Synthesis of carbon clusters by impact of a projectile onto a target including ice in nitrogen gas

窒素ガス中氷含有ターゲットへの飛翔体衝突による炭素化合物微粒子の合成

Dept. Physics, Shizuoka Univ. Tetsu Mieno (sptmien@ipc.shizuoka.ac.jp), Kazuhiko Kondo
ISAS/JAXA Sunao Hasegawa, Keisuke Kurosawa

Abstract In order to investigate production process of carbon clusters by asteroid impacts on satellites and planets, model experiment is carried out using a 2-stage light gas gun. Impact reactions on Titan's surface would include carbonaceous materials, ice and nitrogen gas. A small polymer bullet (a metal bullet) with about 6.5 km/s is injected into a pressurized target chamber filled with 1 atm of nitrogen gas, to collide with an ice + iron target (a water +hexane + iron target). As a result, carbon nano-capsules, and carbon nano-sacks are produced. Signals of production of amino acids are also obtained.

1. Introduction

There are huge amount of carbon clusters in our space. Carbons were produced in stars, and chemical reactions in the interstellar space make various carbon clusters. We are interested in the impact production of carbon clusters on planets and satellites, especially on Titan satellite. [1]. By this motivation, the model experiment has been carried out by use of a 2-staged light-gas-gun for several years. By the impact reactions under nitrogen atmosphere, we have confirmed many types of carbon clusters, like fullerenes, carbon nanotubes, carbon nano-capsules, and balloon-like carbons. [2-5] Effect of adding water in the target is also examined. After the impact reaction, produced sample is carefully collected and analyzed by a TEM, a laser desorption time-of-flight mass spectrometer etc. As a results, it is confirmed that new different kinds of carbon materials are produced. By the laser-desorption time-of-flight mass spectrometer (LD-TOF-MS), signals of amino acids are also obtained.

2. Experimental

The experiment is carried out using a 2-stagde light-gas-gun facilitated at ISAS/JAXA. [6] This gas gun can accelerate a polycarbonate bullet 7.1 mm in diameter (or a stainless-steel bullet 3.2 mm in diameter) by compressed hydrogen gas, to about 6.5 km/s under a vacuum of 0.1 Pa, and the bullet collides with an ice + iron target (an iron target or an ice + hexane + iron target) in a pressurized chamber, filled with 1 atm of nitrogen gas. Schematic of the experimental setup is shown in Fig. 1. At the end of the large target chamber of the gas gun, the pressurized impact chamber is located, which has 255 mm in diameter and 250mm long, made of stainless steel. To collect produced small amount of samples, inside-walls of the chamber are covered with clean

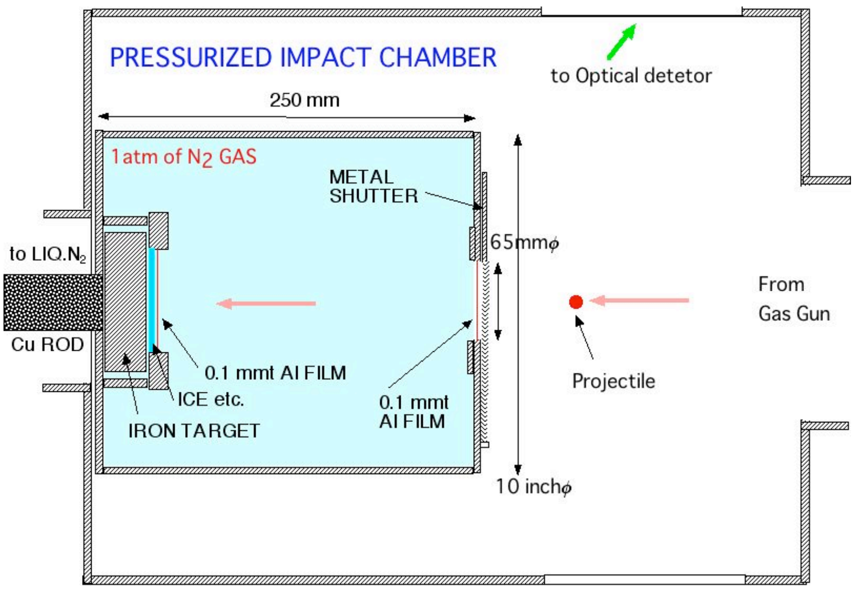

Fig.1 Schematic of the pressurized impact chamber.

aluminum sheets. The pressurized chamber is at first evacuated by a rotary pump and then 1 atm of nitrogen gas is introduced. A projectile penetrates the aperture of the chamber, 65 mm in diameter covered with a 0.1 mm thick aluminum film, and hits an iron target 76 mm in diameter and 25 mm thick. The target can be cooled down to T_t about -100 C by thermal conduction of a copper rod, which is cooled by liquid nitrogen. On the iron target, thin ice (water, hexane) layer about 2 mm thick can be set by covering with an aluminum-sheet.

