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Solid-Gas Reaction between Forsterite and Si-rich Gas: An experimental study

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Magnesium and silicon are the major rock-forming elements to form silicate dust in space. The Mg/Si ratio is ~1 in the solar system elemental abundance, and equilibrium condensation models for the solar abundance predict that forsterite reacts with Si-rich gas to form enstatite at lower temperatures. This solid-gas reaction determines the extent of Mg/Si fractionation since the atomic ratio of Mg/Si in the solid changes from 2 of forsterite to 1 of enstatite, and may have caused the Mg/Si fractionation between solid and gas as seen in chemical groups of chondrites.recorded between dust and gas.

It is thus important to understand the enstatite-forming reaction between forsterite and Si-rich gas. Imae et al. [1] have carried out the experiment between forsterite and Si-rich gas with double capsule technique, where a chip of forsterite in an inner Mo capsule was put in a larger outer Mo capsule containing cristobalite. The double capsule was heated in vacuum at 1378-1550^{o}C, and forsterite in the inner capsule was reacted with Si-rich gas generated from cristobalite. The forsterite was covered with reaction products, which were polycrystalline clinoenstatite, and the thickness of the reaction layer reached up to ~20 micron. However, their experimental temperatures were much higher than the temperature range for enstatite formation in space.

In this study, we carried out solid-gas reaction experiments between forsterite and Si-rich gas at lower temperatures than those in [1] using a newly developed vacuum furnace designed based on a molecular beam epitaxy system. A single crystal of quartz was heated by a tungsten-coil heater at ~1650^{o}C to generate Si-rich gas. A chip of single crystal of forsterite was put ~250 mm above the gas source and heated ~800 or ~900^{o}C by an infrared heating system. We also annealed some of reaction products at 1 atm and 800 or 900^{o}C for 48 hours to see the effects of annealing.

The reacted surface of forsterite looked almost the same as the starting material, regardless of experimental conditions. EDS analyses at the accelerating voltages of 3-5 kV indicate that the surface of forsterite was covered with a very thin layer consisting of Si and O. Although we could not determine the thicknesses of the layer, this observation is consistent with the expected thickness of the reaction layer estimated from the gaseous flux onto the forsterite substrate (less than 1 micron). EBSD analyses showed that the reaction layers formed at ~900^{o}C for 48 hours were amorphous. On the other hand, the surface of the layer additionally heated at 900^{o}C for 48 hours at 1 atm showed crystalline features, which could be attributed to quartz.

Although we cannot exclude a possibility of crystallization at the interface between forsterite and the amorphous condensates, our preliminary results imply that enstatite formation by a reaction between forsterite and Si-rich gas or by annealing of forsterite and Si-rich amorphous may not be expected at temperatures in mass-loss winds from evolved stars. Direct kinetic condensation from gas could be possible formation mechanism of enstatite in space.

References

[1] N. Imae et al. , Earth and Planetary Science Letters. 118, 21-30 (1993).