In-situ synthesis of silicate dust particles by flash heating

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In order to simulate the dust condensation process following the flash heating and rapid cooling environment rising up by shock wave or by lightning in the early solar nebula, dust nucleation and dust growth experiments of the dust particles were conducted. For accurate measuring the vapor pressure and vapor temperature, the nucleation experiments were conducted under microgravity environment to suppress the thermal and concentrational convections.

Forsterite and enstatite were used as starting materials for the nucleation experiment. The starting materials were heated rapidly by tungsten filament under microgravity. The nucleation process of the dust particles was observed in-situ by CCD camera with macro lens. For the dust growth experiments, CO2 laser ablation method was applied for the heating. Although the dust growth experiments were conducted under gravity condition, the convection effects were suppressed by placing a graphite roof 5 mm above the forsterite sphere and by collecting the dust particles along the lateral direction. The experiments were done in Ar atmosphere with Ptotal = 1.0-10000 Pa.

In order to measure the temperature field around the melt, gas temperature around the melt was measured by thermocouples (diameter: 0.1 mm). The partial pressure of the silicate vapor was estimated by the measurement of the thickness of the deposit film from the interference fringes and by the measurement of the weight loss of the starting materials. The dust particles condensed from the vapor was observed by FE-SEM and TEM. The identification of the dust particles was done by analysis of the electron diffraction and measurement of their chemical composition by EDS.

Dust nucleation process was successfully observed under the microgravity environment. The first nucleated particle was amorphous SiO2, while the second nucleated particle was amorphous MgSiO3. The forsterite, which is stable at high temperature, did not nucleate. Thus the metastable phases such as amorphous SiO2 and MgSiO3 can be nucleated prior to the stable forsterite. The in-situ observation under microgravity was found to be a very useful technique to judge which phase nucleated first in very short duration (within 3.0 seconds).

The forsterite was found to grow after the 60 seconds heating. The forsterite form was systematically changed with the variation of temperature and supersaturation of the vapor. As decreasing the temperature and hence increasing the supersaturation of the vapor, forsterite form was changed from bulky type (T= 1000–1450 deg.C, ln(K/Keq): lower than 3) to platy type (T= 700–1000 deg.C, ln(K/Keq) = 4-8), columnar and needly type (T = 500–820 deg.C, ln(K/Keq)= 8-12) and droplet type (T: lower than 500 deg.C, ln(K/Keq): higher than 12).

The growth step was found on the bulky and platy forsterite surface, so the forsterite grow directly from the vapor under this supersaturation region. On the other hand, the surfaces of the columnar and needly forsterite were covered with an amorphous layer. This observation clearly shows that the VLS growth was the dominant growth mechanism for the forsterite under this high supersaturation condition. The vapor supersaturation dependent growth mechanism could be explained by the existing of the metastable liquid phase. The comparison of the forsterite form with the natural olivine form in a primitive meteorite suggests that the olivine particles grew in the highly saturated vapor, which stabilized the metastable forsterite melt.

These experimental results strongly suggest that the primitive dust particles were formed from highly supersaturated vapor which was evaporated following the chondrule melt formation by flash heating.