3. Experimental Results and Discussion

The impact reactions are recorded directly by a high-speed camera (Shimadzu Co., HPV-1), which is set at the side-wall port of the target chamber. Figures 2 and 3 show side views of time evolution of impact emissions near the target, for the two impact conditions. After the impact the strong emission continues for about 30 micro sec. By the nitrogen gas, the emitting plume does not expand straightly. The emission intensity is weaker for the water including target (Fig. 3), showing the lower gas temperature.

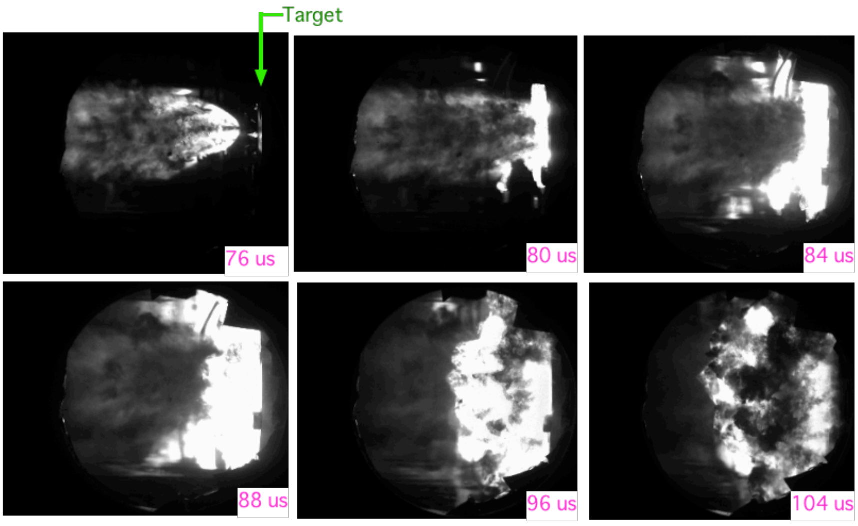

Fig. 2 Time evolution of the impact images (side view). A polycarbonate bullet hits the iron target under 20 C.

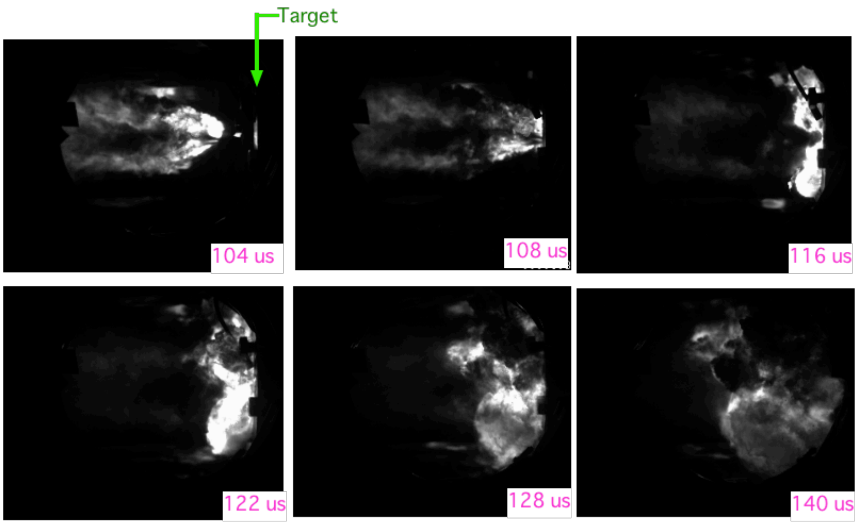

Fig. 3 Time evolution of the impact images (side view). A polycarbonate bullet hits the water + iron target under 20 C.

By using 2 video cameras (Sony Handycum) with band-pass-filters, a profile of C_2 molecular emission at 510 nm is measured (time-integrated images) as shown in Fig. 4. It can be found that the C_2 emission is much stronger than background emission, and it expands widely in front of the target.

