How forms observed low-temperature crystalline silicate: Approach from laboratory experiments

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Astronomical observations have shown the existence of abundant silicate grains around evolved stars in the infrared spectra. It has been realized that most of the silicate grains are amorphous phases based on the infrared features. In contrast, characteristic infrared features attributed to Mg-rich crystalline silicates have been reported in limited number of evolved stars with high mass loss rate (>10^{-5} M_{sun}/yr) [1]. The fraction of the crystalline silicates, particularly forsterite, is typically 10-15 % in the outflows with high mass loss rate of asymptotic giant branch (AGB) stars [2]. During the formation of silicate grains, whether a silicate grain becomes crystalline or amorphous depends sensitively on its formation conditions. To elucidate the crystallization condition of amorphous silicate, several laboratory experiments have been attempted. It has been known that crystalline forsterite grains are formed at a slower cooling rate (<~700 K/s: [3]) or by later annealing (~1000 K: [4]) of previously condensed amorphous grains. Crystallization has generally been discussed on the basis of thermal annealing [5]. However, it seems to be unrealistic to find a mechanism of partial annealing occurred only at the stars with high mass loss rate, because the crystallization of silicate is very sensitive in temperature. In addition, some implications of low-temperature crystallization have been reported from the astronomical observation of both young and evolved stars [6-8]. Generally, the temperatures of the crystalline silicate grains astronomically observed are at as low as 100-250 K. In contrast, warmed amorphous silicates in a stationary circumstellar disk were observed [9]. Therefore, it can be considered that the crystallization of silicates may be not affected by thermal heating.

In this situation, I would like to propose that the astronomically observed crystalline forsterite can be formed by direct condensation from the vapor phase of magnesium and silicon oxide. It was found that the crystallinity, which was deduced from the shape of the 10 μm feature, of the circumstellar silicates could be determined by the balance between heat generation by Mg oxidation and heat dissipation due to radiation. In this case, later annealing of the silicate fraction or the use of a warm substrate for condensation of crystalline silicate is unnecessary. In addition, to explain the existence of highly crystalline silicate grains (75% of total silicate) observed in some silicate carbon stars, the possibility of low-temperature crystallization is presented based on electron irradiation on amorphous Mg-silicate grains, because the environment of the envelope is very low in temperature for the crystallization of silicates due to annealing [10].

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