Solidification experiments of Fe-FeS melt to estimate the cooling histories of chondrules

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Chondrules are sub-millimeter sized silicate spherules formed by instantaneous heating of solid precursors at the early stage of the solar system evolution [e.g., 1]. In order to constrain the chondrule formation mechanism, it is important to understand the thermal history of chondrules. Crystallization experiments of chondrules have shown that chondrule precursors were heated up to 1800–2200 K and cooled at the rate of 10–1000 K/h [e.g., 2]. The absence of isotopic fractionation of sulfur isotopes in chondrule sulfides indicates that chondrule precursors were heated at the rate of $>10^4$ K/h [3]. However, there is no tight constraint on the cooling rate of chondrules at lower temperatures (below the solidus of silicates) although it would provide information on formation environments of chondrules. In this study, we focus on eutectic solidification textures of iron and iron sulfides to develop a new cooling speedometer for chondrules.
Powders of Fe metal and FeS were mixed with a ratio close to the Fe-FeS eutectic composition (slightly enriched in S) to prepare starting materials for the experiments. The mixed powder was sealed in an evacuated silica glass tube with graphite, heated at 1400 degree C, and quenched in water. The quenched sample was grinded into 50-300 micron-sized powder. For solidification experiments of Fe-FeS melts, the starting materials were dispersed in silica wool, and sealed in a silica glass tube with FeS and graphite under vacuum. Pieces of FeS and graphite were put in the tube in order to suppress evaporation of sulfur from the sample and to make a reducing environment. The sealed tube was heated at 1330 degree C for 3 hours and cooled down to ~300 degree C with different the cooling rates of 25, 100, 500, and ~10,000 K/h. The run products were embedded in resin, and the polished sections were observed with FE-SEM-EDS (JEOL JSM-7000F, Spatial resolution: ~0.1 micron). The sizes of metallic iron grains were analyzed with the image analyzing software ImageJ.
The size distribution of metal grains changes with cooling rates. Iron metal grains become larger in samples cooled at slower rates. The typical size of metal grains formed below the eutectic temperature is 1-2 microns for the cooling rates of 25 and 100 K/h and smaller than 1 microns for the cooling rates higher than 500 K/h. The quenched sample (~10,000 K/h) contains dendritic/fan-shaped metal grains.
We compared the size distribution of metal grains in run products with those in opaque assemblages in CR chondrules (the images of opaque phases within CR chondrules were kindly provided by Devin Schrader, ASU). With the cooling speedometer developed in this study, we found that a part of the chondrules cooled at a rate slower than 25 K/h and others cooled at the rate faster than 500 K/h.
References
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