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Kinetics of evaporation of forsterite in vacuum

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Abstract

Congruent evaporation of a crystalline material in vacuum is an extreme reaction in that backward reactions and transport processes in the reactant can be neglected. The evaporation is strongly governed by surface processes and intrinsic nature of the substance. A thorough knowledge of the atomistic evaporation mechanism is fundamental for better understanding reaction kinetics between gas and condensed materials in general. We have conducted a series of evaporation experiments of forsterite in vacuum for crystallographically oriented surfaces at 1500 to 1810 °C. The (100), (010), and (001) surfaces developed their own morphology characterized by evaporation pits and grooves originated from dislocation outcrops. Nominal overall evaporation rate (average retreat rate of a surface) shows significant anisotropy with the maximum difference by a factor of five below 1740 °C. The overall evaporation rates for individual surfaces are fitted with respective Arrhenius relationships, giving the highest activation energy for (100), intermediate for (001), and the lowest for (010). The anisotropy decreases to within 50% at ~1800 °C, which is caused by enhancement of evaporation from (010) owing to preferential evaporation around dislocation outcrops. "Intrinsic evaporation rates" estimated by subtracting contributions of initial roughness and the preferential evaporation around dislocations from the nominal overall evaporation rates show substantial anisotropy even at ~1800 °C. The "intrinsic evaporation rate" for (010) is adequately fitted by an Arrhenius relationship over the examined temperature range giving a single activation energy of 655 kJ/mol. The prevalence of steps with submicrometer to nanometer-scale height shows that forsterite evaporates mostly by layer-by-layer mechanism. The only exception is the (001) surface above ~1650 °C, on which such steps are absent except for surface-parallel minor facets which are rapidly diminishing with time. The (001) surface is inferred to evaporate by direct detachment mechanism at high temperatures. The change of evaporation mechanisms for (001) at around 1650 °C corresponds to a rough-smooth transition kinetically induced by an atomistic evaporation process.

Keywords: Forsterite, evaporation, kinetics, rough-smooth transition, anisotropy