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In-situ visualization of crystallization inside high temperature silicate melt droplets

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Chondrules are the most significant components of a given primitive meteorite. These are small (millimeter-sized) silicate spherules, which consist mainly of forsterite and enstatite and exhibit igneous textures, implying that they were formed by heating of solid precursors and subsequent crystallization following rapid cooling from either fully or partially molten states in the primordial solar nebula. Depending upon the formation conditions, chondrules exhibit variable chemical composition and textures. In addition to the chemical composition, chondrule texture is an important factor, especially in determining the physical conditions of melting and crystallization, and their mechanisms of formation.
Crystallization phenomena of the chondrule melt precursors and the subsequent chondrule textures are intricately linked to the three-dimensional distributions of temperature field inside the melt droplet. Therefore, if one could directly observe the phenomenon of crystallization process and associated transport mechanisms inside the melt chondrule in-situ, it would contribute significantly to the ongoing efforts of investigation of the fundamental growth mechanisms. Simultaneously, radiation-based visualization techniques are required for on-line observation of the whole process of crystallization from its melt precursor. However, high temperature crystallization processes, like those associated with chondrule formation, do not permit convenient in-situ observation of the growth process primarily due to the strong radiation effects which reduce image contrast because of high background intensity. For these reasons, the in-situ visualization of crystallization process of strongly supercooled silicate melts has not been reported till date in the literature.
We report the first in-situ visualization of the crystallization process of experimentally reproduced chondrules from supercooled silicate melts using an especially designed optical projection technique. The optical technique employed aim at observing and recording the whole process of melting, the initiation of nucleation and subsequent crystallization process at temperatures as high as about 2000oC inside the undercooled silicate melt droplets, with very high visibility of the internal structures. The specific objectives of the present study are:
1. Imaging of convection inside the melt droplet at near liquidus temperature using white-light schlieren technique;
2. In-situ visualization of the whole process of crystallization within the supercooled melt volume in real time using shadowgraph technique.
3. Prediction of possible crystalline textures non-invasively using the developed optical projection technique.

The crystallization experiments are carried out for forsterite (Mg2SiO4) composition under container-less conditions. A gas-jet levitation arrangement is employed to hold the silicate spherules during the experimental run time. The spherules are heated up to their liquidus temperature using a high power CO2 laser and allowed to cool down under black body radiation conditions to initiate the crystallization process. The primary objective of in-situ visualization is to explore the potential of optical techniques for imaging melt convection at near liquidus temperatures and prediction of possible chondrule textures in real time non-destructively. To

demonstrate this, the in-situ predictions of experimentally reproduced chondrule textures are compared with the textures revealed by photomicrographs of the corresponding thin-sections and a good agreement is seen between the two observations. The overall assessment to emerge from the present study is that the refractive index-based optical techniques present a novel approach for real time observation of the crystallization processes and provide a pathway for quantitatively determine the experimental conditions responsible for the formation of various textures as observed in natural chondrules.

Keywords: Chondrules, High temperature melts, Crystallization, In-situ visualization, Schlieren, Shadowgraph