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

氷を含むターゲットへの飛翔体衝突反応による炭素クラスターの合成

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Abstract In order to investigate production process of carbon clusters by asteroid impacts in space, model experiment is carried out using a 2-stage light gas gun. Considering about impact reactions on Titan's surface, the reaction would include carbonaceous materials and ice under nitrogen atmosphere. To simulate the impact reactions on Titan, the gas-gun experiment is carried out. A small polymer bullet (a metal bullet) with about 6.5 km/s is injected into a pressurized target chamber to collide with a water + iron target (or a water +hexane + iron target) under 1 atm of nitrogen gas. By including water the products are dramatically changed, in which polymer-like materials and cyanides are produced.

1. Introduction

We are interested in impact reactions on Titan satellite, [1] and the model experiment has been carried out by use of a 2-staged light-gas-gun. By the impact reactions under nitrogen atmosphere, we have confirmed many types of carbon clusters, like fullerenes, nanotubes, metal-encapsulated carbons, and balloon-like carbons. [2-4] Here, effect of water in the target is examined. After the impact reaction including water, produced sample is carefully collected and analyzed by a TEM, a laser desorption time-of-flight mass spectrometer etc. As a results, new different kinds of hydrocarbon materials are produced. Molecules including nitrogen (cyanide) are also produced.

2. Experimental

The experiment is carried out using a 2-stagde light-gas-gun facilitated at ISAS/JAXA. [5] 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 a water + iron target (or a water + hexane + iron target) in a pressurized chamber, where 1 atm of nitrogen gas is filled. Photographs of the pressurized chamber are shown in Fig. 1. Here, a new viewing window is introduced to record the impact images. Schematic of the experimental setup is shown in Fig. 2. 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 as shown in Fig.1. The pressurized chamber is at first evacuated by a rotary pump and then 1 atm of nitrogen gas is introduced.

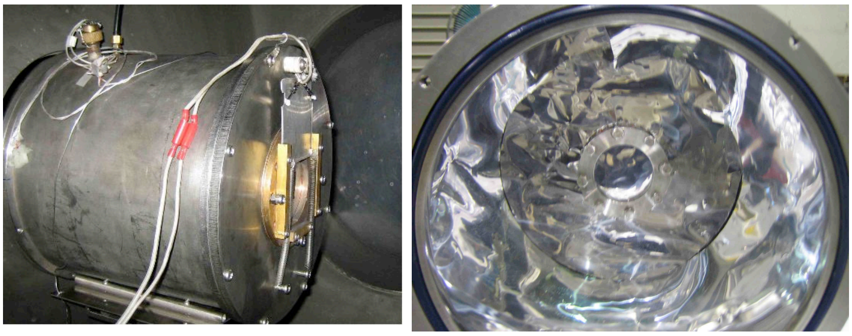

Fig. 1 Photographs of the pressurized impact chamber (left), and the target inside of the chamber (right).

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 ~ - 60 C by thermal conduction of a copper rod, which is cooled by liquid nitrogen. On the iron target, thin water layer about 2 mm thick can be set by covering with an aluminum-film.

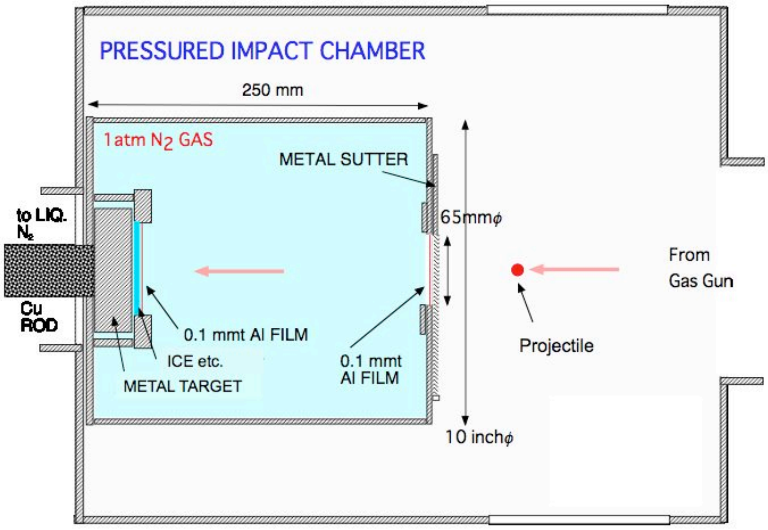

Fig. 2 Schematic of the pressurized impact chamber.

