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CRYSTALLIZATION PROCESSES OF CIRCUMSTELLAR SILICATE DUST

ABSTRACT

Observations with the Infrared Space Observatory (ISO, 1995-1998) have revealed that silicate dust is partially crystallized in circumstellar environments of young and evolved stars, and allowed us to discuss detailed dust mineralogy and processing. Mineralogical information from astronomical observations reflects physical and chemical conditions of formation and processing of circumstellar dust. Since then, a new scientific field called “astromineralogy” has been opened. This thesis is related to this young scientific field. In this thesis, we focused on crystallization process of amorphous silicate materials in circumstellar environments, since the crystallization is a fundamental process to formation of the important and major component of dust: crystalline silicates. The crystallization reflects physical and chemical conditions, especially at high temperature around 1000 K, where dust particles have been formed and processed. Using amorphous silicate materials synthesized by a sol-gel method, we have carried out laboratory simulations of crystallization process in circumstellar environments of young and evolved stars.

This thesis consists of four parts (chapter 2-5). In chapter 2, we evaluated quantitatively the time constant of enstatite crystallization in the Johnson-Mehl-Avrami equation, and determined the activation energy of crystallization. The result suggested

that enstatite can be crystallized only in the inner disk region around young stars and in the vicinity of the condensation zone around evolved stars. In stellar winds of evolved stars, the final degree of crystallization of silicate dust has very large dependence on the condensation temperatures.

A detailed IR spectroscopy of enstatite sample produced in chapter 2 was carried in chapter 3. There is a discrepancy between the IR feature of enstatite obtained in this experiment and that obtained in the previously reported experiments using the single crystals, due to stacking faults. We discovered that astronomical observed dust emission of enstatite is similar to the IR feature measured in this experiment.

In chapter 4, crystallization kinetics of olivine from an Fe-bearing amorphous silicate is discussed. We suggested that crystallization processes in circumstellar regions should depend on the properties of amorphous silicates, such as the existence of crystallites and/or the Fe content.

We also show in chapter 5 the first experimental evidence that Fe-depleted olivine can be formed by crystallization processes via thermal heating of FeO-bearing amorphous silicates. In the past, there has been an inconsistency in compositions between coexisting crystalline and amorphous phases. Our discovery that the crystallization process is involved in Mg/Fe fractionation can answer the composition paradox of the coexistence of Mg-rich crystalline silicates and Fe-bearing amorphous silicates around stars.