The reproduction of type I chondrules and the implications

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The origin of chondrules would play key role in elucidating the origin of the solar system, but it has not been included in the dynamic model for the formation so far (e.g., Batygin et al., 2016). This is because the models have not been unified but several formation stages and places have been considered. The experimental study is indispensable for specifying them. Recently, we succeeded in reproducing type I chondrule, consisting of magnesian silicates (Fe#≤10), in the Knudsen cell using newly designed vacuum furnace on the experimental condition of 0.001 atm the total pressure dominant of hydrogen gas, 1450 ºC peak temperature, 100 ºC/h cooling rate, and oxygen fugacity of IW-2 to 3.8, from chondritic starting materials (Imae and Isobe, 2017). The synthetic type I chondrule formed via evaporation of FeO component in the charge and condensation of SiO_2 component. There are mainly three important implications; (1) precursors of chondrules, (2) physico-chemical conditions during the chondrule formation, and (3) isotopic fractionations during the chondrule formation, and discuss the implications in the following.

(1) The experiments suggested the chondritic precurors including fine-grained silicates implying the dust-aggregates or planetesimals for chondrule precursors. The flash heating event would have occured in these precursors. The complemental feature for bulk compositions of chondrules and matrices is also consistent with the precursors (e.g., Hezel and Palme, 2010).

(2) Silicate liquid is stable under the higher pressure (~1 atm) than the solar nebula gas (Yoneda and Grossman, 1995). On the other hand, silicate liquid is also stable under the dust enriched system at the total pressure of ~0.001 atm usually assumed in the solar nebula (Wood and Hashimoto, 1993; Ebel and Grossman, 2000). The present experiments support the latter condition. On the other hand, type II chondrules may have formed at the formed condition (Tsuchiyama et al., 1980). The physico-chemical environment in the Knudsen capsule satisfies the x100 dust enriched system compared with the solar nebula gas, in which it has been predicted that the silicate melt is stable based on the thermodynamic calculation (Ebel and Grossman, 2000). The present experiments thus suggested that type I chondrule would have formed under the low pressure (0.001 bar) rather than high pressure ($\geq$ 1 bar) to form silicate melt stably.

(3) Isotopes of natural chondrules are not fractionated for major elements (Mg, Fe, and Si) (e.g., Mullane et al., 2005; Hezel et al., 2010; Dauphas et al., 2015). The environment in the Knudsen cell in the present study also suggests that any severe isotopic mass dependent fractionations for rock forming cations (Si, Mg, and Fe) are not expected in the present experimental environment since the Kudsen cell would surpress them (e.g., Young et al., 1998). This is very contrastive with the observations of that significant amount of mass dependent fractionations from evaporation residues in the vaccum furnace (Wang et al., 1999), FUN inclusions of CAIs (Davis and Richter, 2003) and some cosmic spherules (Alexander et al., 2002).

In conclusion, if any isotopic fractionations for these elements do not occur in the experiments, then the phenomena would be consistent with the observation of natural chondrules. The isotopic measurements of the run products would thus support the implications.

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