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 3 and 4 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 μs. By the nitrogen gas, the emitting plume does not expand straightly. In case of the water including target (Fig. 4) the emission intensity is weaker, which mean the plume gas temperature is lower. By using a streak camera (Hamamatsu Photonics Co.), short emission spectra are measured as shown in Fig. 5. In this case, a polycarbonate ball hits a stainless steel target under 20 degree C. From the emission, CN bands and N_2-swan bands are clearly measured. From the blackbody emission theory, the plume gas temperature is estimated to about 4500 K, which is in consistent with a report by Kurosawa et al. [6] By including water, the plume gas temperature would be lower by the heat of vaporization of water. The ablated molecules react each other in the hot gas plume and they make many kinds of

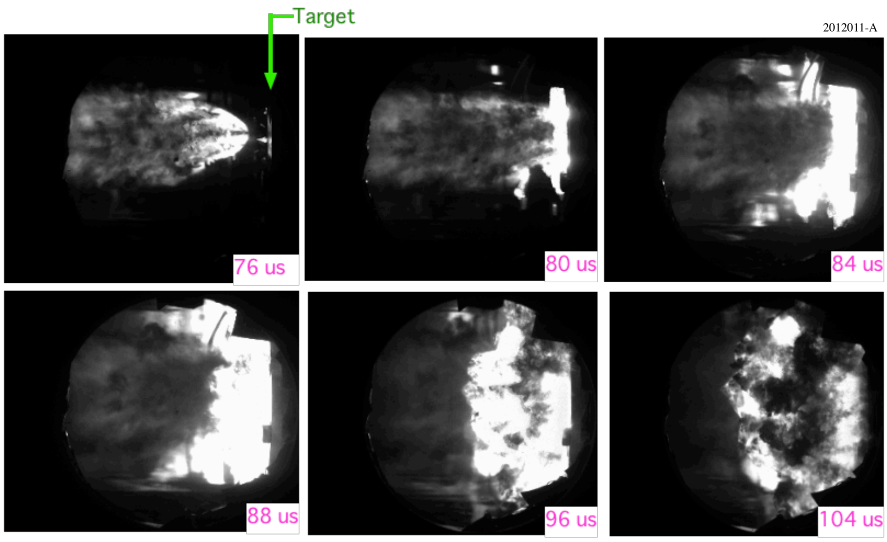

Fig. 3 Time evolution of the impact image (side view by the high-speed camera). A polycarbonate bullet hits the iron target under 20 C.

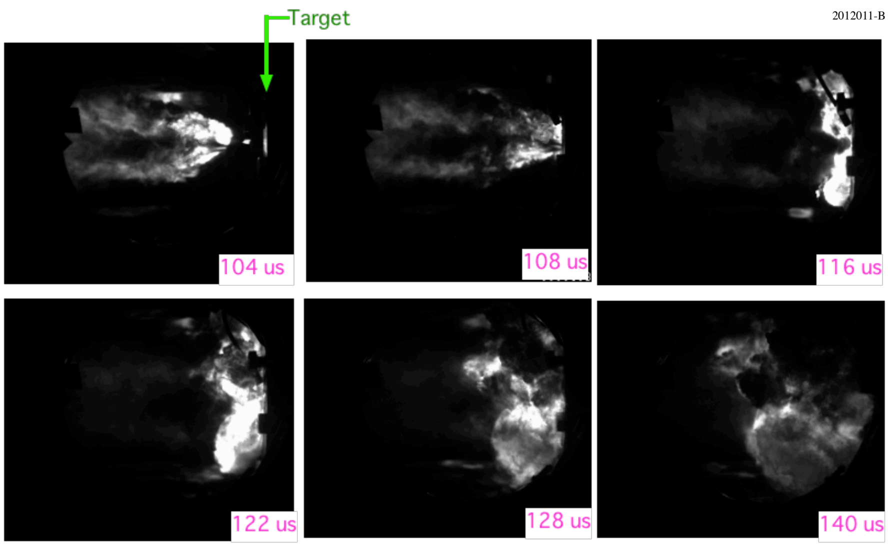

Fig. 4 Time evolution of the impact image (side view). A polycarbonate bullet hits the water & iron target under 20 C.

molecules and carbon clusters during the cooling process. After the impact, the pressurized chamber is opened and produced soot is carefully collected. The samples are measured by a TEM (Hitachi High Technologies Co., H-7650 V_{acc}= 100kV). Figure 6 shows typical example of produced particles in which many carbon particles and iron particles are included, where a polycarbonate bullet hits the iron target under 20 C. Meanwhile, a bullet hits the cooled ice & iron target, the produced material dramatically changes. Figure 7 shows a typical photo of the samples, where a polycarbonate bullet hits the ice and iron target under – 60 C. There are many polymer-like sheets (shown by arrows) and polymer- like flakes. And, we found a new structure as shown in Fig. 8, where a polycarbonate bullet hits the ice + hexane + iron target under – 60 C. We can confirm that polymer-like flakes and an iron particle are encapsulated in a spherical graphite cage for the first time. As the graphite cages are usually produced under more than 1000 C, and the evaporation temperature of polymers is less than 1000 C, it is hard to encapsulate polymers in a small graphite cage.

