

Evaporation experiments of SiC in low-pressure H₂-H₂O gas mixtures: Implication for the survivability of presolar SiC grains under the oxidative protosolar disk conditions

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Presolar SiC is a good indicator of the physicochemical conditions of the protosolar disk because of their thermodynamically unstable nature under relatively oxidative conditions of the disk gas (e.g., Larimer and Bartholomay, 1979). Mendybaev et al. (2002) conducted evaporation experiments of SiC under controlled oxygen fugacity (f_{O_2}) conditions at 1 atm and discussed the survivability of presolar SiC grains in the disk. However, the kinetics obtained at 1 atm may not be applicable to the low-pressure disk conditions. In order to investigate the survivability of presolar SiC grains in the disk, we conducted evaporation experiments of SiC in a low-pressure H₂-H₂O gas mixture.

The starting material was a polycrystalline β (3C)-SiC plate with dimensions of $\sim 4 \times (4-5) \times 0.6$ mm synthesized through the chemical vapor deposition technique. β -SiC is a major polytype of presolar SiC grains (Daulton et al., 2003). Experiments were conducted at 1450–1250°C and 0.5 and 2.5 Pa of an H₂-H₂O gas mixture ($P_{tot.}$) for 4–110.3 h using a temperature vertical vacuum furnace equipped with a gas flow system. In the gas flow system, water vapor from deionized pure liquid water kept at a room temperature was mixed with hydrogen gas supplied from a gas cylinder. The H₂/H₂O ratio in the experiments at $P_{tot.}$ of 0.5 and 2.5 Pa was estimated to be ~ 225 and 420, (i.e., P_{H_2O} of 2.2×10^{-3} and 6.0×10^{-3} Pa), respectively, based on the amount of liquid water consumed and the total gas flow rate. The sample weight and dimensions were measured with an ultra-micron balance and a micrometer, respectively, to estimate evaporation amount of the sample. FIB lift-out sections of some samples were prepared with a FIB-SEM (Hitachi NX2000), and analysis of the thin sections were carried out with a STEM-EDS (JEOL JEM-2800).

Thermodynamical calculations suggest that solid SiO₂ is not expected to form under the experimental conditions. STEM-EDS analysis of the heated samples showed that there was no excess of oxygen near their surface in EDS spectra. These results suggest that evaporation of SiC would have proceeded via active oxidation (SiC (s) + 2H₂O (g) = SiO (g) + CO (g) + 2H₂ (g)) (Narushima et al., 1997). The evaporation rate k (cm s⁻¹) was estimated from the weight loss and original size of the sample as in Takigawa et al. (2009), and the k was converted to the evaporation flux J (g cm⁻² s⁻¹). The J depends only weakly on temperatures higher than 1350–1400°C, while larger temperature dependence of J was observed at temperatures < 1300°C. The J at $P_{tot.}$ of 2.5 Pa is ~ 2 –3 times larger than that at $P_{tot.}$ of 0.5 Pa at temperatures > 1400°C, while the J at $P_{tot.}$ of 2.5 and 0.5 Pa is the same within the variance of several experimental results at temperatures < 1300°C. These results imply that the transition of the rate-limiting step occurs at ~ 1300 – 1350°C , and a similar transition was also observed in SiC evaporation experiments with the H₂-H₂O gas mixture at 1 atm (Kim and Readey, 1989). The little dependence of the J on temperature above 1300–1350°C indicates that the supply of water vapor is a rate-limiting step, and the difference between the values of J at $P_{tot.}$ of 0.5 and 2.5 Pa is broadly consistent with the difference in P_{H_2O} because the flux of water vapor is proportional to P_{H_2O} . The temperature-dependent J at $T < \sim 1300^\circ\text{C}$ is similar to those obtained at f_{O_2} of IW-3 and IW-6 reported by Mendybaev et al. (2002).

We found that presolar SiC grains are unlikely to survive heating events associated with the igneous CAIs formation ($\sim 1400^\circ\text{C}$ and $P_{H_2O} > 0.1$ Pa for ~ 2 –3 days; Yamamoto et al., 2021, 2022). It was also found that presolar SiC could survive better than presolar silicates whose presolar signature would be erased by

O-isotope exchange with disk gas, but could not escape complete evaporation under the conditions where O-isotopic exchange between presolar corundum and disk gas occurs effectively in the protosolar disk.

Keywords: Presolar grains, SiC, evaporation kinetics, protosolar disk