

Condensation experiments in the system of Mg-Si-O using an infrared vacuum furnace

Shogo Tachibana[1]; Shinnosuke Tamada[2]; Hiroko Nagahara[3]; Kazuhito Ozawa[4]

[1] Earth and Planet. Sci., Univ. of Tokyo; [2] Department of Earth and Planetary Physics, The University of Tokyo; [3] Dept. Earth Planet. Sci., Univ. Tokyo; [4] Univ. Tokyo, EPS

Magnesian silicates such as forsterite and enstatite are major minerals in the solar system and in circumstellar environments. It is thus crucial to understand evaporation and condensation behaviors of magnesian silicates in order to understand evolution of solid in space.

In this study, we developed a new infrared vacuum furnace, and performed condensation experiments in the system of Mg-Si-O in order to understand condensation behaviors of magnesium silicates at low pressures.

We designed a vacuum furnace consisting of a silica glass (~300 mm in length and 40 mm in outer diameter) tube connecting to a turbo molecular pumping system, two infrared heating systems, and a quadrupole mass spectrometer. The ends of a silica glass tube was sealed to Fe-Ni-Co alloy and to vacuum flanges by changing chemical compositions of ends of the tube in order to obtain high vacuum. The vacuum in the furnace reached down to $\sim 10^{-6}$ Pa. Infrared heating systems consist of halogen lamps and gold mirrors, and light from halogen lamps is focused by gold mirrors to heat a sample located in the silica glass tube. Temperature was controlled by a Pt-PtRh₁₃ thermocouple closely located to the sample.

A single crystal of forsterite was used as a gas source of Mg-Si-O system. Because forsterite is transparent against infrared light, it was put in a graphite capsule for effective heating. The heating temperature was controlled at $\sim 1650^\circ\text{C}$, but the obtained evaporation rate of forsterite suggests that the actual temperature of forsterite may have been several tens degrees lower than the controlled temperature.

A substrate of molybdenum plate was put at various distances from the gas source to change condensation temperatures from 1145-480°C. Condensation experiments were carried out for 24-72 hours at a pressure of $\sim 10^{-5}$ Pa.

The condensates were observed with a field-emission scanning microscopy, and their chemical compositions and crystallinities were determined by EDS and EBSD equipped with FE-SEM.

No condensation occurred on the substrate at 1145 and 1040°C except for small amounts of platinum, which was from the thermocouple, as Mo-Pt alloy. No silicate condensed at 860°C either, but silicon condensed as Mo-Si alloy. Amorphous silicates condensed at temperatures of 570 and 480°C. Such condensates found in the present study are different from those formed in the Mg-Si-O system in previous studies (Tsuchiyama, 1998; Ogawa et al., 2006), where crystalline forsterite and enstatite and amorphous silicate condensed on substrates depending on temperatures.

Gas analyses by the quadrupole mass spectrometer showed that the graphite capsule reacted with residual gas in the furnace or oxygen evaporated from forsterite to form CO and CO₂ molecules. If most of oxygen from forsterite reacted with graphite, the Mg : Si : O in the gas phase available for condensation might be 2 : 1 : smaller than 4 (or even ~ 0). Neither graphite nor SiC was observed as condensates, implying that the C/O ratio was not larger than unity, and thus forsterite could have condensed in this study. However, no crystalline forsterite was found in this study, which may be because encounter of three different molecules containing Mg, Si, and O are rare due to low total pressure or low abundance of oxygen. Although more systematic experiments are needed, the present study indicates that crystalline forsterite cannot condense at ~ 850 K at pressures as low as circumstellar conditions around evolved stars, but amorphous silicates condense.