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原始太陽系星雲の高温過程で形成されたコンドリュールの再現実験

Reproduction experiments of chondrules formed at high-temperature processes in the protoplanetary disk

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1. Introduction

Chondrules are solid spherical materials with a diameter of about 1 mm contained in primitive meteorites (Figure 1) and are the major component of solid particles that were suspended in the solar nebula before the formation of planets and asteroids. Chondrules are thought to have been formed by high-temperature heating (approximately 1200°C or higher) of the precursor material in the no gravity conditions of the nebula, followed by rapid cooling, but the specific formation mechanism has not been clarified. The main reason is that the structure and the elemental distribution of chondrules cannot be reproduced by ground-based experiments. In this study, we aim to reproduce chondrules in microgravity melting experiments for the first time in the world.

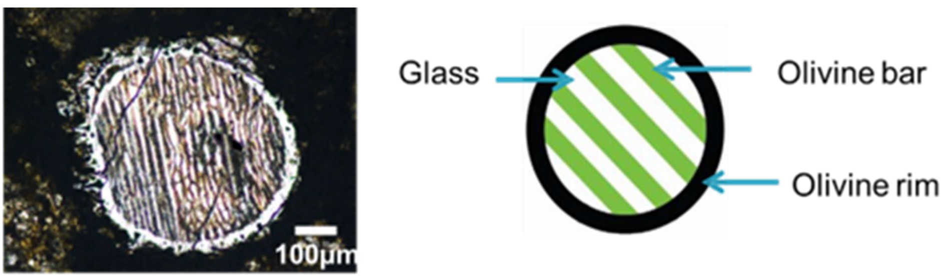

Figure 1. Barred olivine chondrule in meteorites and corresponding structure.

Chondrules are classified into several categories based on their structure (Grossman et al. 1988), and the chondrule that we will attempt to reproduce in this experiment is barred-olivine (BO) chondrule (Figure 1). We chose this type of chondrule because (i) it was formed by total melting of the precursor material, which clearly constrains the melting and cooling conditions in the experiment, and thus the high-temperature phenomena that occurred in the nebula, (ii) it has a characteristic texture (Figure 1: barred olivine and glass between them, with an olivine rim surrounding the whole structure). (iii) because it is easy to determine the success or failure of reproducible experiments.

In this study, we would like to focus on the olivine rim (Figure 1) in particular. The reason is that past ground-based experiments have reproduced barred-shaped olivine (in 3D, plate-like crystal), but not olivine rims.

2. Past experiments for BO chondrule reproduction

Over the past 30 years, experiments have been conducted to reproduce BO chondrules. Most of the experiments have been performed using high-temperature furnaces[1, 2]. Our research group also attempted ground-based experiments using (1) gas-jet levitation and laser melting (the equipment is detailed in a previous paper [3]) and (2) electrostatic levitation and laser melting, but failed to reproduce the olivine rim structure (Figure 2).

The reason for the failure is that in (1) the gas-jet levitation method, the sample is levitated by gas, which causes strong vibrations on the surface of the molten sample and strong convection currents in the melt, which inhibits crystallization of the rim (Figure 2). Therefore, (2) the electrostatic levitation method was tried, but this method also levitated the melt under high voltage against gravity, which caused strong microvibration of the melt surface, and the crystals that were first crystallized go down to the bottom of the melt, resulting in no rim formation. In addition to the surface vibration and the convection of the melt, another possible reason for the lack of successful rim formation in the ground experiments was the difficulty in attaching temperature and compositional gradients due to evaporation on the melt surface in the ground experiment. We believe that crystallization experiments under microgravity can avoid all of these causes.

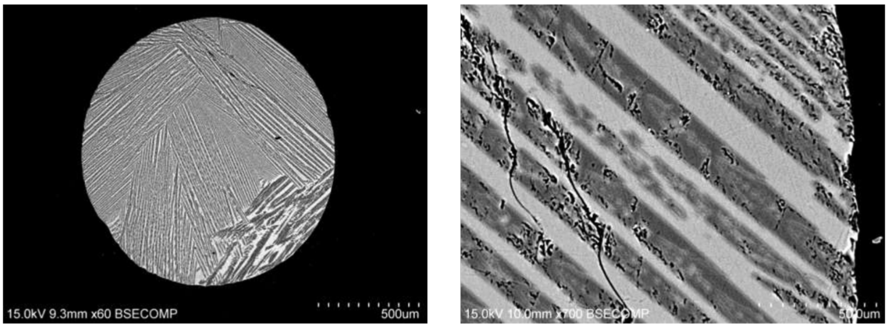

Figure 2. Experimentally produced BO chondrule without rim structure. This sample was produced by gas-jet levitation system using Ar gas. Cooling rate is 74.6℃/s.

3. Experiments at ELF

In this study, starting materials with the actual chemical composition of BO chondrules in meteorites (type I with high Mg/Fe and type II with low Mg/Fe: Table 1) will be used, and the samples are heated to a temperature (about 1800°C) above the melting point (about 1650°C) and totally melted. After confirming melting, the sample is cooled to approximately 700°C by various cooling rates (0.5 K/s to 100 K/s in the crystallization temperature range). The detailed cooling profile will be determined basis on the results of ground experiments. In developing the experimental conditions, we would like to conduct the experiment under conditions that can clarify the reason why the BO chondrule could not be achieved in the ground experiment. Table 2 shows the success criteria for our experiment.

Table 1. Chemical compositions of starting materials.

	Type I	Type II	
Na_2O	0.15	1.50	mol %
MgO	50.59	40.16	mol %
Al_2O_3	3.15	1.99	mol %
SiO_2	38.82	39.82	mol %
CaO	5.59	3.66	mol %
FeO	1.26	12.50	mol %
NiO	0.45	0.38	mol %

Table 2. Success criteria of our experiment.

Success	Criteria
Minimum Success	To obtain the temperature history of the sample from melting to solidification. To recover the solidified samples to the earth. To obtain information on the internal structure and composition of samples solidified at different rates of cooling.
Full Success	In addition to the above conditions, the following must be fulfilled: Formation of olivine bar structures as seen in natural chondrules. In addition, to obtain information on the elemental fractionation between olivine bars and the surrounding glass.
Extra Success	In addition to the above conditions, the following must be fulfilled: To reproduce chondrules with, at least parts of, olivine rim structures.

4. Summary

Since chondrules are the raw material of asteroids and the Earth, they are the most important solid particles in the formation of solar system bodies [4]. Therefore, understanding chondrule formation is a first-class issue in planetary science. Currently, the most supported model is that nebular gas is accelerated by shock waves and impacts the progenitor, causing melting and chondrule formation[5, 6]. In this case, crystallization occurs when the nebular gas is blowing against the chondrule (strongly surface oscillating). If our ELF experiment can reproduce the structure of BO chondrules by crystallization in a state of suppressed surface oscillation, it will greatly constrain the model described above. Clearly, this result will have a major impact on the model of the solar system formation.

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