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How did chondrules crystallize?

Ken Nagashima[1]; Katsuo Tsukamoto[1]

[1] Graduate School of Science, Tohoku University

http://www.ganko.tohoku.ac.jp/shigen/tsukamoto.html

Chondrules are small silicate droplets which were formed at 4.6 billion years ago. And they are thought to be crystallized from silicate melt in space. The formation conditions are still an open issue and several heating and cooling processes have been proposed and are under discussion. Simulation experiments have been done to clarify the formation conditions of chondrules in the early solar system and the experiments revealed that the cooling rate at crystallization of chondrules is required to be 10-1000 K/hr (Lofgren 1996) to reproduce the observed chondrule textures.

However, the nucleation rate during levitation is known to be reduced considerably because of the absence of heterogeneous nucleation. So, in order to understand the crystallization process of chondrules in containerless condition, we have done the crystallization experiments at the levitated and the suspended silicate melt droplets (Nagasima et al., 2006). The results showed that nucleation of chondrule melts are very difficult under levitated environment and almost chondrule melts (except for SiO_2 poor composition; i.e. forsterite) could not crystallize and turned to be glasses. Of course, chondrule melts had to be crystallized in some way; (1) cooling of partial melt, (2) annealing of glass spherule and (3) contacting with cosmic dusts. However, some textures in chondrules (i.e. radial pyroxene textures) could not be obtained by the (1) and (2) methods. Therefore, we have tried the crystallization experiments to inject dust particles into levitated droplet as heterogeneous nucleation center.

The crystallization experiments were done by using gas-jet levitator (Nagashima et al., 2006). The starting materials were silicate crystal or glass spherules (diameter =˜2mm). Starting material was set at the top of nozzle of the gas jet levitator and then levitated by introducing Ar gas from the nozzle. The levitated glass spherule was melted by CO_2 laser (100 W) irradiation. By adjusting the CO2 laser power supply, the melt temperature was decreased and then kept at a certain supercooling temperature. To investigate the seeding effect, dust particles were accreted to the supercooled melt. The nucleation process from the supercooled melt was observed by high speed CCD camera.

Crystallization of levitated enstatite melt droplets was not observed in the temperature range of the experiment during the duration of ˜1000 s, indicating that no crystallization occurred in the levitated enstatite melt droplets. In contrast, by seeding of dust particles, we succeeded to reproduce for the first time the typical radial texture, which have a single nucleation center at surface of the spherule. And natural radial textures starts from the surface, which strongly suggests that nucleation starts dust particles collided at the melt surface.

In addition, we obtained porphyritic textures at very large supercooling (= ˜400). This result is contradiction to the commonly accepted concept the porphyritic texture appears only at low supercooling as the result of regrowth of undissolved relict crystals (Nagahara, 1981). The reason why non-dendritic crystals are formed at small or large supercooling is expected by the concept of hypercooling limit (Glicksman, 1967). In hypercooled melts, a low supercooling texture is predicted to be crystallized by theoretically (Trivide and Kurz, 1994) and computer simulation (Kobayashi, 1993), because the hypercooled melt acts as a large heat sink for the absorption of the latent heat due to crystallization.