
Introduction. While equilibrium calculations provide first-order insights into the thermal mechanisms that affected a variety of high-temperature condensates and evaporative residues found in meteorites, it is clear that many of these phases were formed in a non-equilibrium state [c.f. 1]. Isotopic fractionation observed in CAI’s, chondrules and circumstellar condensates [e.g. 2, 3] indicates that measured species are different from predicted equilibrium species, implying that the formation of many of these objects involved kinetic effects. In an effort to understand more clearly the kinetic (or non-equilibrium) processes associated with evaporation and condensation we have recently built a high-temperature furnace that admits species evaporated from a sample directly into an electron-impact ionization source and quadrupole mass spectrometer, following the experimental technique pioneered by Inghram [4, cf. 5]. The furnace can presently be operated up to temperatures above 2100 K (stable to ±2 K) in either the Knudsen (equilibrium) or Langmuir (non-equilibrium) configurations [cf. 5]. We present here our first results of a Knudsen configuration analysis of forsterite.

Motivation. Several workers have studied condensation and evaporation of forsterite (Fo₁₀₀-Fo₀₉₀) under a variety of compositional, temperature and pressure conditions [6-8], but none have directly measured the vapor-phase species. Hashimoto [6] utilized a mass-loss technique in a Langmuir cell to predict that solid or liquid SiO₂ (and pure forsterite), under non-equilibrium conditions, would evaporate with SiO₂(g) as the most abundant Si-bearing vapor-phase species due to kinetic effects. Direct measurement by Knudsen cell mass spectrometry of solid SiO₂ [9] indicates, however, that SiO is the principal gas-phase species in equilibrium and is at least 200-300× more abundant than SiO₂ between 1800-1900 K. A direct determination of the species produced by evaporation of forsterite under equilibrium and non-equilibrium conditions should more clearly delineate the kinetic effects.

Results. The present sample of forsterite (Fo₀₉₀, 25 mg, 100-200 μm) was sequentially heated to a given temperature between ~1475-1875 K, in the Knudsen configuration, and held at each temperature for 30-600 minutes while up to 40 mass peaks were monitored. Data were acquired at 20-50 K intervals, and this process was repeated at each step up to five times while cycling the temperature up and down in the range. Temperatures cited are approximate and might be shifted with more refined calibration. Blank measurements were performed at each temperature step by means of a shutter mounted between the cell vacuum chamber and the vacuum chamber containing the ion source, each of which is continuously pumped by its own turbo-molecular pump. Mg, Fe, and SiO are the dominant species detected in the equilibrium gas-phase between 1675-1875 K. SiO₂ is observed at the higher temperatures of this range, but only in an abundance relative to SiO similar to those observed by [9] for solid SiO₂. Other oxides of Si (SO₃ and SO₄) and of Mg and Fe, in particular MgO, were not detected at the 0.1% level relative to Mg and SiO. Oxygen was also abundant as O and O₂, but high background signals prevented quantitative measurements. Above 1875 K the vapor pressure was so high that there was a major depletion in the reservoir. While accurate determination of absolute pressures is not possible for most evaporated species [cf. 5], the partial pressure of a given species effusing from a Knudsen cell is proportional to I’T, where I’ is the measured positive-ion signal of a given species and T is the

absolute temperature [10]. Figure 1, a van't Hoff plot, shows the linear behavior of \( I'/T \) for the Mg, SiO and SiO\(_2\) as a function of 1/T; a similar plot is obtained for Fe. Each data point is an average of up to five measurements at a given temperature. The reproducibility of the peak intensities at a lower temperature after having previously cycled the sample to higher temperatures indicates that forsterite evaporates congruently at equilibrium, as has previously been shown by [11]. The slopes of the lines in Fig. 1 would yield an enthalpy for a reaction such as \( \text{Mg}_2\text{SiO}_4(s) \leftrightarrow 2\text{Mg}(g)+\text{SiO}(g)+3\text{O}(g) \), but due to our incomplete knowledge of all reactions involved (e.g. \( \text{O}_2(g) \leftrightarrow 2\text{O}(g) \)) such enthalpies cannot be calculated at the present time. After analyzing a larger suite of samples under different source conditions, however, such calculations may be possible. That SiO is the dominant Si-bearing gas-phase species is consistent with the predictions of [6] and the measurements of [9]; whether this is the case for a Langmuir configuration remains to be determined. Figure 2 shows the variation in the \( I'(\text{Mg})/(I'(\text{Mg})+I'(\text{Fe})) \) ratio with temperature. This ratio follows the same trend as the \( \text{Mg}/(\text{Mg}+\text{Fe}) \) ratio in the gas phase, but the plotted ordinate values are probably slightly different due to unknown relative ionization cross sections of Mg and Fe. At higher temperatures the gas-phase becomes more forsteritic due to the volatility of Fe, consistent with the condensation experiments of [7].

Summary and Future Work. SiO is clearly the most abundant Si-species in the equilibrium vapor of forsterite between 1675 and 1875 K. To investigate the magnitude of the kinetic effects that occur during the free evaporation of forsterite we are currently analyzing forsterite in the Langmuir configuration. In subsequent experiments, where the sample is not completely vaporized, the mass and the composition of the residual sample will be measured.