

Formation of nanoparticles in gas phase

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Nucleation and growth processes of nano-crystallites are same as that of bulk crystal or on a substrate?

In nanoparticles, it has been known that the melting point decreases and diffusion coefficient becomes larger. For example, the melting point of gold (1336 K) decreases to 950 K as the particle size decreases to 2-3 nm [1]. In addition, the diffusion coefficient of copper atoms in gold nanoparticles changes to 8.3×10^{-19} from 2.4×10^{-28} ($\text{m}^2 \text{s}^{-1}$) in the bulk at 300 K [2]. The shifts of solid state properties induce a new formation process, which was named coalescence growth, of nanoparticles. Coalescence growth is regarded as an important formation process of nanoparticles. Coalescence among the smoke particles was explained in terms of two stages: a liquid-like coalescence stage and a surface melting coalescence stage [3]. These two stages depend mainly on particle size and temperature. The liquid like coalescence predominantly occurs in smaller size than surface melting coalescence. In liquid-like coalescence, when nanoparticles with several nm in diameter are contact each other, they fused together like water droplets but in solid state. If two different kinds of particles are met, a single compound particle can form. For example, iron and nickel nanoparticles make a tetrataenite nanoparticle. Namely, tetrataenite does not need direct nucleation from gas phase. Surface melting coalescence occurs, when the surface temperature of the particle is higher than surface melting temperature, which depends on the surface Debye temperature. In this growth mode, when two kinds of different particles are coalesced, chemical compound can be produced at the interface by diffusion. On the formation of nanoparticles, we have to understand the singular properties appeared only in nano-scale, because even in the pathway for over the size of critical nucleus is different from that on general crystallization model, such as BCF theory, in a view of bulk material.

Understanding of the growth of nanoparticles is very important not only for the field of crystal growth but also for planetary science. Since the initial size of the cosmic dust is on the order of ~ 100 nm or smaller, significant effects due to nanoparticle interactions must be understood to model the growth and evolution of cosmic dust. Since cosmic dust formed in very low gas atmosphere, it condensed directly from the gas phase. Because cosmic dust is a basic ingredient of primitive objects, smoke experiments are useful studies to discuss the evolutionary history of our solar system. Although astronomical conditions cannot be exactly duplicated in the laboratory, smoke experiments are favorable production methods for dust analogies. When an evaporant is initiated in an inert gas, rising smoke from the evaporation source can be observed. The evaporated vapor subsequently cools and condenses in the gas atmosphere, i.e., solid grains are obtained directly from the gas cloud. Using such methods, several nm to micro-m sized particles can be produced. The morphology and particle size are the result of the mass density and the temperature of the smoke, which depend on the atmospheric gas and gas pressure.

Results of experimental studies of cosmic dust to determine their characteristics such as optical properties, formation conditions and crystal habits, can then be compared with the actual material. Recently, fresh cometary dust was recovered from Wild 2 by the Stardust Mission. Since then, experiments on cosmic dust analogs will be more essential to reproduce observed characteristics. In this study, we will show a formation of nanoparticles concerning nucleation and growth, and apply to evolution of cosmic dust.

References

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