An experimental study of chondrule formation under the nebular pressures controlling gas conditions.

N. Imae[1] and H. Isobe[2], [1]National Institute of Polar Research, Tachikawa, Tokyo 190-8518, Japan [2]Kumamoto University, Chuo-ku, Kumamoto 860-8555, Japan. e-mail: imae@nipr.ac.jp.

Introduction: Chondrules have formed at the beginning of the solar system, most probably in the primordial solar nebula. The standard pressure of the primordial solar nebula has been assumed to be 1-100 Pa based on the theoretically estimated gas density. Experiments on chondrule formation have been carried out mainly under the atmospheric pressure (10^5 Pa), controlling oxygen fugacity. Experiments on chondrule formation in the pressure of the primordial solar nebula have been insufficiently carried out. We set up a new furnace controlling the nebula pressure range, and started to reproduce the chondrules. The focus is on the interaction of chondrule melt with the surrounding gas, and the condition is probable in the primordial solar nebula when the precursor materials are heated.

Experiments: The total pressure in the newly installed vacuum furnace was controlled to be ~100 Pa by a batterfly valve (Fuji Technology), indicated from the diaphragm-seal type pressure gauge (MKS Baratron Type 626). Under the condition, the hydrogen gas is introduced by the electric decomposition of water (~50 cc/min), and the total pressure nearly equals to hydrogen molecule pressure. The small chip of the Allende CV3 chondrite was used per one run with the weight of ~30-50 mg (~3 mm in size), being avoid of large CAIs. The size may nearly represent bulk composition, considering the size of chondrules. Two type experiments were carried out: one is that the charge is held in the capsule (cruicible 1 in Fig. 1), and another is that it is held and silica powder is on the bottom of the cruicible (cruicible 2 in Fig. 1).

The charge was holded mainly using the platinum (Pt) wire with the diameter of 0.2 mm for #Al runs and using the molybdenum (Mo) wire with the diameter of 0.2 mm for #Al-T runs. The absorption of iron content in the charge into Pt was much larger than that of Mo. When the capsule is heated in the furnace, the interior of the capsule is dominant of H_2 gas (Figs. 2 and 3). The expected partial pressures were calculated using the JANAF thermochemical tables.

The activity coefficients of the melt were assumed to be unity as the maximum estimation. Even if taking account into consideration of the maximum estimation of partial pressures from melt, the oxygen fugacity of the interior of the capsule is estimated to be in the range of IW-2 and IW-4.

When the silica powder is put (cruicible 2), the SiO pressure from silica is larger than that from the melt (Fig. 3). The oversaturated SiO_2 component in the gas may cause condensation of SiO_2 component into the melt during the heating.

The maximum temperatures and the cooling rates were controlled in the range of 1525-1225 ^oC (25 ^oC step) for #Al runs 13 times with the cooling rate is ~10^4/h, at the temperatures of 1450 ^oC and 1250 ^oC for #Al-S runs with the cooling rate of ~100 ^oC/h, and at the temperatures of 1450 ^oC, 1350 ^oC, 1300 ^oC, and 1250 ^oC for #Al-T runs with the cooling rate of ~100 ^oC/h.

Results: The common main mineral species from #Al runs were olivines (Figs. 4 and 5). Pyroxenes joined from #Al-S runs (Figs. 4 and 7). While, large euhedral enstatites ~several hundreds μm in size) crystallized from #Al-T1 and -T3 runs of #Al-T runs. They poikilitically enclose rounded olivines (Fig. 4). The enstatites of #Al-T5 were dominant only on the periphery (Fig. 4), and the Fe content of the enstatite is slightly higher than those of #Al-T1 and -T3. The interior of #Al-T5 was dominant of olivines. At the lower temperatures, slightly ferroan pyroxenes crystallized only near surface of the charge (Fig. 8).

