Synthesis of carbon clusters by impact reaction of gas gun
(Model experiment of impact reaction on the surface of Titan)

ガス銃衝突反応による種々の炭素クラスター合成実験（タイタン表面衝突反応のモデル実験）

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Abstract In order to investigate production process of carbon clusters by asteroid impacts in space, simulation experiment is carried out using a 2-stage light gas gun. Especially, impact reactions on Titan's surface with rich hydrocarbons are considered. A small polymer bullet (a metal bullet) with about 6 km/s is injected into a pressurized target chamber to collide with an iron target (or a hexane + iron target) under 1 atm of nitrogen gas. As a result, production of many kinds of nano-scale carbon clusters such as metal-capsulated carbon particles and balloon-like carbons is confirmed. Possibility of production of amino acids and nitrogen addition to carbon clusters is considered.

1. Introduction

A huge number of carbon atoms have been produced and stored in space. They react in space by collisions, irradiation of UV light and X ray, and make many kinds of carbon clusters and hydrocarbons. We hope to know what kinds of carbon molecules and carbon compounds are stored in space. Recently, Cassini/Huygens explorer was sent to Saturn by NASA/ESA, investigated the surface of Titan, and sent back clear IR images of huge and many methane seas on the surface. [1] This explorer is now measuring the upper atmosphere and the surface of Titan by optical cameras, mass spectrometers and particle energy analyzers. From the measurement of the mass spectrometers, it was confirmed that there are many kinds of hydrocarbons in the upper atmosphere like ethane, propane, benzene, which were mainly synthesized by UV-light irradiation from Sun. These molecules coagulate to make hydrocarbon clusters, and are floating in the lower atmosphere as "haze". These products would fall onto the surface and are stored under the cold and dark condition, the model of which is shown in Fig. 2. [1-5] Here, we suggest that the impacts of many asteroids onto the Titan's surface in long period of time have caused large-scale explosions in the nitrogen atmosphere, and many types of carbon clusters, hydrocarbon molecules and amino acids have been produced. [6-10] Many of the products fell on the surface and remain under low-temperature and UV-shielded conditions. However, some of the products would have been dispersed into space by the impact force. Therefore, we expect that many types of carbon clusters

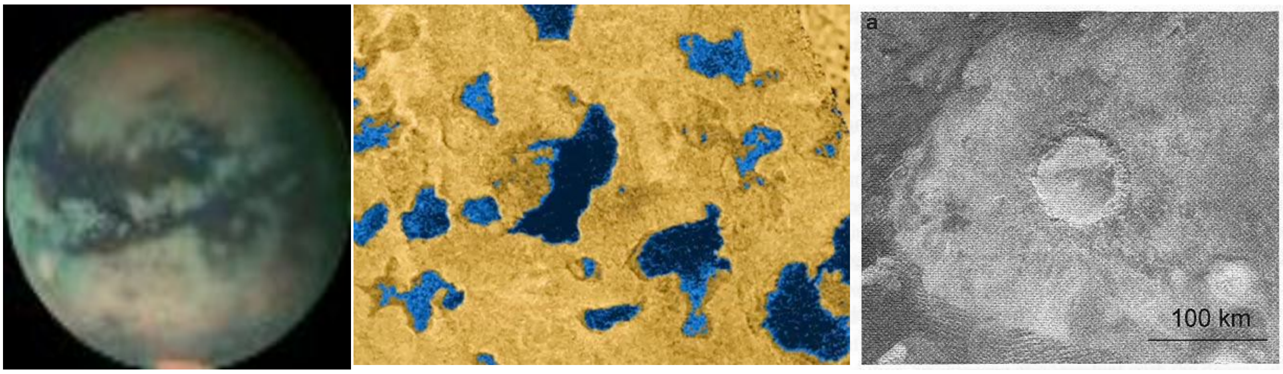

Fig. 1 Images of Titan (left) and methane seas on Titan (middle) (from NASA homepage). Titan is always covered with haze. An image of craters on Titan (right) (quoted from Ref. 1).

produced by the impacts are stored on Titan's surface. In order to prove the possibility of this hypothesis of the carbon-cluster production on Titan's surface, a model experiment was carried out by using a 2-stage light-gas gun. [11. 12] A projectile with a velocity of about 6 km/s collides with a target in a nitrogen environment causing an impact reaction in gas phase. The produced samples are carefully analyzed by a TEM etc.