Shapes of the craters after the impact are measured. The diameter and depth of the crater on the iron targets are shown in Fig. 5. For the 3 impact conditions, the diameters are almost the same, but the depth is much smaller in the case of ice-included target, in which the ice would change the impact pressure.

The electron density in the impact plume is estimated by using a Langmuir probe (a cylinder, 4.0 mm diam. & 10 mm), which is located at the edge of the target (ca. 2 cm from the target), as shown in Fig. 6. Using the electron saturation current to the probe and the gas temperature, the electron density is estimated. By introducing water (ice), the electron density is considerably decreased.

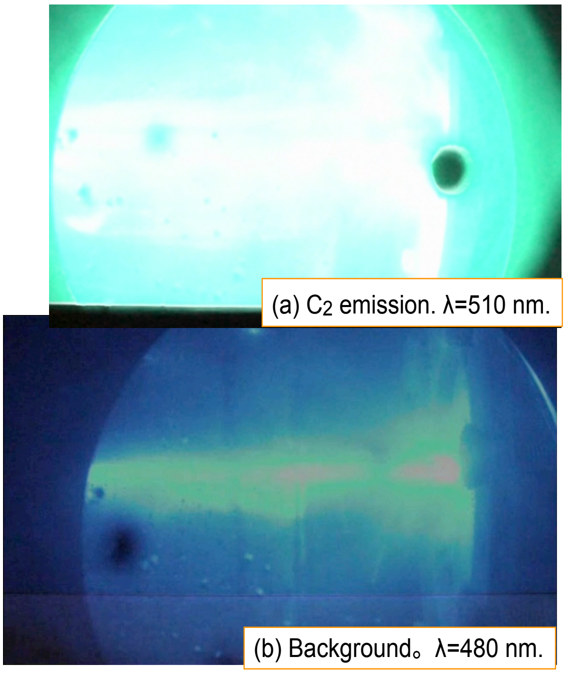

Fig. 4 Side-view images at the 2 wave lengths regions.

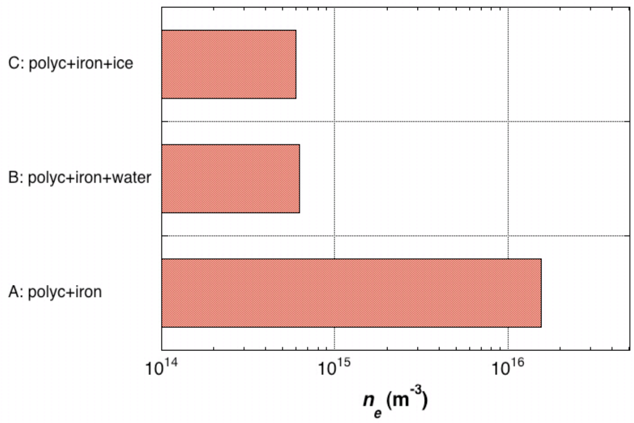

Fig. 6 Electron densities estimated using a Langmuir probe, which is located at the edge of the target (ca. 2 cm from the target).

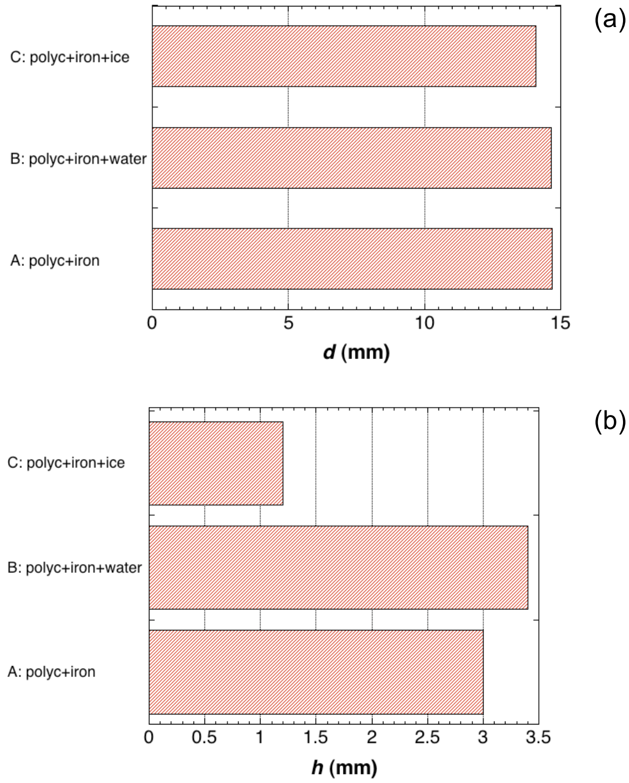

Fig. 5 Diameters of the crater (a), depths of the crater (b) .