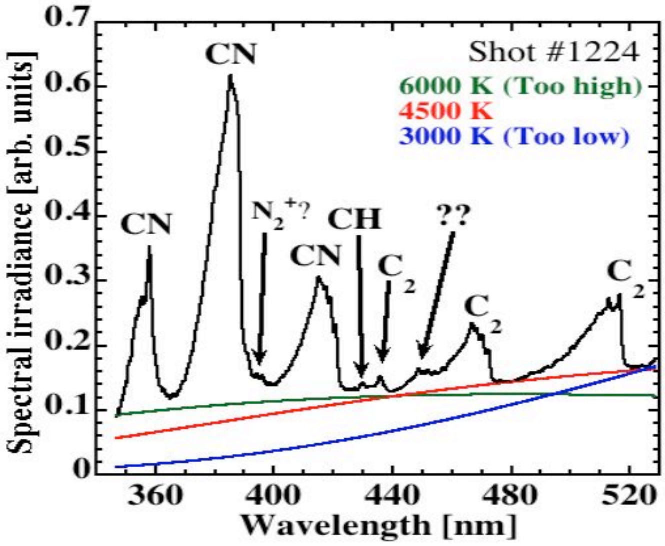

Fig. 5 An emission spectrum of the impact by a streak camera. A polycarbonate bullet hits the stainless steel target under 20 C.

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 a laser-desorption time-of-flight mass spectrometer (LD-TOF-MS) (Bruker Co., Auto Flex). Figure 9 shows one example of the spectra, where a polycarbonate bullet hits the hexane + Ni + iron target under 20 C. In the wide range of the spectrum (1-2000 Da), there is a clear signal of 133 Da, which corresponds to asparagine acid (one of amino acids). Same way, when a polycarbonate bullet hits the water + iron target under 20 C, a clear signal of glutamic acid (147 Da) in the spectrum of the LD-TOF-MS. There are several signals of nitrogen-included molecules in LD-TOF-MS spectra. As we observe CN emission spectrum in the impact, it is expected that many kinds of nitrogen-included molecules are produced, which are under study by several analysis methods.

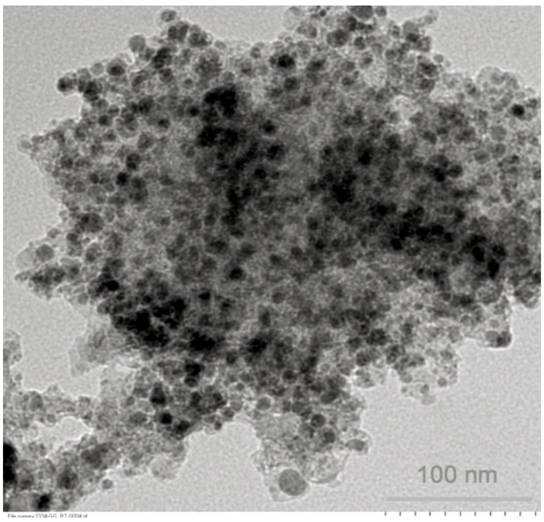

Fig. 6 A typical photo of carbon clusters and metal particles produced by the impact. A polycarbonate bullet hits the iron target under 20 C.

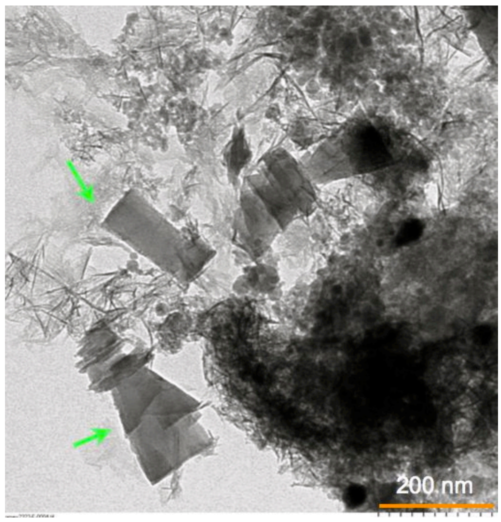

Fig. 7 A typical photo of carbon material produced by the impact. A polycarbonate bullet hits the ice & iron target under - 60 C.

