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Condensation experiments of Mg-silicates in the system of Mg2SiO4-H2O-H2

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Condensation from vapor is a fundamental process responsible for dust formation in protoplanetary disks. The kinetic aspect of dust formation should be quantitatively understood to evaluate the size, the number density, and the chemical variety of dust particles. Condensation experiments of Mg-silicates, dominant dust species, were performed in previous studies, but it has not yet been fully possible to make quantitative discussion on kinetics because there are still some experimental difficulties. Here we report our recent improvements of the low-pressure infrared furnace and experimental techniques for condensation experiments of magnesium silicates under protoplanetary disk conditions. The concept of condensation experiment in this system is as follows; vapor evaporated from a gas source is condensed onto a substrate placed at a cooler region of the chamber. We use synthetic powder of forsterite put in an iridium crucible as a gas source and a synthetic single crystal of forsterite as a substrate.

The infrared vacuum furnace used in this study consists of a silica glass tube, connecting to a turbo molecular pump and a rotary pump, and two infrared heating systems. The chamber is connected to a gas line to flow a mixed gas of H2 and H2O. The H2O vapor is supplied by flowing H2 through a water vapor saturator, in which an opened microtube containing distilled water is placed. The total pressure in the chamber is controlled by a balance between a pumping speed of the pump system and the gas flow rate. The pressure range of 100-0.1 Pa, close to that of protoplanetary disks, is fully covered in the present system. Considering the condensation temperature of Mg-silicates, the temperature of the substrate is required to be controlled within the temperature range of ˜1600-1100 K. The temperature calibration of the substrate is done by using an irreversible transition of orthoenstatite to protoenstatite at 1258 K. In order to make a controlled supersaturated condition at the surface of the substrate, the gas source is required to be heated at a constant temperature higher than the substrate temperature. We heat the gas-source forsterite, located at the focal point of the two lamps, at a constant lamp current, and have found that the evaporation rate of the gas source shows a clear correlation with the lamp current. The temperature of the gas source at the lamp current of 16.3 A is estimated to be 1900-1950 K by a pyrometer, which is consistent with the estimate based on the measured evaporation rate and the evaporation coefficient. The H2O/H2 ratio of the ambient gas is controlled by the temperature of the water vapor saturator, and can be checked by the weight change of water in the microtube. The ratio is well controlled at the ratio expected from the saturation pressure of H2O at a fixed temperature, including the solar H2O/H2 of ˜10-3. The SiO/H2 ratio of the gas hitting the substrate is determined from the evaporation rate of the gas source. Because a part of evaporated gases condense onto the wall of the silica tube, its effect should be evaluated. Our preliminary experiment on condensation of metallic iron onto an alumina substrate, of which condensation coefficient is nearly unity, under the same experimental condition showed that ˜1 % of evaporated gas hit the substrate surface. The SiO/H2 ratio at the surface of the substrate could be ˜0.4 x the solar ratio at the total pressure of 5.3 Pa and at the lamp current of 16.3 A.

In summary, the low-pressure infrared furnace has been developed and improved to simulate the dust growth under protoplanetary-disk conditions. We will use the furnace to determine the condensation kinetics of forsterite as a function of temperature, pressure and gas chemistry, which will be reported at the meeting.

Keywords: condensation, protoplanetary disk, kinetics, silicate