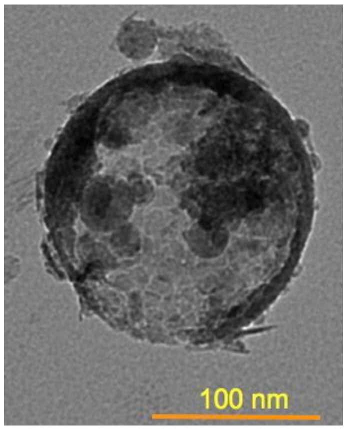

Fig. 7 On a balloon-like carbon particle, smaller carbon particles are attached. A polycarbonate bullet hits an ice + hexane + iron target (-70 C).

The produced particles deposited on the aluminum sheet of the inner wall and on the target surface are carefully collected and stored in glass bottles. The morphologies are observed using a TEM (Hitachi High Technology, H-7650, V_{acc}= 100 kV). As already reported in the previous papers, many kinds of nano-particles are confirmed. In aggregations of these nano particles (carbon particles, carbon capsules etc.), there are strangely shaped nano-particles. Figure 7 shows one example, where a polycarbonate bullet hits an ice + hexane + iron target under – 70 C. This is a balloon-like carbon nano-particle, on which smaller carbon particles are attached. The surfaces of the carbon particles would be small reaction places. On the other hand, there are balloon-like carbon particles with a “mouth” as shown in Figs. 8 & 9. These particles look like stable and they can store other particles and materials. In Fig. 8, an iron particle covered by carbon layer is stored. In Fig. 9, the biggest balloon includes carbonaceous materials, which could be polymers. We conjecture that the high-temperature reaction makes balloon-like carbons in the impact plume, and

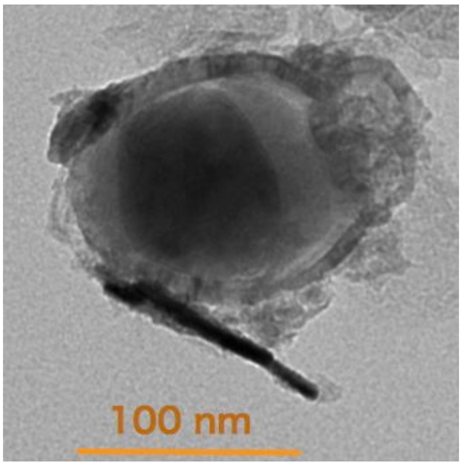

Fig. 8 A carbon capsule with a "mouth" including a carbon + metal particle. A polycarbonate bullet hits an ice + hexane + iron target (-70 C).

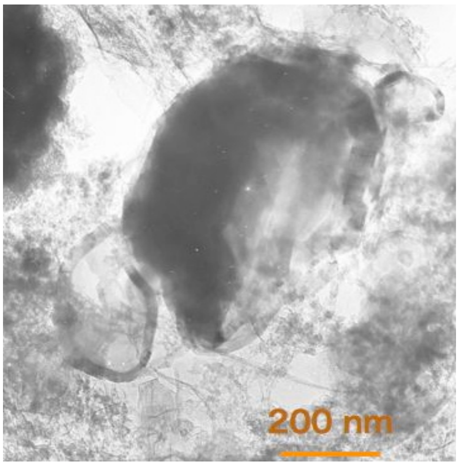

Fig. 9 Carbon capsules with a "mouth", which can store materials. A polycarbonate bullet hits an ice + iron target (-60 C).

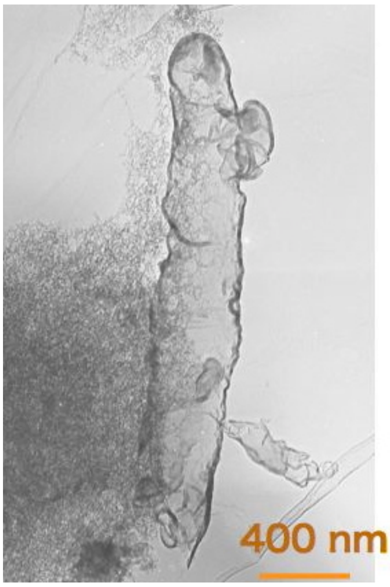

Fig. 10 A "carbon sack" with a graphite wall. A polycarbonate bullet hits an ice + iron target (-60 C).

