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高出力レーザーによる飛翔体の加速と惑星科学への応用
Flyer Acceleration by High-Power Laser and Applications to Planetary Science

門野敏彦[1]，境家達弘[2]，重森啓介[3]，弘中陽一郎[3]，他
T. Kadono[1], T. Sakaiya[2], K. Shigemori[3], Y. Hironaka[3], et al.

[1]産業医科大学，[2]大阪大学大学院理学研究科，
[3]大阪大学レーザーエネルギー学研究センター
[1]Univerisity of Occupational and Environmental Health, [2]Faculty of Science, Osaka University,
[3]Institute of Laser Engineering, Osaka University

Introduction

Hypervelocity impacts of meteorites at velocities exceeding 10 km/s occurred on the surfaces of proto-planets. Such impacts would cause a large amount of silicate vapor, which should play very important roles in the origin and evolution of atmosphere, ocean, and life. To quantitatively investigate such impact phenomena in laboratories, flyers larger than sub-mm in size are necessary for present measurement and analysis systems. However, it has been difficult for previous acceleration facilities to accelerate flyers with such sizes to velocities higher than 10 km/s. Recently, we have developed a new acceleration method of spherical and sheet flyers with a size of sub-mm and succeeded to accelerate these flyers to velocities exceeding 10 km/s. Here, we show the flyer velocities obtained by this method and introduce some planetary applications now proceeding.

Experiment

Our acceleration method is as follows. High-power laser, GEKKO XII at Institute of Laser Engineering of Osaka University (ILE), irradiates spherical or sheet flyers. The surface of the flyers vaporizes and becomes high-temperature and pressure plasmas. The expansion of the plasma causes the acceleration of the flyers. We have carried out the experiments with various flyer shapes, sizes, and materials [1-4].

The velocity of the flyers was measured using a streak camera [1-2]. Simultaneously, using a framing camera, we took the images of the flyers and confirmed the shape of the flyers during the acceleration [3-4].

Using this acceleration method, impact experiments with rocks were conducted. As measurement methods, VISAR, a streaked optical spectrometer, X-ray pin-hole cameras, and a quadrupole mass spectrometer, were used. Also, we recovered the targets after the laser shots, and analyzed craters, fragments, and the inside of the craters in detail.

Result

We have succeeded to accelerate aluminum (Al), glass, gold (Au), and diamond spherical projectiles, and tantalum (Ta) sheet flyers. In Fig. 1, we show all results

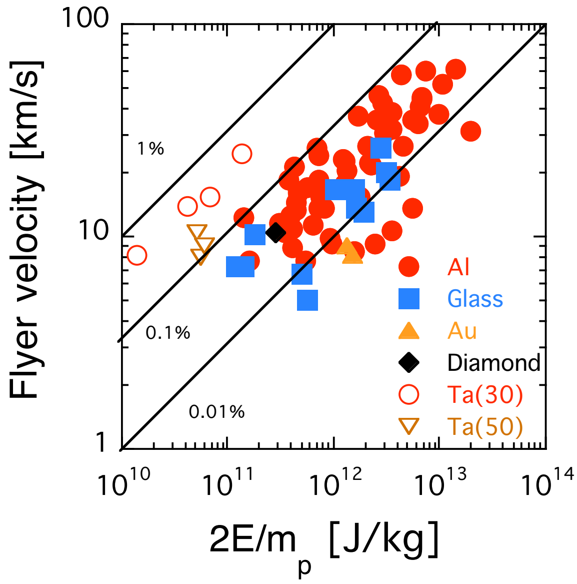

Figure 1. Flyer velocity as a function of laser energy over flyer mass. Close and open symbols denote spherical projectiles and Ta sheet flyers, respectively. The transfer efficiency from laser energy to kinetic one in the case of sheet flyers is higher (~ 0.1-1 %) than that of spheres (~ 0.1-0.01 %).

of the acceleration experiments [1-4]. The vertical axis is the flyer velocity V [km/s] and the horizontal axis is $2E/m_p$ [J/kg] in log-log form, where E and m_p are the laser energy and flyer mass, respectively. If the ratio of laser energy to flyer kinetic one is constant, the velocity should increase linearly with a slope of 1/2 in this plot. We show three lines with a constant transfer efficiency of 1 %, 0.1 %, and 0.01 %. The experimental results indicate that, though there are some scatter, the slope is roughly 1/2, and that the efficiency is ~0.1-0.01 % for the spherical projectiles and ~1-0.1 % for the sheet flyers. Also, Al projectiles are more efficiently accelerated than the glass ones, and the efficiency of the Au ones is less than 0.01 %.

Application

Using this acceleration method, various impact experiments are proceeding as follows.

（1） Equation of state of minerals at high pressures and thermo-dynamic states of vapor caused by impacts [5-7] (Collaboration with University of Tokyo (UT), Institute of Space and Astronautical Science (ISAS), Planetary Exploration Center, Chiba Institute of Technology (PERC), and ILE)

We obtain the Hugoniot equation of state of Forsterite and Diopside at a few hundreds GPa by measuring shock velocity and/or particle velocity using VISAR. Also, we investigate the thermodynamic states of vapor, released from the high-pressure states, using time-resolved spectrometers.

（2） The composition of impact generated vapor and its implication to the K/Pg mass extinction event [8] (Collaboration with PERC, UT, and ILE)

It is known that the impact would play important roles in the K/Pg mass extinction, but the mechanism has not been clear. We carry out the impact experiments with anhydrate and investigate the composition of generated vapor (SO_2 and SO_3). The result reveals the mechanism of the extinction.

（3） Crater size and scaling law (Collaboration with Kobe University (KU) and ILE)

Crater size, the most basic physical quantity impact cratering, is investigated. We verify and improve the accuracy of the scaling laws previously established on the basis of the data below 10 km/s.

（4） Size distribution of fragments [9] (Collaboration with KU and ILE)

The sizes of recovered fragments ejected from craters are measured. Comparing the results with the previous data obtained below 10 km/s, smaller fragments are relatively dominant.

（5） Shock attenuation and recovery of shocked materials (Collaboration with Osaka University (OU) and ILE)

The free surface velocity of rear surface of thin rock samples is measured by VISAR and the shock pressure is estimated. Varying sample thickness, the pressure attenuation rates are evaluated. Also, from the analyses of recovered shocked samples, the morphology change as a function of the distance is investigated. The color and crack distributions indicate the pressure decreases with the distance.

（6） Organic materials in impacts (Collaboration with OU and ILE)

The impact experiments with meteorites are carried out and the composition of generated vapor and recovered materials in condensed phases is investigated.

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