

Dust Formation from Vapor through Multistep Nucleation in Astrophysical Environments

Kyoko K. Tanaka

Tohoku University
email: kktanaka@astr.tohoku.ac.jp

Cosmic dust grains are believed to form in outflows in the late stages of evolution of stars such as AGB stars and supernovae. The condensation and crystallization processes are important for understanding the origin of cosmic dusts and have been seen by various observations. For instance, the silicate dusts condense in outflows with amorphous structure, as evidenced by the broad and smooth appearance of around $9.7\ \mu\text{m}$ spectrum of silicate. Some observations suggest an increase in the fraction of crystalline as it cools from an intrinsic change in optical properties of the dust (Waters *et al.* 1996). Despite the transition from vapor to solid is a familiar process, the process is not fully understood yet. One reason is that size of nuclei is usually very small ($< \text{nm}$) and the properties of nuclei are poorly understood.

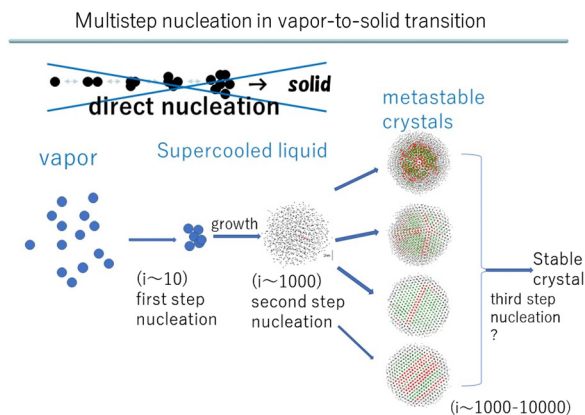


Figure 1. Overview of vapor-to-solid transition obtained by our molecular dynamics simulation (Tanaka *et al.* 2017).

In the study, we present molecular dynamics (MD) simulations of vapor-to-solid phase transition with a simple potential model (Lennard-Jones type) and discuss the transition process. In the simulations, the nuclei of supercooled liquid appear and growth. After the growth of nuclei, the crystallizations of supercooled nano-clusters are observed and the crystallized nano clusters have various structures of metastable phase (Tanaka *et al.* 2017). Our simulations indicate that the vapor-to-solid transition occurs through multistep nucleation which is vapor-to-liquid nucleation (first step nucleation) and crystallization in the supercooled liquid droplets (second step nucleation), even though the temperature is much lower than the triple temperature (Fig. 1). Recent experimental studies support the multiple processes of nucleation for various substances including

silicate materials (Kimura *et al.* 2012, Ishizuka, Kimura & Sakon 2015). Our results with the experiments indicate that the multistep nucleation is a common phenomenon in the first stage of condensation from vapor to solid in the astrophysical environments.

This work was supported by JSPS KAKENHI Grants No. 18K03689 and No. 15H05731.

References

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