Discussion: The bulk composition of the charge is saturated with olivine. Thus the crystallization of a large amount of low-Ca pyroxenes (mainly enstatites) from #Al-T runs suggests that the bulk composition changed to enstatite liquidus field from the olivine liquidus field to Si-rich composition. It has been difficult to make enstatite having the solar ratio (~1) phase of the Mg/Si ratio in the early solar nebula so far [1]. The rapid formation of enstatite in the present experiments is a new path to form enstatite in the early solar nebula. The study is also consistent with the earlier study by [2].

This study is supported by Grant-in-Aid for Scientific Research of JSPS (No. 23340165).

References: [1] Imae N. et al. (1993) EPSL, 118, 21-30. [2] Tissandier L. et al. (2002) *Meteorit. Planet. Sci., 37,* 1377-1389.

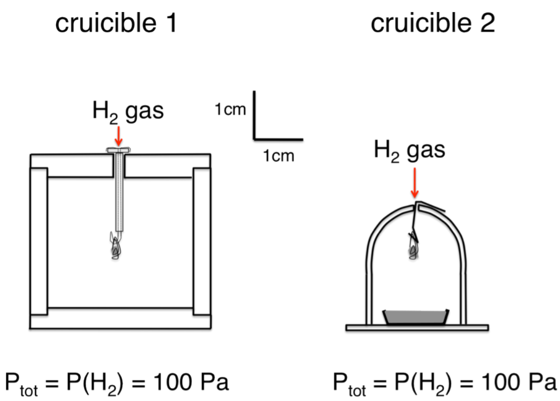

Fig. 1. Alumina cruicibles for the present experiments. The orifice diameter of the cruicible 1 and 2 is 3 mm and 1 mm, respectively.

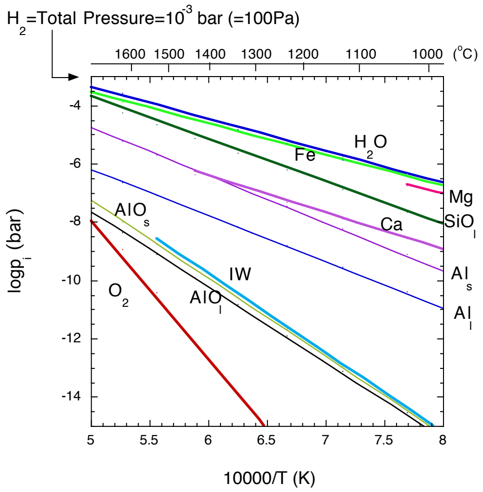

Fig. 2. Partial pressures of gas species in cruicible 1.

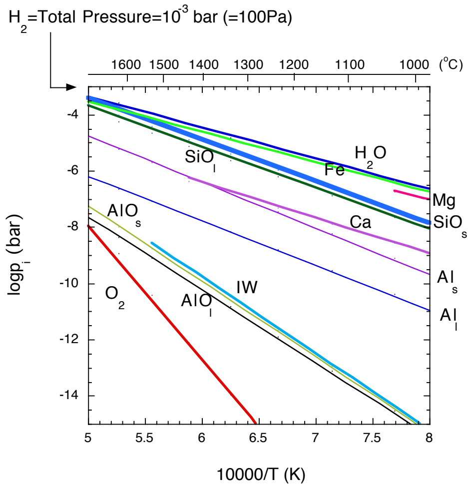

Fig. 3. Partial pressures of gas species in cruicible 2.

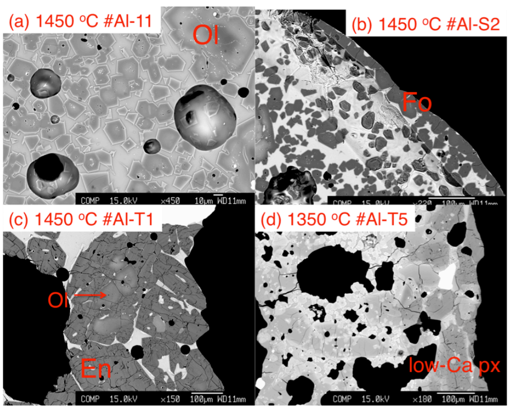

Fig. 4. Run products. Ol: olivine. Fo: forsterite. En: enstatite. low-Ca px: low Ca pyroxene.