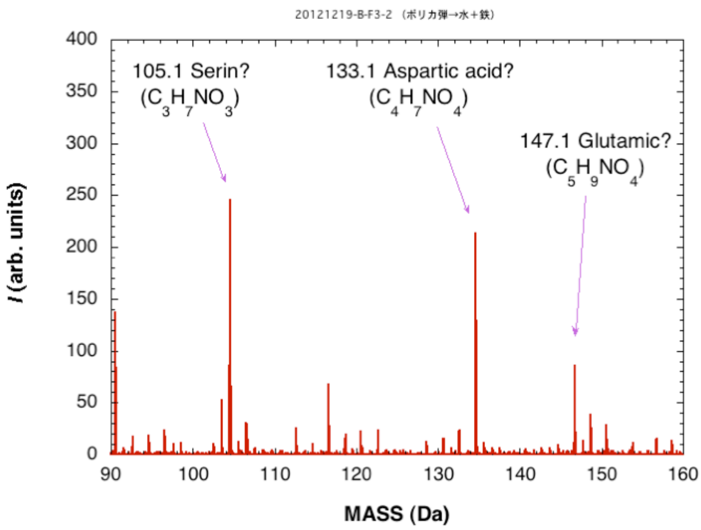

Fig. 11 A mass spectrum of LD-TOF-MS (+ ion, 50 shots averaged). A polycarbonate bullet hits a water + iron target (-60 C).

then, some materials can be stored in the balloons under the lower temperature condition. Figure 10 shows a curious "carbon sack", which is found when a polymer bullet hits an ice + iron target under – 60 C. This has a mouth and would store more materials in the sack. From these facts, we can expect encapsulations of polymers and organic materials in balloon-like carbons and sack-like carbons, which would be much stable under UV/X ray radiation conditions.

Finally, measurement of amino acids should be mentioned. Until now analysis by a LD-TOF-MS (Bruker, Auto-Flex) is successful. Figure 11 shows one typical result, in which the sample with propanol matrix is measured (+ ion, 50 shots averaged). Frequently we can obtain signals corresponding to Serin (*M*= 105.1), Aspartic acid (*M*= 133.1) and Glutamic acid (*M*= 147.1). The impact reaction would be able to make amino acids. The crosscheck using the liquid-chromatography method is under investigation, now.

4. Summary

1) Time evolution of the impact images is clearly recorded, in which water addition in the target reduces the impact scale and the gas temperature.

2) By using 2 video cameras with band–pass-filters, profile images of C_2 emission and background emission are recorded.

3) Comparisons of the shapes of craters and electron temperatures are carried out.

4) When ice (ice + hexane) is added in the target, balloon-like carbons and sack-like carbons with a mouth are produced. They can include nano particles and nano materials.

5) From the LD-TOF-MS measurement, mass-signals of amino acid molecules are recorded, several analysis methods are necessary to confirm the production of amino acids.

6) We believe that the impacts on Titan have made many kinds of carbon clusters and carbonaceous molecules and they are stored on Titan surface.

Acknowledgement

This study was supported by a Grant-in-Aid for Scientific Research from MEXT, Japan. This study was also supported by ISAS/JAXA as a collaborative program of the Space Plasma Experiment.

References

[1] R. Jaumann *et al.*: *Titan from Cassini-Huygens* (Springer, Dordrecht, 2009).

[2] T. Mieno, S. Hasegawa, K. Mituishi: Jpn. J. Appl. Phys. **50** (2011) 125102

[3] T. Mieno, S. Hasegawa: Appl. Phys. Express **1** (2008) 067006.

[4] T. Mieno, S. Hasegawa, K. Mituishi: Proc. Space Plasma Meeting (2011, Sagamihara) No. 24 (2011) pp. 1-4.

[5] T. Mieno, S. Hasegawa, K. Mituishi: Proc. Space Plasma Meeting (2012, Sagamihara) No. 31 (2012) pp. 1-4.

[6] N. Kawai, K. Tsurui, S. Hasegawa, E. Sato: Rev. Sci. Instrum. **81** (2010) 115105.