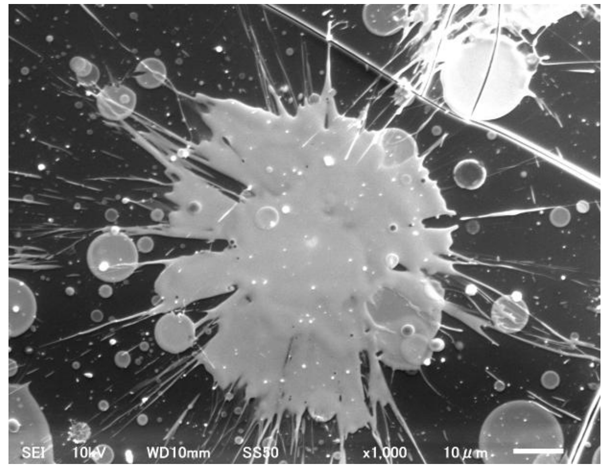

Figure 2: An example of the SEM image of the collected impact-induced melt droplets.

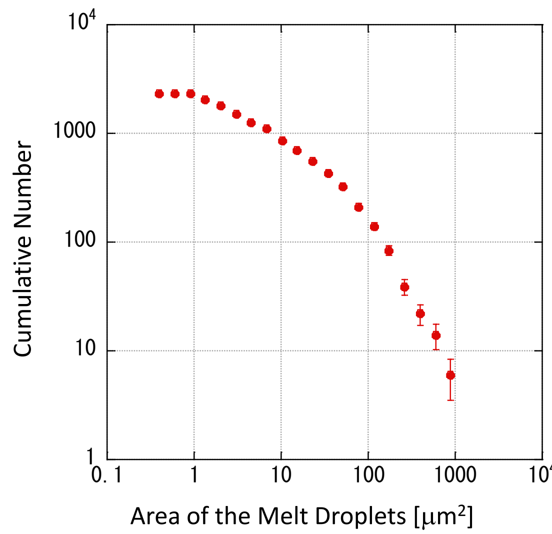

Figure 3: An example of the size distribution of melt droplets obtained from a SEM image of the collected impact-induced melt droplets.