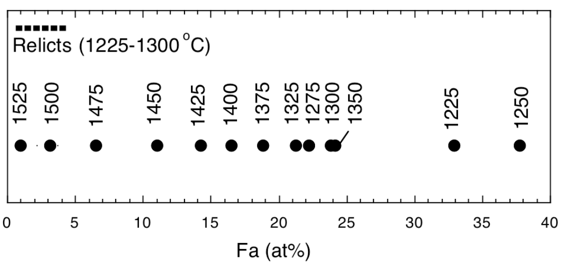

Fig. 5. Averaged olivine compositions from rapidly cooled runs (#Al-runs) using cruicible 1.

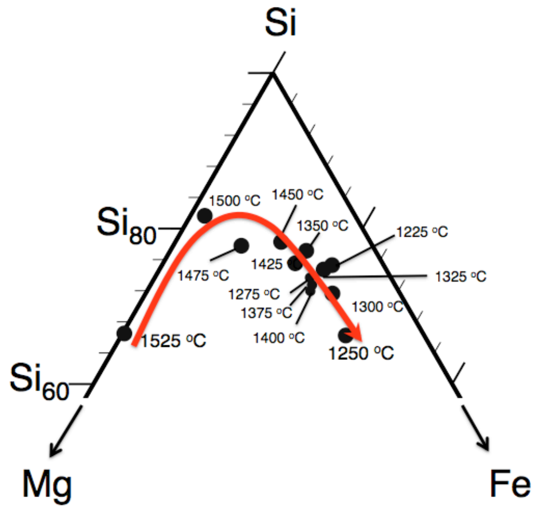

Fig. 6. Glass compositions from rapidly cooled runs (#Al-runs) using cruicible 1. Plot of atomic ratio.

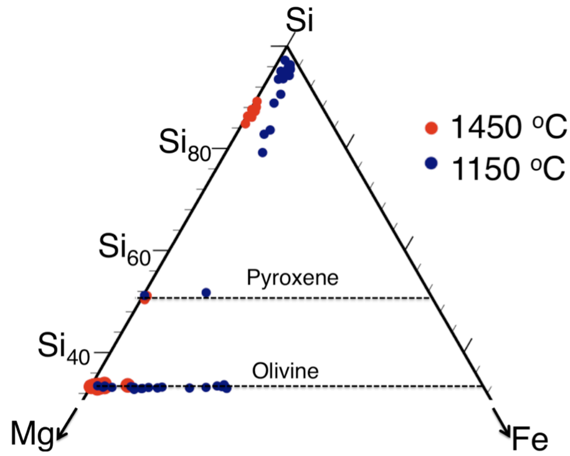

Fig. 7. Phase compositions from runs cooled at ~100 °C/h (#Al-S runs) using cruicible 1. Plot of atomic ratio.

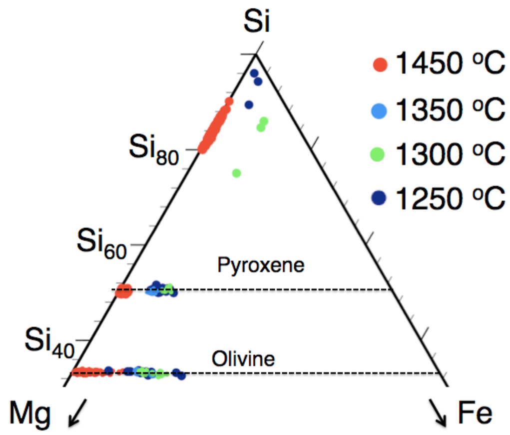

Fig. 8. Phase compositions from runs cooled at ~100 °C/h (#Al-T runs) on the gas condition of SiO_2 oversaturated using cruicible 2. Plot of atomic ratio.