

DUST CONDENSATION EXPERIMENTS AT CONTROLLED LOW PRESSURE CONDITIONS

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Introduction: Condensation of solid from gas is a crucial process for formation of solid in circumstellar environments. For instance, dust particles observed around evolved stars spectroscopically should be formed by condensation of gas, and such circumstellar dust grains have been observed in chondrites as presolar grains. Some chondritic components such as fluffy Type-A CAIs (Ca-, Al-rich inclusions), amoeboid olivine aggregates, and metallic iron grains with Ni zoning in CH chondrites show the signatures of condensation during their formation. Condensation with accompanying separation of solids also played an important role in making volatility-controlled chemical diversities in solar-system materials.

Equilibrium condensation calculations predict thermodynamically equilibrium mineral assemblages as a function of temperature in a system of fixed pressure and gas compositions though, condensation does not necessarily occur in equilibrium. Dust forming conditions and environments vary with time in circumstellar environments, and thus it is quite important to understand condensation kinetics of solids. Moreover, equilibrium calculations do not provide any information about the size and number density of condensates and the texture of composite grains, which can only be examined by kinetics.

Surface-reaction-controlled Condensation Kinetics: The reaction rate is controlled by the slowest step of the process (the rate-limiting step). In the case of direct condensation of solid from low-pressure disk gas, the rate-limiting step is generally the surface atomistic process and the rate is expressed by the Hertz-Knudsen equation [1];

$$J_c = \frac{\alpha_c p - \alpha_e p^{eq}}{\sqrt{2\pi mkT}},$$

where p is the pressure of condensing gas species, p^{eq} is the equilibrium vapor pressure, m is the weight of the condensing gas molecule, k is the Boltzmann constant, and T is temperature. α_c and α_e are condensation and evaporation coefficients representing kinetic hindrances of condensation and evaporation. α_c and α_e should be a function of pressure, temperature, and gas compositions, which makes it difficult to predict them theoretically, and thus they should be determined by experiments under well-controlled conditions.

Condensation Experiments: There have been many experimental studies on evaporation of major minerals in chondrites such as forsterite, enstatite, metallic iron, and troilite [e.g., 2-7], while it has not been easy to carry out condensation experiments under controlled low-pressure conditions for quantitative

discussion on kinetic processes. However, recent progresses of experimental studies have made it possible to determine the growth kinetics of major minerals [7, 8]. Here we report the growth kinetics of major minerals from vapor obtained by our recent condensation experiments. Condensation and evaporation of corundum, as well as their anisotropy, will be reported by [8] at the meeting.

Condensation of Metallic Iron: Condensation experiments of metallic iron were carried out under known pressure conditions of metallic iron vapor, which was generated by evaporation of metallic iron heated in a vacuum furnace [7]. It was found that α_c is almost unity at 1235 and 1337 K for a supersaturation ratio S of >10 . This suggests that metallic iron grows without large kinetic hindrance. In the experiments, metallic iron nucleates easily on a corundum substrate, indicating that metallic iron can form without significant delay for homogeneous nucleation.

Condensation of Forsterite: We recently reported the condensation experiments on forsterite at ~ 1340 K and at 1 Pa of the H_2 - H_2O mixed vapor [9], where vapor evaporated from a gas-source forsterite condensed on a forsterite substrate placed at a cooler part of a vacuum furnace. The experimental conditions were much more similar to protoplanetary disk conditions and better controlled than those in previous studies. We succeeded to obtain 10-100-nm-sized crystalline forsterite as condensates on the forsterite substrate. The α_c of forsterite estimated in these experiments is smaller than 0.05, which indicates the presence of larger kinetic hindrance for condensation of forsterite than that for metallic iron.

Formation of troilite: Troilite (FeS) formation experiments in the He- H_2S mixed gas at 1 Pa showed that the formation rate of troilite is controlled by the surface reaction and that α_c is in the order of 0.02 at ~ 770 K [10]. The obtained α_c is consistent with that predicted by a simple collision theory [11].

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