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Flyer acceleration using high-power laser and impact experiments at velocities 10-60 km/s

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Abstract

Impact velocity of meteorites on planetary and satellite surfaces at the final stage of planetary accretion becomes more than 10 km/s. However, the details of the effects by such impacts on the environments have not been understood well yet. The reasons are probably that macroscopic (> ~ 0.1 mm) flyers are not easily accelerated to more than 10 km/s in laboratories. This makes it difficult to investigate experimentally the impact phenomenon with impact velocities higher than 10 km/s. In this presentation, we show that, using a high-power laser, higher impact velocities than 10 km/s can be achieved using sheet flyers with a diameter of ~ 0.5 mm and a thickness of ~ 50 μm and spherical projectiles with a diameter of 0.1 - 0.3 mm.

1. Introduction

The average impact velocities of asteroids on Earth and other terrestrial planets at the final stage of planetary accretion are estimated to be higher than 10 km/s. The impacts with velocities higher than 10 km/s generate very large craters and a large amount of silicate vapor, melt, and fast ejecta, and would make great effects on the planetary surface environments. However, macroscopic (> ~ 0.1 mm) flyers are not easily accelerated to more than 10 km/s in laboratories.

One possible method for velocities larger than ~ 10 km/s is the irradiation of high-intensity lasers. We have applied this technique to the case of projectiles with an aspect ratio of ~ 1 and have obtained some results [1-3]. Here, we describe the additional data of glass and aluminum (Al) spheres and tantalum (Ta) sheet flyers acceleration experiments over velocities higher than 10 km/s.

2. Experiment

GEKKO XII - HIPER laser at Institute of Laser Engineering, Osaka University (~ 0.8 - 5 kJ and ~ 10 - 20 ns) was used to accelerate flyers. For spherical projectiles, glass and Al spheres with a size of 0.1 - 0.3 mm were irradiated. A very thin surface of the projectiles vaporized and became high density and temperature plasma. This accelerated the projectiles. For sheet flyers, Ta sheets of ~ 0.5 mm in diameter and 50 μm in thickness attached by plastic (CH) layers with a thickness of ~ 50 μm as fuel were used. Laser irradiated CH layer and ablation plasma of CH accelerated Ta sheets. We observed the acceleration process using an x-ray streak camera. Schematic view of the experiments is shown in Fig. 1.

3. Results

Figure 2 shows an image obtained by the streak camera. Time proceeds from top to bottom. Full scale indicates 20.5 ns. An Al projectile with a diameter of 110 mm is irradiated from right. The scale of space in the figures indicates the projectile diameter, 110 μm. We can observe self-luminous emission from ablation plasma on the right-hand side of the projectile. We trace the positions of the laser irradiation surface as a function of time, and obtain the velocity of projectile. The estimated final velocity in this shot is 45 km/s.

Figure 3 shows the final velocity v of projectiles as a function of laser energy E normalized by projectile mass m_p, $2E/m_p$. If a constant fraction k of laser energy is transferred to the kinetic energy of projectiles, v should vary with $2E/m_p$ as $v = (2kE/m_p)^{1/2}$, indicated by straight lines in this figure. We show the cases of $k = 0.1$ and 0.01 %. It can be seen that v obtained by the experiments increases with $2E/m_p$, and most data exist between $k = 0.1$ and 0.01 %, though there is some scatter. Also, it appears that k for glass projectiles are slightly lower than that for aluminium.

4. Summary and Conclusions

We demonstrate that higher impact velocities than 10 km/s can be achieved with glass and Al projectiles of 0.1 - 0.3 mm in diameter and Ta sheets of ~ 0.5 mm in diameter and 50 μm in thickness using a high-power laser, GEKKO XII-HIPER. The projectiles were accelerated to velocities ~ 10 - 60 km/s.

Based on this technique, we now investigate impact vaporization of silicates, scaling laws of crater diameter and depth, silicate melt, size and velocity distributions of ejecta, and recovering highly pressured minerals at such high impact velocities.

Since the stress received by projectiles would be rather large during the acceleration in the direct irradiation method as described here, we should improve the acceleration method, as a next step. The indirect methods are plausible such that laser irradiates some fuels, and the vapor of the fuels with well-controlled density and pressure distributions accelerates projectiles as moderately as possible.

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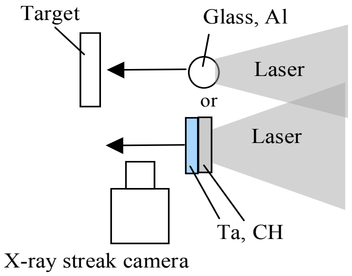

Figure 1: Schematic view of the experimental setup.

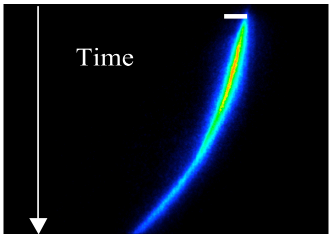

Figure 2: An x-ray streak camera image on the projectile acceleration. Laser irradiated from right. The vertical axis is time and 20.5 ns from top to bottom. The horizontal bar indicates the projectile size of 110 μm as the space scale.

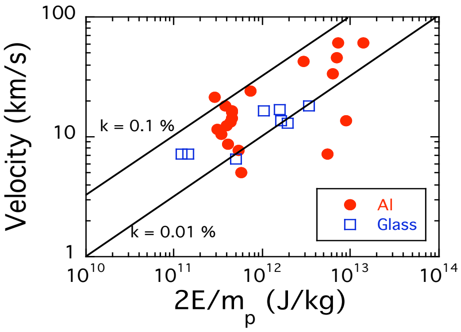

Figure 3. v as a function of laser energy normalized by projectile mass. Two lines indicate the constant energy transfer rate from laser to kinetic energy $k = 0.1$ and 0.01 %.