Spherical silicate particles as analogues of circumstellar dust: IR spectral features and crystallization kinetics.

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It is widely accepted that amorphous silicate dust in circumstellar regions of evolved stars are formed by condensation of outflowing gas. Cicumstellar crystalline silicate dust are formed either by crystallization of these amorphous dust or direct condensation from the gas. In order to discuss the possibility of the crystallization origin, amorphous silicate condensation and crystallization experiments have been carried out.

We synthesized spherical amorphous particles by condensation of melt droplets from high-temperature gas and quench using ITP (induction thermal plasma) method. Two kinds of amorphous silicate particles with forsterite and enstatite compositions 50-200 nm in diameter were synthesized at Nisshin Engineering Co. Ltd. Two types of experiments were made; (1) IR spectrum measurement of spherical crystalline particles, which were made from the amorphous particles, for comparison with IR spectrum observation and (2) heating experiments for crystallization kinetics of the amorphous silicates.

(1) IR spectra of spherical forsterite and enstatite. Spherical particles of forsterite and enstatite were made by heating amorphous particles with forsterite composition at 800^{o}C for 24 hrs. and enstatite composition at 750^{o}C for 60 days, respectively. Observed 11 μm, 16 μm, 23 μm and 33 μm bands can be explained by spherical forsterite grains [1]. The 9.1 and 9.3 μm double peaks observed around evolved stars can be identified as the feature from the spherical enstatite grains. These results strongly suggest that spherical grains of forsterite and enstatite dust exit around evolved stars.

(2) Crystallization experiments. The amorphous materials were heated at constant temperatures at 600- 850 ^{o}C (forsterite) and 780-850 ^{o}C (enstatite) for durations from 0.5 to 240 hr. The degrees of crystallization of forsterite and enstatite were obtained from the IR spectra of run products. The time evolution of the crystallization was evaluated using Johnson-Mehl-Avrami equation, and the crystallization time constant, τ, and kinetic parameter, n, were obtained. The n values are ~1.5 and ~2.5 for forsterite and enstatite, which correspond to three-dimensional diffusion-controlled growth without nucleation and three-dimensional crystal growth with constant nucleation rate, respectively. Temperature dependence of τ shows Arrhenius relation, which gives the activation energies, E_a/k, of 2.8×10^4 K and $8.6\pm0.1\times10^4$ K for forsterite and enstatite, respectively. These values are similar to those in previous experiments with different chemical compositions [2,3]. TTT diagram for the forsterite and enstatite crystallization suggests that circumstellar crystalline silicates around evolved stars can be mainly explained by partial crystallization of pyroxene from SiO_2-rich amorphous silicate. It is also suggested from the TTT diagram that olivine and pyroxene crystallization occur in outer and inner regions, respectively, in an accretion disk around a young star.

[1] Koike et al. (2010) Astrophys. J., 709, 983-992. [2] Murata et al. (2007) Astrophys. J., 668, 285-293. [3] Murata,et al. (2009) Astrophy. J., 697, 836-842.