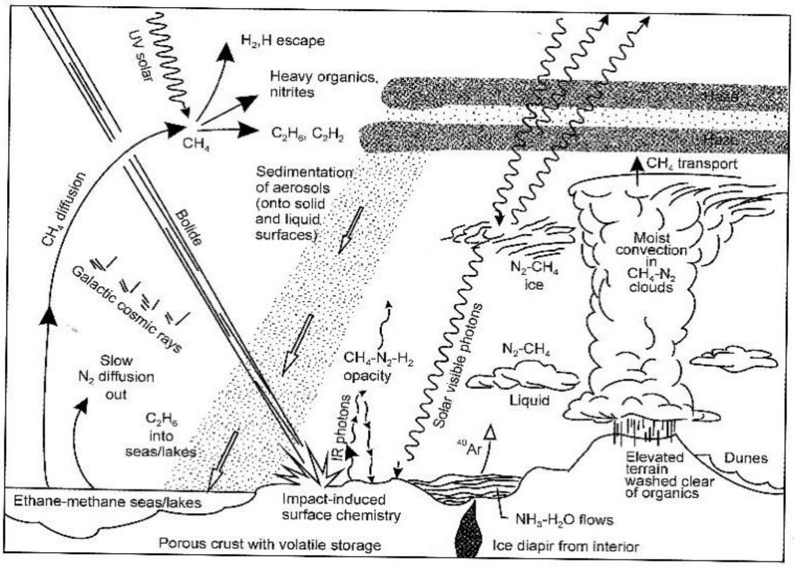

Fig.2 Surface reactions on Titan. Impacts of asteroids (bolids) make surface chemistry. (Quoted from ref. 1.)

2. Experimental

The experiment is carried out using a 2-stage light-gas gun facilitated at the Institute of Astronautical Science (ISAS), JAXA. 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 km/s under a vacuum of 0.1 Pa, and the bullet collides with an iron target (or a hexane + iron target) in a pressurized chamber, where 1 atm of nitrogen gas is filled. Photographs of the pressurized chamber are shown in Fig. 3. And schematic of the experimental setup is shown in Fig. 4. At the end of the big target chamber of the gas gun, a pressurized impact chamber is placed, which has 255 mm in diameter and 250 mm long, made of stainless steel. To collect produced small amount of samples, inside-walls of the chamber are covered with clean aluminum sheets, and contamination is carefully protected. 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 30 mm thick. The target can be cooled down to T_t ~ - 50 degree Celsius by thermal conduction of a copper rod, which is cooled by liquid nitrogen. On the iron target, thin hexane layer about 2 mm thick can be set by covering with an aluminum-film. After the impact, a metal shutter immediately closes the aperture to protect impurity inflow from the gun region.

Fig. 3 Photographs of the pressurized chamber (left), the target and inside of the chamber (middle) and the target after an impact (right).

3. Experimental Results and Discussion

The impact reactions are recorded indirectly by a high-speed camera (Shimadzu Co., HPV-1), which is set at the side-wall port of the target chamber. Figure 5 shows time evolutions of impact emissions from the aperture of the pressurized chamber, for the two impact conditions. After the impact the strong emission continues for about 30 ns. From this emission, N_2-swan bands can be measured and the gas temperature is estimated to about 5000 K, which was reported by Kurosawa et al. [13] Even the target is cooled down to – 50 C, the emission was strong, which means that the impact immediately heats up an impact part of the target surface to 5000 C, and ablation of the target takes place.

