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Experimental reproduction of microtexutures of chondrules and CAIs by reducing-gas levitation technique

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Chondrules are the most abundant component in chondrites. They are mm-sized round (or irregularly) shaped particles mainly composed of silicates, which formed by the rapid cooling of droplets of molten or partially molten rock in space before they accreted. They show unique and diverse internal micro-textures (e.g., porphyritic olivine, barred olivine, radial pyroxene, etc.), even if they have same bulk compositions. These internal textures, therefore, should reflect not only stating material compositions, but also nebular conditions, such as gas species and their partial pressures, heating and cooling rate. CAIs are another major component in chondrites, which are also known to show the evidence of molten and quenching textures. The conditions of chondrule formation, however, remain poorly constrained, because the reproduction of the chondrule formation processes in a laboratory is experimentally difficult, especially in terms of container-less arrangement and reducing (low-fO_2) ambient. In the present study, we conducted gas-levitation and laser heating experiments in order to reproduce micro-textures of chondrules and CAIs, and constrain their formation conditions.

As stating materials, we used (i) natural olivine (Fo_{90}) from San Carlos, USA, (ii) matrices of Murchison CM meteorite, and (iii) mixed compounds of melilite ($Ca_2Al_2SiO_7$) + spinel ($MgAl_2O_4$) which are analogue to CAIs. The molten-quenched droplets of these samples were obtained using the gas-levitation and laser-heating experiments, which avoided both contamination of the molten samples and heterogeneous nucleation by crucible surfaces, at SPring-8 BL04B2. 1-2 mm-sized droplets were heated by a continuous-wave CO_2 laser, and were levitated in 96% Ar + 4% H_2 gas to achieve reducing ambient. The temperature during heating was monitored by a pyrometer. Surfaces and internal textures of the recovered samples were analyzed using SEM-EDX and -EBSD (JEOL, JSM-6480LAII and JSM-7100F).

(i) As a result of experiments using San Carlos olivine, olivine was re-crystallized under any condition. They show micro-porphyritic texture consisting of fine grained (1 to 5 μm) olivine, which are equal in composition to the starting material. Magnetite (Fe_3O_4) or hematite (Fe_2O_3) was completely absence, which suggests the low fO_2 (at least MFQ buffer) was maintained during the present experiments. (iii) The recovered sample of Murchison CM chondrite shows barred-olivine like texture. The platy (10 μm thickness) olivine crystals (Fa_{20-40}) are embedded in a FeO-SiO_2-rich glass. Idiomorphic fine (1 μm) magnetite are also observed in the glass. EBSD analyses revealed that most of the olivine plates are normal to b-axis, and the crystallographic orientations in a parallel platelet domain are identical. (iii) As a result of experiments using melilite and spinel compounds, dendritic spinel was always crystallized from surfaces to core irrespective of sample size and cooling rates, and they are embedded in Al-rich glass phase. The demonstrations of the present study show that reducing-gas levitation experiments is a powerful technique to simulate the molten-quenched texture of early solar materials.

Keywords: Chondrule formation, Molten-quenched texture, Crystal growth, Containerless heating, Barred olivine