ACCELERATION OF PROJECTILES TO >10 KM/S WITH A LASER GUN: TOWARD SILICATE IMPACT VAPORIZATION EXPERIMENTS.

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Introduction: The average impact velocities of asteroids on Earth and other large terrestrial planets are estimated to be higher than 10 km/s. At such high velocities, even silicates, the most abundant constituent of the terrestrial planets, would vaporize [e.g., 1]. Such silicate vaporization would lead to a variety of important consequences in planetary evolution, such as origin of the Moon [e.g., 2], atmospheric blow off [e.g., 3], global vaporization of ocean [4]. Thus, the impact vaporization processes have been extensively investigated both experimentally [e.g., 5-9] and numerically [e.g., 1,10]. However, acceleration of macroscopic projectiles to planetary-scale impact velocities (>10 km/s) has been a major technological challenge. Consequently, the details of vaporization process of silicates have remained highly unknown. Although qualitative hydrodynamic and thermodynamic natures of both silicate vaporization and vaporized silicates can be inferred from numerical calculations and impact experiments using materials with low heats of vaporization, quantitative predictions are still very difficult. This is because behaviors of silicate vapor are expected to depend on material properties at extremely high pressures and temperatures.

One approach to launch projectiles at such highly desired >10 km/s velocities is to use an extremely high intensity laser. Thin metallic sheets have been accelerated to velocities higher than 10 km/s using high-power lasers [11]. Thin sheet impact experiments are useful for high-pressure physics measurements. In our current efforts, we are developing a technique to launch projectiles with aspect ratio close to unity (e.g., spheres and cylinders) [12]. Here, we present our initial result of silicate projectile acceleration experiments to higher than 10 km/s using GEKKO XII-HIPER laser, which was originally built to conduct nuclear fusion research, at Institute of Laser Engineering of Osaka University in Japan.

Laser Gun Experiments: A high energy laser beam was made by the GEKKO XII-HIPER facility and irradiated on a glass sphere 100 μm in diameter, where wavelength, energy per a pulse, pulse duration time, focused beam diameter of the laser were 1.06 μm, ~800 J, ~10 ns, and ~200 μm, respectively. When the laser irradiation starts, a part of the glass sphere vaporizes and creats a high density and temperature plasma. The resulting plasma rapidly expands and then accelerates the sphere. We observe the acceleration process using an x-ray streak camera with a backlight system.

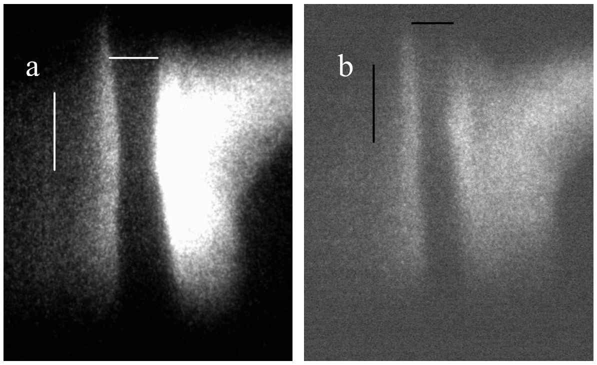

Figure 1. X-ray streak images of projectile acceleration. Time proceeds vertically from the top to the bottom of the figure. (a) shot # 30740 and (b) shot # 30741 are shown. The scales of time (vertical) and space (horizontal) in both panels are 3 ns and 100 mm, respectively. The position of the spatial (i.e., horizontal) scale bars correspond to the initial position of glass spheres. The laser irradiates from left, driving a projectile sphere to right. In this configuration of a streak image, a vertical shadow would be a stationary object. A band of shadow going toward lower right would be an object moving to right. Note that the bright areas of the figure are x-ray illumination from the other side of the projectiles. The brightness varies because the x-ray saurce does not illuminate uniformly in either space or time.

Experimental Results: Figures 1a and 1b show two images obtained by the streak camera (a: shot # 30740 and b: # 30741). The experimental conditions are the same in both shots. The streak images indicate that the glass spheres move to right; i.e., accelerated. We measured the locations of both sides of the projectile (irradiated side (irradiated) and not irradiated side (antipodal)) every ~0.5 ns. The uncertainties in the positions and time are ~2 μm and 30 ps, respectively. From these measurements, we obtained velocities of projectiles averaged over three adjacent points (i.e., the average velocities within a duration of ~1 ns). The uncertainty is +/- ~1/5 of the velocity.

Fig. 2a shows that the velocity of the antipodal side of the sphere reaches ~15 km/s in shot #30740, but this is much higher than that of the irradiated side ~5 km/s. This would suggest that the glass sphere are broken unon laser irradiation. In contrast, the velocities of both sides of the projectile in shot #30741, are comparable at ~15 km/s (Fig. 2b). This indicates that the sphere is likely to be intact during the laser-driven acceleration Note that the decrease in velocity of the irradiated side between 8 and 9 ns is probably due to the decrease in the intensity of the x-ray backlight source (see Fig. 1). Thus, we tentatively conclude that we could successfully accelerate a 100 μm glass sphere to velocity higher than 10km/s, probably around 15 km/s in shot #30741. This is high enough to cause, at least, partial impact vaporization of silicate materials within the main phase of impact compression/decompression stage [6], which follows the higher temperature initial jetting phase [13].

Discussion and Concluding Remarks: A problem revealed by our experiments is disruption of accelerated projectiles. High-pressure plasma generated by intense laser produces shockwaves in projectiles, which may lead to projectile disruption. Such projectile disruption before impact with a target will become a major obstacle for impact vaporization experiments. However, because accleartation/shock-induced disruption of a projectile is one of the most common problems in hypervelocity launchers, a variety of techniques have been invented to reduce such undisirable phenomena.

Thus, the next step is to reduce the occurrence of rojectile disruption. Now we are planning to observe the condition of projectiles during the acceleration process. This will be done with a framing camera and a witness plate. Then, we change controlling parameters, such as the shape and materials of projectiles and laser intensity, and look for the optimunm condition for projectile acceleration.

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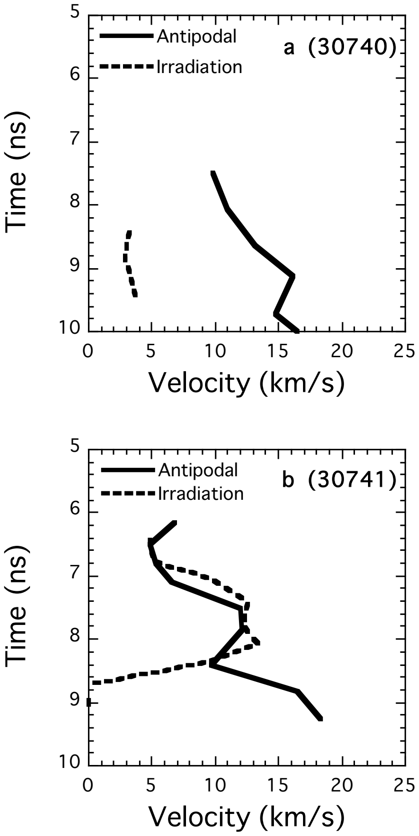

Figure 2. The velocity of the antipodal and irradiated surfaces of the spheres as a function of time. (a) shot No. 30740 and (b) shot No. 30741 are shown. The velocity of the antipodal surfaces is ~15 km/s in both shots. The uncertainty is ~20% of the velocity.