

## Effects of anisotropic evaporation of forsterite on infrared spectroscopy

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Forsterite ( $Mg_2SiO_4$ ), one of the major minerals in circumstellar environments and meteorites, plays a key role in physical and chemical evolution of a protoplanetary disc because of its abundance and larger Mg/Si ( $\approx 2$ ) ratio than that of the solar abundances ( $\approx 1$ ). Astronomical observation has revealed the presence of crystalline forsterite in protoplanetary discs based on spectrum energy distributions (SED) [e.g., van Boekel, R. et al. (2004)]. Because interstellar silicates are almost exclusively amorphous, amorphous silicate dusts must experience crystallization during disc evolution and are expected to evaporate at high temperature regions in the disc.

Forsterite evaporate congruently in a wide range of conditions. Because its evaporation in vacuum is anisotropic (Ozawa et al., 1996), it is also expected that forsterite evaporates anisotropically in the presence of hydrogen gas, which is a dominant gas species in a protoplanetary disc. Anisotropic evaporation changes the size and shape of the pre-existing grains, so that it should also change the SED. In order to investigate the evaporation anisotropy of forsterite in hydrogen gas, we conducted experiments on evaporation of forsterite in a vacuum chamber made of stainless steel with a tungsten mesh heater, into which hydrogen gas is introduced through alumina pipes. A single crystal of forsterite was cut into rectangular parallelepipeds, about  $1 \times 3 \times 4$  mm in size, for the starting material. A set of three crystals with largest area vertical to one of the a-, b-, or c-axes was put together in the furnace for each experiment. The samples were heated at 1535C for a desired duration (1.5-30 hours). Hydrogen gas was introduced in the furnace at 500C and the pressure of hydrogen ( $p(H_2)$ ) in the chamber during experiments was kept at 0.01-1 Pa. Evaporation experiments in vacuum without hydrogen gas at the same temperature were carried out for comparison. Evaporation rates along three crystallographic axes were calculated from the weight losses and the original shapes of three starting materials (Nagahara and Ozawa, 1996).

Evaporation rates of forsterite ( $V$ ) in hydrogen gas are much faster than those in vacuum and increase with  $p(H_2)$ . The evaporation rates seem to increase linearly with  $p(H_2)$

$\sim 0.5$ , which is consistent with an prediction from the kinetic theory of gases. The rates are 10-30 times smaller than the ideal rate as found in many previous studies probably due to kinetic hindrances of surface atomistic processes. The evaporation rate is anisotropic in hydrogen gas as well as that in vacuum (Ozawa et al., 1996), which is fastest along the c-axis and slowest along the b-axis. The degree of anisotropy is, however, different from that in vacuum: the  $V_c/V_b$  ratio for evaporation in hydrogen gas is  $\sim 3.0$ - $2.8$ , while that for evaporation in vacuum is  $\sim 4.7$ , where  $V_b$  and  $V_c$  are the evaporation rates along the b- and c-axis, respectively. The  $V_a/V_b$  ratio seems to decrease with increasing  $p(H_2)$  and vary from  $\sim 2.8$  in vacuum to  $\sim 1.0$  for  $p(H_2)=1$  Pa. The  $V_c/V_a$  ratio seems to vary from  $\sim 1.7$  in vacuum to  $\sim 2.7$  for  $p(H_2)=1$  Pa. The difference of anisotropy in evaporation rates in hydrogen gas from that in vacuum indicates that forsterite grains tend to have platy shapes in the direction of the c-axis when they were heated in a high-temperature region of protoplanetary discs, whereas grains that evaporate in a circumstellar environment may have a rod-like shape elongate along the b-axis. Such a difference in crystal shapes and/or in sizes results in different shapes of SEDs even if forsterite is a dominant crystalline phase.