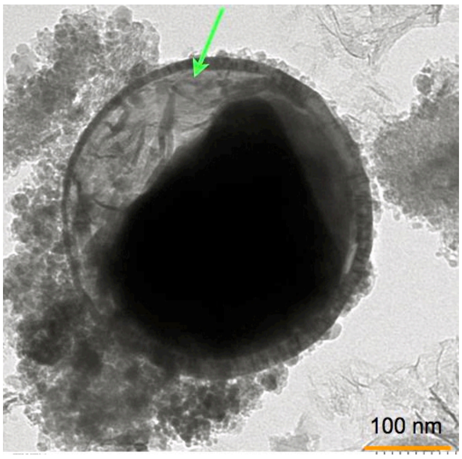

Fig. 8 An iron particle and polymer-like flakes are encapsulated in a graphite cage. A poly-carbonate bullet hits the ice + hexane + iron target.

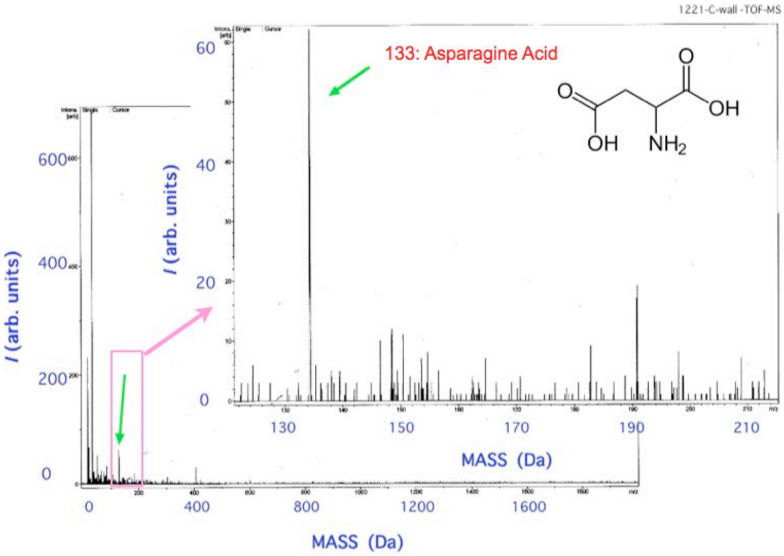

Fig. 9 Mass spectra of the sample by the LD-TOF-MS (+ ion, 50 shots averaged). A polycarbonate bullet hits the hexane + Ni + iron target under 20 C.

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 the streak camera, the emission spectrum at the impact is obtained, where emissions of CN and C_2 are clearly observed. From the blackbody emission spectrum, the gas-plume temperature is about 4500 K.

3) When ice is added in the target, nano-scale polymer-like sheets and polymer-like flakes are produced.

4) From the LD-TOF-MS measurement, mass-signals of amino acid molecules are recorded, for which several analysis methods are under study.

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

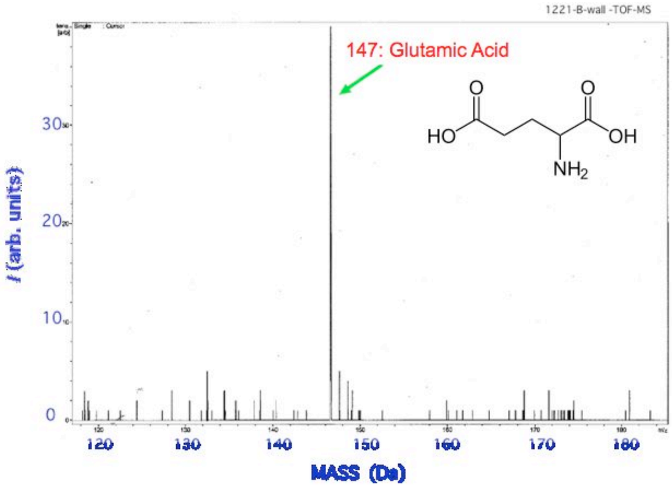

Fig. 10 A mass spectrum of the sample by the LD-TOF-MS (+ ion, 50 shots averaged). A polycarbonate bullet hits the water + iron target under 20 C.

This study was supported by ISAS/JAXA as a collaborative program of the Space Plasma Experiment.

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