Evaporation and Condensation Experiments of Corundum under Circumstellar Conditions. A. Takigawa[1], S. Tachibana[2], H. Nagahara[3], and K. Ozawa[3], [1]Dept. of Geology and Mineralogy, Kyoto University, [2]Dept. of Natural History Sci., Hokkaido University, [3]Dept. of Earth and Planetary Sci., University of Tokyo

Introduction: In circumstellar environments such as extended atmospheres around AGB stars or protoplanetary disks, solid dust particles condense from high temperature gas. Equilibrium condensation models predict that corundum (Al_2O_3) is one of the first condensates from gas of the solar composition, and it is thus an important mineral that can potentially record the onset of dust formation process in circumstellar environments. Corundum belongs to the trigonal crystal system and growth of anisotropic crystals also often undergoes anisotropically and results in formation of crystals with a specific crystallographically anisotropic shape. The processes responsible for dust evolution in space are condensation and evaporation of solid. In this study, I conducted evaporation and condensation experiments of corundum in order to obtain the anisotropic evaporation and condensation rates quantitatively and understand the dust formation condition in circumstellar environments.

Evaporation & Condensation Experiments: Three rectangular single crystals of corundum (3-5 x 10 x 0.5 mm^3), of which largest surfaces were {0, 0, 0, 1}, {1, 1, -2, 0}, and {1, -1, 0, 0} planes (sample C, sample A, and sample M, respectively), were prepared for evaporation and condensation experiments of corundum. The <0001>* and <11-20>* orientations of corundum correspond to the crystallographic c- and a-axes, respectively. The <1-100>* direction, which is perpendicular to the plane containing the a- and c-axes, called m-planes, is referred to as the m-axis hereafter. Evaporation experiments were conducted in a vacuum chamber with a tungsten mesh heater. Samples C, A, and M were put in the furnace together in each experiment. Samples were heated at 1598, 1677, or 1787°C for duration ranging from 24 to 200 hrs. Condensation experiments were conducted in another vacuum chamber with a tungsten mesh heater. The chamber was evacuated to high vacuum (~10^{-5} Pa) and a pellet made of alumina powder (11.5 mmϕ x 5 mmL) was put at the bottom of an iridium crucible (15 mmϕ x 40 mmL) as a gas source. The weight of the pellet was measured before and after each experiment to obtain the evaporation flux from the pellet. Samples C, A, and M were used as substrates for condensation. In each experiment, one or a few corundum substrates were put on an Ir pedestal set at 40 mm from the bottom of the crucible. The temperatures of the gas source (T_{gas}) and the substrates (T_{sbst}) were 1705°C and 1575°C, respectively.

Results and Discussion: (*Evaporation experiments)* Evaporation rates along the c-, a-, and m-axes (V_c, V_a, and V_m) were calculated from the weight losses and the original shapes of the three starting samples [4, 5]. The evaporation rate along the m-axis is largest and that along the c-axis is smallest at 1600-1790°C ($V_m >> V_a > V_c$). The ratios of V_m/V_a and V_c/V_a are about 2.2 and 0.6, respectively. The evaporation coefficients of corundum, the parameter showing the degree of deviation from the ideal evaporation rate due to kinetic hindrances, are ranges 0.1-0.01.

(Condensation experiments) The weight gain of each substrate divided by the effective front surface area (c-, a-, and m-substrates) increased almost linearly with time. The obtained condensation rates along the c-, a-, and m-axes are 0.49±0.01 x 10^{-7}, 0.62±0.01 x 10^{-7}, and 1.42±0.01 x 10^{-7} g/cm^{2}s, respectively. The condensation rates along the c-, and a-axes are ~0.3 and ~0.4 times smaller than the fastest rate along the m-axis. In order to determine the supersaturation ratio of condensation, the flux of the gas molecules hitting the substrates was evaluated. The flux of Al atoms hitting the substrates (u) is calculated to be 2.0 x 10^{-7} g/cm^{2}s using the conductance of the crucible, the evaporation flux of the gas source, an equilibrium vapor pressure of corundum at T_{gas}, the evaporation coefficients of corundum, and the actual condensation flux onto the substrates. The supersaturation ratio on the front surface of the substrates (S) is given by the ratio between u and the equilibrium vapor pressure of Al for corundum at T_{sbst}, and the S in the present experiments is estimated to be ~5. The condensation coefficient of corundum under the present experimental condition is <0.1.

Mass absorption coefficients of condensed corundum: We calculated IR mass absorption coefficients of ellipsoidal corundum with various aspect ratios. The shape difference of corundum was found to be distinguished with the peak positions and their relative intensities in the 10 μm band. The peak position of 13 μm feature, commonly observed from O-rich AGB stars, is well reproduced by corundum ellipsoid slightly flattened along the c-axis (r_c/r_a ~0.7), which is consistent with the aspect ratio of corundum condensates expected from the present experiments (r_c/r_a ~0.79). The width of the observed 13 μm peak is also well reproduced if the grain size is ~1 μm in diameter, or a thin coating of amorphous alumina is present on a corundum grain. If the condensed corundum grains re-evaporate by high-temperature thermal events, the aspect ratio of the grains could approach to unity by ~75 % of evaporation and exceed unity by further evaporation. However, the outflow from the evolved star is basically a monotonically cooling system, and re-evaporation is hardly expected to change the morphology of condensed corundum except for episodic high-temperature heating events such as propagation of shockwaves. These results strongly suggest that the carrier of the observed 13 μm peak is corundum condensates.