IN-SITU SPECTROSCOPIC OBSERVATION OF SILICATE VAPORIZATION DUE TO >10 KM/S IMPACTS USING A LASER-DRIVEN LAUNCHER. S. Sugita[1], K. Kurosawa[1], T. Kadono[2], Y. Hironaka[2], K. Otani[2], A. Shiroshita[2], N. Ozaki[3], K. Miyanishi[3],Y. Sekine[1], K. Nakamura[1], S. Fukuzaki[1], T. Sano[2], T. Sakaiya[4], T. Fujiwara[2], T. Mochiyama[2], K. Takarada[2], S. Fujioka[2], K. Shigemori[2], S. Ohno[5], S. Tachibana[6], and T. Matsui[1,5], [1]Dept. of Complexity Sci. & Eng., Univ. of Tokyo (Kashiwa, Chiba, JAPAN; sugita@k.u-tokyo.ac.jp), [2]Inst. of Laser Eng., Osaka Univ. (Suita, Osaka, JAPAN), [3]Graduate School of Eng., Osaka Univ., (Suita, Osaka, JAPAN), [4]Graduate School of Sci., Osaka Univ., (Toyonaka, Osaka, JAPAN). [5]Planetary Exploration Center, Chiba Inst. of Tech. (Narashino, Chiba, JAPAN), [6]Dept. of Earth & Planet. Sci., Univ. of Tokyo, (Hongo, Tokyo, JAPAN).

Introduction: Hypervelocity impacts are among the most important geologic processes controlling the origin and evolution of planets. In particular, shock compression and heating of silicates and subsequent rapid decompression induce a variety of phase changes, chemical reactions, and dynamic motions. Previous studies have proposed many important processes, such as atmospheric erosion [1], circum-terrestrial silicate vapor disk formation by a giant impact [2], atmospheric heating [3] and methane formation [4] by reentry of vapor condensate from large impacts.

However, these proposed mechanisms have not necessarily been validated by laboratory experiments. More specifically, model parameters on impact vaporization of silicates are not well determined by laboratory experiments. These parameters have been very difficult to measure because relevant planetary-scale impact velocities are not readily achieved even with two-stage light-gas guns. In this study, we conduct impact experiments using a laser-driven launcher achieving such velocities (> 10km/s) to observe impact vaporization process of silicates.

Impact Experiments: The laser-driven gun experiments were conducted at GEKKO XII-HIPER facility of Institute of Laser Engineering of Osaka University. Details of the experimental system are given by [5, 6]. In this study, a high power laser pulse (5000 J) was focused on a circle 0.5 mm in diameter on a 50-μm-thick Ta metal sheet. Ta was used as flyers because of its high density (16.7 g/cm^3) and high melting and boiling temperatures (3269 K and 5698 K, respectively). X-ray backlight photography measurements reveal that the flyer speed was 9 ± 1 km/s. The accelerated Ta sheet collides with either quartz (SiO_2) or diopside ($CaMgSi_2O_6$) target. In order to minimize 3-dimensinal expansion effect of shockwave, we sliced target samples very thin (150 μm for quartz, 250 μm for diopside). These materials were chosen because of their geologic importance and transparency, allowing observation of radiation from shock front traveling in a target. Another reason for the choice of diopside is that it contains Ca, whose atomic emission lines are well suited for impact vapor measurements [7]. The impact area of a thin silicate target on the side opposite from the flyer impact was observed by a high-speed spectrometer (Roper Scientific, SpectraPro 300i and PI-MAX). The field of view was 0.6mm slightly larger than the laser beam diameter on the flyer, covering the entire impact-heated region of the target. In order to obtain the general characteristics of the impact flash spectra, we chose a wide spectral coverage (410 – 630 nm) with moderate resolution. Although the laser wavelength (1053 nm) is out of this range, its second harmonic light at 526.5 nm, generated by non-linear interaction between laser photon and high-temperature plasma, might damage the sensitive light detector of the spectrometer. Thus, we placed a notch filter to cut out light from 520 – 530 nm. Similarly, short-cut filter is placed to cut the third harmonic light at 351 nm.

The wavelength and spectral sensitivity of the spectrometer were calibrated with a mercury lamp and a NIST-tracable halogen tungsten lamp, respectively. Because the number of available laser shots was limited, we chose a relatively long exposure time (100 ns) for the spectrometer to ensure to capture impact flash. The peak shock state within the silicate targets is expected to last only 10 – 20 ns.

Spectroscopic Results: A few high-quality emission spectra of impact flash from Ta impacting silicate targets have been successfully obtained. Fig. 1 shows typical impact flash spectra. The flash from a quartz target exhibits a featureless continuum spectrum, most likely blackbody radiation, with an unidentified emission line at 505 nm (Fig. 1a). The flash from a diopside target shows a number of emission lines of Ca at 445, 559, and 615 nm, Mg at 518 nm, and Na at 589 nm along with a strong continuum (Fig. 1b).