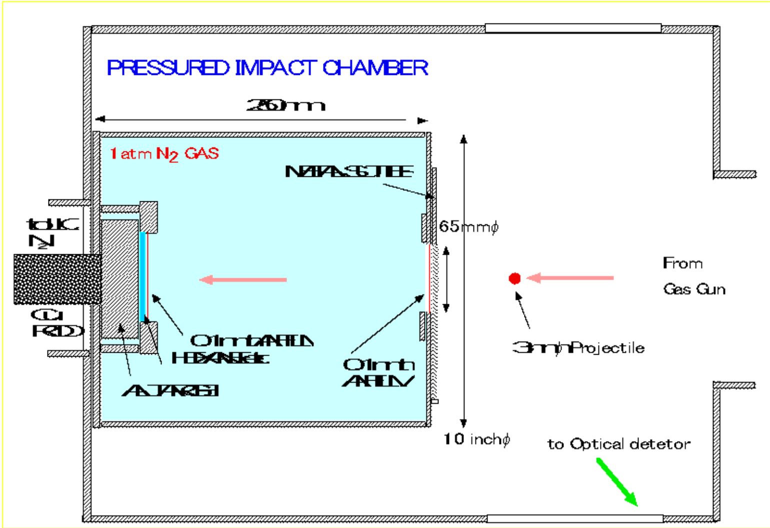

Fig. 4 Schematic of the pressured impact chamber.

The ablated molecules react each other in the hot gas plume and they make many kinds of carbon clusters during the cooling process. After the impact, the pressurized chamber is opened and produced soot is carefully collected. Then, the samples are measured by TEMs. Figure 6 (left) shows typical example of produced carbon clusters, in which many nano-particles and amorphous-like material are measured by a TEM (JEOL Co., JEM-3000F, acceleration voltage of 300kV). By the EELS method, [14] carbon-atom and iron-atom mappings are obtained by the TEM. Figures 6 (middle) & (right) show the carbon atom distribution and the iron atom distribution (bright parts), respectively, from which it is confirmed that the dark particles are made of iron, and the amorphous material and the brighter particles are mode of carbon.

