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Metastable liquidus of radial pyroxene chondrule melts: Investigation with supercooling experiments

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Since 1980s, many researchers have tried to reproduce chondrule texture experimentally, and found that chondrules were formed at the cooling rate about 100-1000 K/hr. However, the driving force which forms a crystal texture is theoretically dependent mainly on supercooling temperature but cooling rates. We have conducted experiment to reproduce chondrule from the melts of forsterite, enstatite, and so on. Typical chondrule texture was produced from large supercooled melt (e.g., Nagashima et al., this meeting's report on 2000-2002). We here report the experimental results of melt crystallization of natural-like radial pyroxene chondrule (MgO: 30.34, FeO: 7.71, CaO: 1.72, Al_2O_3: 3.40, Na_2O: 0.31, SiO_2: 56.52 wt.% = $En_{74.5}Fe_{14.1}An_{8.8}Ab_{2.6}$) under various supercooling (up to 500 K).

The experiment was conducted with infrared image furnace of an FZ instrument. Starting material was heated at more than melting point, 1480 deg C and checked it had melted completely. Then, it was cooled rapidly (within 10s.) and held at constant temperature below a melting point. Crystallization started after waiting induction period. Since there is almost no temperature change during induction period (+/- 5 K), this experimental method can suppress the heat fluctuation, which contributes to nucleation. Starting material was held on the Pt wire loop with a diameter of 4mm. Sample temperature was measured with a near-infrared pyrometer. When crystallization started, the temperature increased by release of latent heat of crystallization. Temperature and CCD camera image during experiments were entirely recorded by a data logger and video recorder, respectively. Obtained run-products were observed with optical microscope and electron microprobe.

When the supercooling is less than 180 K, samples turned into glass. And supercooling is 180-300 K, we observed very long forsterite barred crystal which stretched the whole sample. These crystals were arranged in parallel toward the almost same orientation. The width of barred texture is about 10-20um. The interval of barred texture was the same as the width of it. The supercooling is over 350 K, the volume percent of glass increases as supercooling becomes large. When over 500 K, samples turned into glass but there were some enstatite spherulites into glass.

Our previous rapid cooling experiments (Nagashima et al., 2000) revealed that enstatite could be crystallized from enstatite melt. In this experiment, however, forsterite always nucleated and developed barred texture from the radial pyroxene melt composition.

According to classical nucleation theory, free energy required for nucleation is defined as a*r^3(Tm/LdT))^2 (a: constant, r: interfacial tension, Tm: melting point, L: latent heat of fusion, dT: supercooling temperature). So, forsterite liquidus, enstatite metastable liquidus and interfacial tensions between them are important to decide which crystals nucleate from melt. The formation of enstatite spherulite suggested that the free energy for nucleation of enstatite could have been less than that of forsterite at the temperature. Resultantly, the ratio of interfacial tensions r(en)/r(fo) was estimated to be 0.68-0.70.

Our obtained result suggests that enstatite crystal nucleates prior to forsterite if the supercooling temperature of enstatite melt (SiO_2: 59.85 wt.%) is over 210-280 K. However, if SiO_2 wt.% decreases only 1%, over 310-480 K and 3% is over 470-600 K. Nevertheless, the crystallization texture is not radial texture even if enstatite crystal nucleates from very large supercooled melt. We confirmed to reproduce radial enstatite texture in the similar rapid cooling experiment using $En_{68.0}Fe_{9.6}An_{8.4}Ab_{2.0}Qz_{3.0}$ melt (SiO_2: 62.55 wt.%). In order to produce radial pyroxene chondrule, following conditions could be necessary: (1) melt composition with more SiO_2-rich than in $MgSiO_3$; otherwise, (2) heterogonous nuclei promoting enstatite nucleation such like dusts.