Estimation of crystallization temperature of chondrules from levitated hypercooled melt droplets

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In order to understand the condition for the formation of typical radial pyroxene and barred olivine chondrules, the crystallization process of Enstatite (MgSiO3) and Forsterite (Mg2SiO4) melt droplets (2 ~ 3 mm, diameter) were observed in-situ. Experiments were performed under microgravity condition, which was realized by the parabolic flight of airplane and under containerless condition, which was levitated by supersonic.

Under normal gravity experiments, all Enstatite melt droplets were crystallized from the heterogeneous nucleation center to form radial pyroxene texture. The crystallization temperature was about 1050 ~ 1100 deg C (supercooling, 450 ~ 500 deg C) and crystal growth speed was 1.0 ~ 1.5 mm/second. Under microgravity, only small amount of Enstatite melt droplets were crystallized from the Pt wire (0.1mm, diameter) leaving the other parts being glass. In aero-acoustic levitation experiment under normal gravity, no crystallization could be seen at high supercooling (~ 500 K). These results suggested that heterogeneous nucleation center was necessary to form Enstatite crystals and very high supercooling was necessary to form radial texture.

Barred texture in Barred olivine chondrule had to be crystallized from low supercooling melt, because of it's flat face. However, double structures at Barred olivine chondrule can be crystallized from very high supercooling (700 K) using aero-acoustic levitation experiment (Tsukamoto et al., 1999). These results were contradictory to each other. Barred texture has a flat face on ground, which it was crystallized from very large supercooling such as over hypercooling limit. Hypercooling limit is defined as enthalpies of fusion divided by specific heat. Hypercooling limit of Forsterite, which is the main component of barred texture, is 347 K from theoretical calculation. That is much lower than the experiment results, 700 K. But then, in aero-acoustic levitation experiment, radial olivine was crystallized from supercooled melt at 850 K. Therefore, it was shown that barred texture can not be formed when supercooling was too large. From these results, it is concluded that Barred olivine chondrules were crystallized from about 1100 ~ 1600 deg C (supercooling, 300 ~ 800 K). In addition, Radial pyroxene chondrule seems to be crystallized from hypercooled melt, since radial texture was formed by hypercooled melt of Forsterite experimentally. Consequently, hypercooling limit of Enstatite, which is the main component of radial pyroxene chondrule, is 450 ~ 550 K from theoretical calculation. This temperature was almost the same as 450 ~ 500 K of supercooling in which radial texture was formed experimentally. However, Enstatite became glass if the supercooling was too high. Therefore, it was necessary for Enstatite to be crystallized at the temperature higher than glass transition temperature (about 750 deg C). That is, in order to form Radial pyroxene chondrule, heterogeneous nucleation is fundamental at the temperature between about 800 to 1100 deg C. The most qualified candidate of heterogeneous nucleation center was dust that probably existed around.

These data concluded that both chondrules were crystallized from very large supercooling and formed within about 1 second. And it is indicated that chondrules were formed in a very rapid process rather than it was thought previously.