Peak shock temperature and Pressure: Based on blackbody fitting of the continuum spectra, we can estimate the peak shock temperatures of the silicate targets; $13{,}000 \pm 1000$ K for quartz and $12{,}000 \pm 2000$ K for diopside. The pressure of peak shock can be calculated from flyer speed and the Hugoniot parameters of Ta, quartz, and diopside [8, 9], yielding 230 ± 40 GPa for quartz targets and 280 ± 50 GPa for diopside targets. These correspond to a quartz-quartz collision at 13.5 ± 1.4 km/s and a diopside-diopside collision at 13.4 ± 0.8 km/s, respectively.

Vapor temperature and pressure: The temperature (T) of vaporized diopside can be estimated by line intensity ratio method [7]. Although the noisy data and small number of Ca lines may not alow us make a clear Bolzmann plot, it is possible to estimate vapor temperature by comparing an observed spectrum with theoretical synthetics with different temperatures. Such comparison is shown in Fig. 2, indicating that Ca vapor temperature is most likely around 8000 K.

When the individual emission line profiles are examined more closely, one can notice their extremely large breadth. The line profile is well fitted by a Lorenz function (Fig. 3), strongly suggesting that this is due to pressure broadening [10]. If the broadening is due to mutual collisions among Ca atoms, then the vapor pressure (P) is estimated to be 4 ± 1 Ga based on 4.2 ± 0.5 nm of FWHM of the Ca line at 559 nm.

Discussion: Although the data are still preliminary, we can obtain a significant knowledge on silicate vaporization processes from the above results. First, diopside vapor observed by the spectrometer is the vapor that is just vaporized from shock-heated melt. Thus, the observed P-T condition is on the vapor-liquid boundary of diopside. This will provide a very important data point regarding silicate vaporization at extremely high T and P, perhaps near the critical points.

Second, the obtained P-T condition for vaporization can be compared with theoretical estimates for silicate vaporization to improve thermodynamic models. Since no phase diagram for diopside vaporization at GPa pressures can be found in the literature, we compare our results with theoretical models for SiO_2 [11] and Mg_2SiO_4 [12] based on ANEOS. Because of the difference in composition, direct comparison would require caution. Nevertheless, experimental data show that the vaporization pressure for diopside is higher than that for the Mg_2SiO_4 model at 8000 K by an order of magnitude and is located in a super-critical region of SiO_2 but approximately along an extension of SiO_2 vapor-liquid phase boundary.

The location of the phase boundary of impact-heated silicates would have significant effect on the dynamic evolution of vapor plume produced by a moon-forming giant impact, for example. If vaporization occurs at a higher pressure along an isentropic decompression path of an impact vapor plume, it would be accelerated very efficiently, resulting in circum-terrestrial disk with larger mass and radius. Such change in the initial condition of the disk will influence the condition of formation for the Moon significantly.

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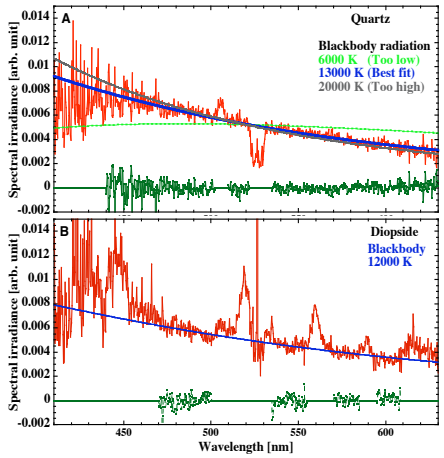

Figure 1. Emission spectra of Ta sheets impacting (A) quartz target and (B) diopside target. The blackbody continuum curves are shown for comparison. The difference between observed and best-fit blackbody spectra is also shown in the figure near the zero irradiance level. The wavelength ranges where emission lines, large error, and notch filter absorption band are located are excluded from the fits.

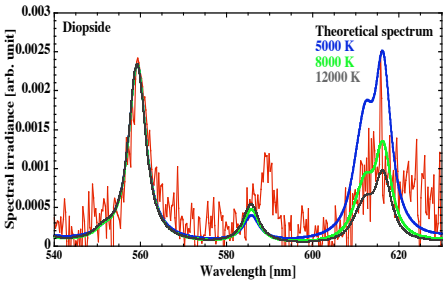

Figure 2. An impact flash spectrum from Ta impacting diopside target subtracted with the best-fit blackbody spectrum (12,000 K). Synthetic spectra of atomic Ca lines at different temperatures are also shown.

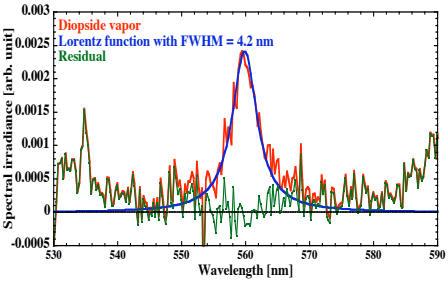

Figure 3. A line profile of a Ca atomic line emitted from Ta impact into a diopside target. The best fit FWHM of Lorenz profile is given for comparison.