Condensation experiments in the system of Mg-Si-O and its application to formation of silicates around evolved stars

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Magnesian silicates are major constituents of dust particles in protoplanetary disks and circumstellar environments. Their sizes, shapes, compositions, and crystalline/amorphous ratios reflect their formation histories, and thus understanding of formation processes of Mg crystalline/amorphous silicates leads to estimation of physical and chemical conditions in dust-forming environments. Condensation of Mg silicate dust particles is one of the most crucial processes for dust-formation, and several experimental studies have been done under plausible low-pressure conditions [e.g., Nagahara et al., 1988; Tsuchiyama, 1998]. However, quantitative discussion on kinetic processes has not been made in previous studies due to experimental difficulties. We report here preliminary results of kinetic condensation experiments in the Mg-Si-O system using infrared vacuum furnace, where partial pressures of condensing gas and supersaturation ratios can be estimated, and discuss non-equilibrium condensation behaviors of Mg silicates.

A single crystal of forsterite put in a graphite capsule was heated at ˜1850 K by focusing infrared lights from halogen lamps. The graphite capsule was used as an infrared-light absorber, but it may react with oxygen evaporated from forsterite to form carbon monoxide, which may affect condensation behaviors of silicates. We carried out experiments with forsterite powder put in an iridium crucible for comparison.

Gaseous Mg, SiO, and O evaporated from forsterite were condensed on a substrate of molybdenum plate, put at various distances from forsterite to control condensation temperatures from 1310 to 650 K. The total pressure in the silica glass vacuum chamber was ˜1E-5 Pa, and the experimental duration ranged from 24 to 72 hours. Condensates were observed with FE-SEM, and their chemical compositions and crystallinities were determined by EDS and EBSD.

In experiments using a graphite capsule as a container of forsterite, condensation did not occur at tempeartures higher than 1310 K, Si condensed as molybdenum silicide at ˜1130 K, and amorphous Mg silicates condensed at temperatures lower than 840 K. Condensates in the present study are different from those formed in the Mg-Fe-Si-O system [Nagahara, 1988] and in the Mg-Si-O-H system at a total pressure of 1.4 Pa [Tsuchiyama, 1998]. Very little condensates were found in Tsuchiyama, I998) at the total pressure of 0.14 Pa and lower, which is consistent with the present study. Partial pressures of Mg and SiO above the molybdenum substrate were estimated to be much larger than equilibrium vapor pressures of forsterite, MgO, and SiO2, indicating that such mineral phases could be condensed in the present experimental conditions. However, such phases, all of which require encounter of different gas species on the substrate for heterogeneous nucleation, did not condense in this study. SiO condensed as silicide probably due to reduction on the substrate, which required no other gas species. Globular amorphous Mg silicates condensed at lower temperatures, which could be because condensation of relatively-volatile SiO was allowed with lowering temperatures, and Mg began to condense once amorphous SiO (or SiO2) formed. These condensation behaviors could be due to smaller incoming fluxes of Mg, SiO, and O onto the substrate than those in previous studies with condensation of crystalline silicates.

Preliminary results from condensation experiments using an iridium crucible as a container of forsterite, i.e., experiments under more-oxidizing conditions, also show that aggregates of 10-nm sized globular Mg silicate condensed at lower temperatures, while platy angular Mg silicates condensed at higher temperature. No observable condensates were found at the highest temperature, but Si was detected by EDS anlyses, implying that Si condensed as an alloy into molybdenum. Further detailed results will be reported at the meeting.