

Mg diffusion in forsterite from 1250–1600 °C

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ABSTRACT

²⁶Mg tracer diffusion coefficients were determined in single crystals of pure synthetic forsterite (Mg₂SiO₄). Isotopically enriched powder sources both acted as the ²⁶Mg source and buffered the activities of silica (a_{SiO_2}) at forsterite + protoenstatite (Mg₂Si₂O₆) (high a_{SiO_2}) and forsterite + periclase (MgO) (low a_{SiO_2}). Experiments were conducted at atmospheric pressure between 1250 and 1600 °C, and at oxygen fugacities (f_{O_2} s) between 10⁻¹² bars (CO-CO₂ mix) and 10^{-0.7} bars (air). The resulting diffusion profiles were measured along the three principal crystallographic axes (a , b , and c ; \parallel [100], \parallel [010], \parallel [001]) using laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS), with a quadrupole mass spectrometer. These measurements were corroborated by ion microprobe using the sensitive high resolution ion microprobe-reverse geometry (SHRIMP-RG) instrument.

Mg tracer diffusion is anisotropic, with $D_{[001]} > D_{[010]} > D_{[100]}$, the difference in diffusion coefficients varying by about one order of magnitude at a given temperature with crystallographic orientation. Diffusion is faster in protoenstatite-buffered than periclase-buffered conditions, again with around one order of magnitude difference in diffusivity between buffering conditions. There is no apparent effect of f_{O_2} on diffusion. A global fit to all data, including data from Chakraborty et al. (1994) and Morioka (1981) yields the relationship:

$$\log_{10} D = \log_{10} D_0 (m^2 s^{-1}) + 0.61 (\pm 0.03) \log_{10} a_{\text{SiO}_2} + \frac{-359 (\pm 10) \text{kJ/mol}}{2.303RT}$$

where $\log_{10} D_0$ is $-3.15 (\pm 0.08)$, $-3.61 (\pm 0.02)$, and $-4.01 (\pm 0.05) \text{ m}^2 \text{ s}^{-1}$ for the [001], [010], and [100] directions, respectively (1 s.d.). The LA-ICP-MS technique reproduces diffusion coefficients determined by SHRIMP-RG, albeit with slightly different absolute values of isotope ratios. This shows that LA-ICP-MS, which is both accessible and rapid, is a robust analytical method for such tracer diffusion studies.

Keywords: Diffusion, olivine, forsterite, magnesium, experimental petrology