Anisotropy of isotopic fractionation of Mg and diffusion of Mg during evaporation of forsterite

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Isotopic fractionation of a solid material due to kinetic evaporation is controlled by the evaporation rate (v), diffusion rate (D), size of the solid (X), and kinetic isotopic fractionation factor (alpha) [1]. Understanding of such fundamental parameters for kinetic evaporation allows us to elucidate high temperature events in the early solar system, of which signatures may have been recorded in primitive meteorites and interplanetary dusts. In this study, we measured Mg isotopic compositions of forsterite, one of the most common minerals in the solar system, evaporated in vacuum at a rate of v [2], by depth profiling with ion microprobe to determine alpha for Mg and D(Mg) based on a diffusion-controlled evaporation model.

Depth-profile measurements of Mg isotopes along each crystallographic axis showed diffusion profiles of Mg isotopes induced by preferential evaporation of lighter isotopes, where isotopically fractionated regions were limited within several tens of µm from the surface.

The diffusion profiles along different crystallographic axes of a sample heated at 1692 degrees C were not identical and alpha and D(Mg), both of which were obtained by fitting the profiles with the diffusion-controlled evaporation model, showed anisotropy. D(Mg) is larger along the c-axis than those along the a- and b-axes. Similar anisotropy was found for Fe-Mg diffusion in olivine [3]. D(Mg) along the a-axis at 1692-1504 degrees C agrees well with that in [1], and that along the c-axis seems to be consistent with the extrapolation of [4] from lower temperatures.

Alpha is farthest from and closest to unity along the c-axis and b-axis, respectively. The degree of anisotropy of alpha is the same as that seen in evaporation rates [2]. We also found temperature dependences of alpha along the a, b and c-axes for samples heated at 1692-1504 degrees C. It was clearly seen that alpha is farther from unity at higher temperatures. Moreover, we have found that the values of alpha in this study were always closer to unity than the square root of mass ratios expected from the kinetic theory of gases. These lines of evidence suggest that isotopic fractionation of Mg due to evaporation of forsterite cannot be attributed only to difference of detaching velocities of isotopes from the surface and that some surface kinetic processes should play a role in kinetic isotopic fractionation.

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