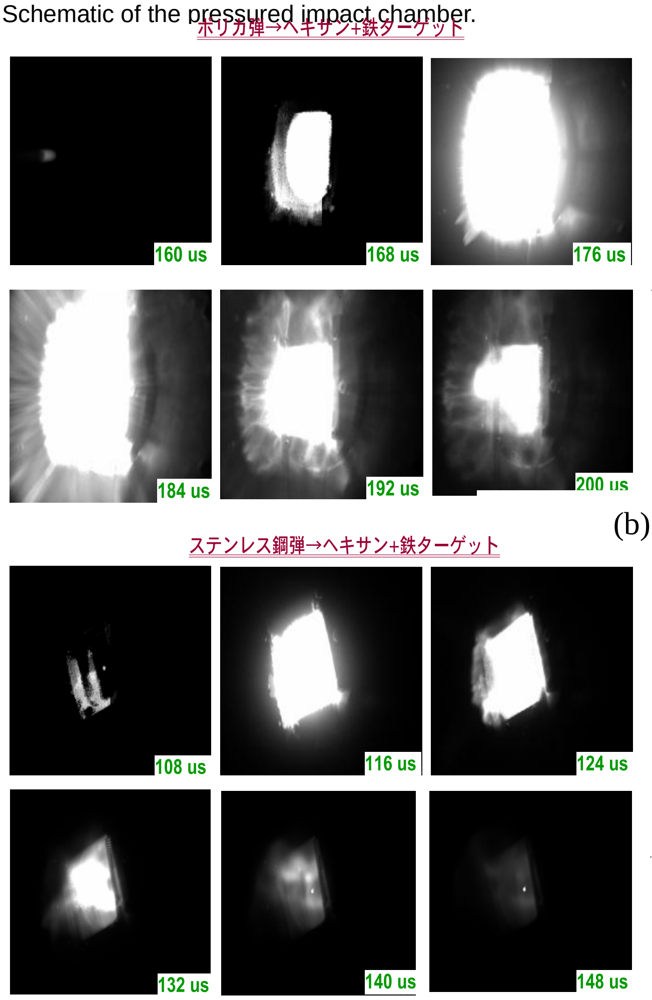

Fig. 5 Time evolutions of the impact emission recorded from a side port by a high-speed camera. (a) A polycarbonate bullet and (b) A stainless bullet hits a hexane+ iron target under –50 C.

Many samples are measured by the TEM, and iron-encapsulated carbon nanoparticles and balloon-like carbon nano-particles are often observed. Typical TEM images of iron-encapsulated carbon nanoparticles and balloon-like carbon nano-particles are shown in Fig. 7.

As the impact reaction takes place under nitrogen gas, production of amino acids and other carbon-nitrides is expected. Therefore, mass spectra are measured by using a laser-desorption time-of-flight mass spectrometer (LD-TOF-MS) (Bruker Co., Auto Flex). Figure 8 shows one

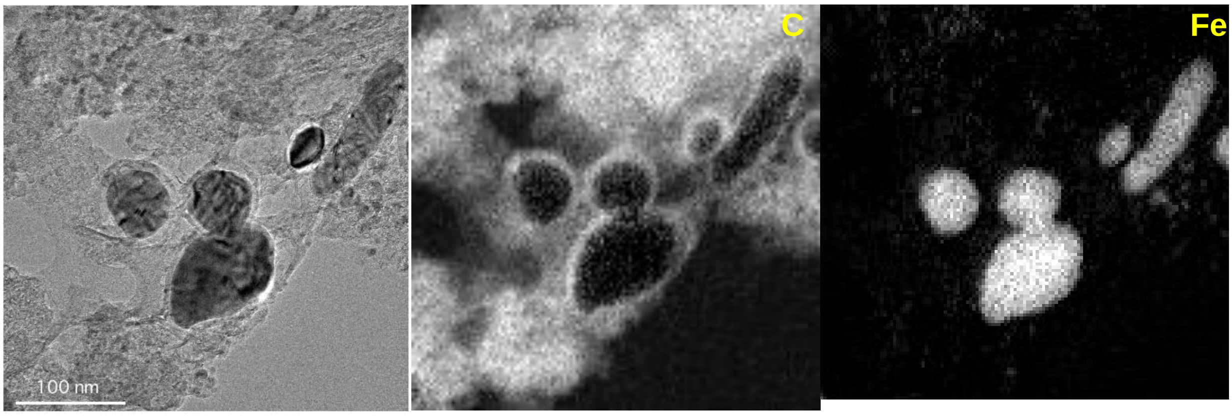

Fig.6 A tyical image of produced carbon clusters (left). Carbon-atom mapping (middle) and iron-atom mapping (right) by the EELS method.

