Numerical study on chemical zoning of olivines at chondrule formation

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Chondrules are millimeter-sized and spherical silicate objects contained in chondritic meteorites. It is considered that chondrules were formed from dust aggregates (precursors), which experienced melting and subsequent rapid solidification in some flash heating events. Chondrules include some silicate minerals such as olivines, in which chemical zoning is observed. The chemical zoning reflects environmental change during solidification. However, it has not been understood what zoning profile is recorded in minerals when the actual thermal history experienced by chondrules is considered.
In this study, we carried out the numerical simulations of melting and growth processes of an olivine crystal in a flash heating event in order to investigate the zoning profile recorded in the crystal. Because the chemical composition of the growing crystal differs from that of the ambient liquid phase, incompatible elements are swept out to the liquid phase (element partitioning). We considered the element partitioning at the crystal-liquid interface and the element diffusion in the solid and liquid phases at the calculation. As the numerical method, we adopted a phase-field method combined with the ideal solution model of Mg-Fe olivine.
First, we considered a simplified thermal history, which is divided into three periods: heating at a constant rate, isothermal at peak temperature, and cooling at a constant rate. Olivine was melted at the heating and isothermal periods. At the cooling period, olivine was turned to growth and the chemical zoning was formed. The zoning profile did not depend on the heating rate and the duration of the isothermal period significantly, but varied with the cooling rate. In addition, we confirmed a local minimum in the Fe concentration at the position where the olivine was turned to growth.
Second, as the more realistic situation, we considered the thermal history predicted by a shock-wave heating model. We found that the slope of the zoning profile agreed with that predicted by a theoretical model [1], which considered the cooling period only. These results suggested that the chemical zoning of olivine crystals formed during chondrule formation mainly reflects the cooling condition.
References: [1] H. Miura and T. Yamamoto (2014), The Astronomical Journal 147, 54 (9pp).

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