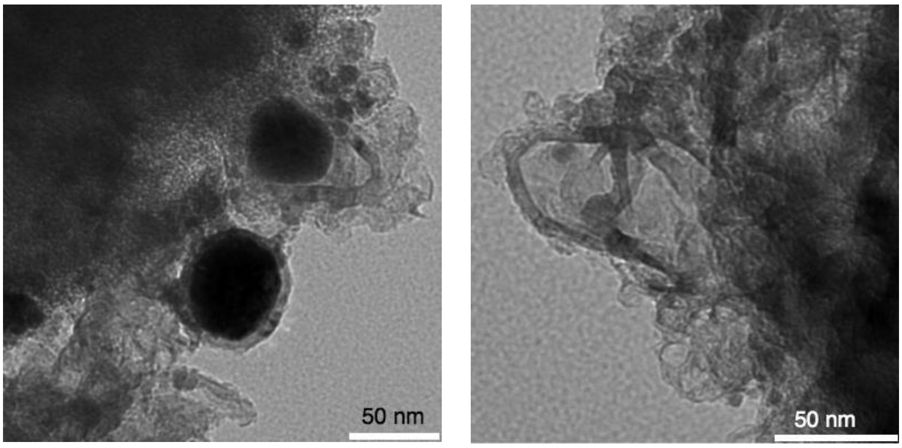

Fig. 7 Typical images of produced iron-encapsulated nano-carbons (left) and balloon-like nano-carbons (right).

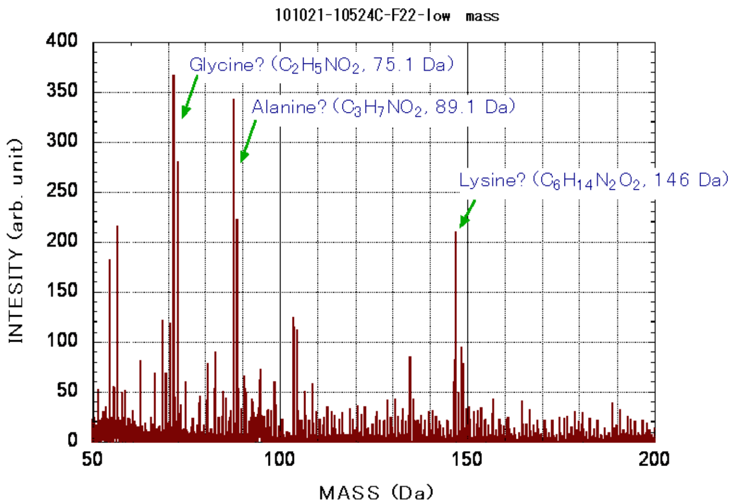

Fig. 8 A mass spectrum of the produced soot by the LD-TOF-MS. (+ ion mode, 50 shots averaged. A polycarbonate bullet hits an iron target under 20 C.)

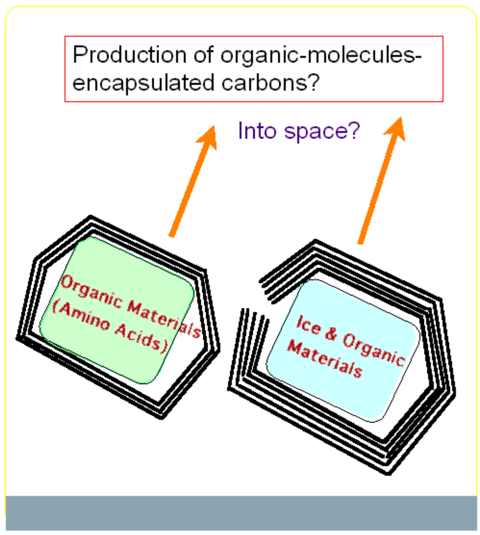

Fig. 9 A model figure of possibility of production of amino-acids encapsulated carbon clusters.

spectrum. In the low mass part (M< 200 Da), there are several signals corresponding to amino acids molecules, for which careful check is now under way.

4. Summary

Nano-scale carbon clusters such as iron encapsulated carbon particle, balloon-like carbon particles are produced by the impact reaction of a polycarbonate bullet (a metal bullet) onto an iron target (a Hexane + iron target) under 1 atm of nitrogen gas. The production process would depend on the projectile materials, target materials and target temperature. Amino acids and carbon nitrides could be synthesized by this impact, which is now under investigation. It is expected from the experiment that many kinds of carbon clusters and hydrocarbons have been produced and stored on the Titan's surface. We expect that produced amino acids or ices including amino acids are encapsulated in carbon shells, model of which is shown in Fig. 10, and they would have chance to diffuse into space from Titan. Such special clusters we are also trying to produce by the impact reaction.

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