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Forsterite-Si gas reaction and chemical fractionation in the early solar nebula

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Introduction: Magnesium and Si are the majorrock-forming elements. Elemental fractionation in the early solar system occurred as a result of chemical reactions that form chemical diversity between solid and gas and their physical separation. Equilibrium condensation calculation in the system of solar abundance indicates that a potential reaction capable of changing Mg/Si ratios of solid and gas is formation of enstatite (MgSiO3) by a reaction between forsterite (Mg2SiO4) and Si-rich gas during cooling of the system. A large fraction of Mg-bearing gas condense into solids by formation of forsterite in the cooling system, and most of Si-bearing gas go into solids by formation of enstatite. The bulk Mg/Si ratio in condensates thus changes largely during formation of enstatite, and becomes close to the solar value after formation of enstatite. The Mg/Si fractionation in the early solar system should have occurredin the course of processes of forsterite condensation and enstatite formation. Note that it may have occurred during evaporation of enstatite and forsterite when the system was heated.
Experiments: The MBE-type furnace consists of a vacuum chamber equipped with a pumping system, a furnace with a tungsten-coil heater for gas generation, a infrared furnace for substrate heating, and a gas inlet ystem to introduce oxygen in the chamber. Silica glass was heated at ~165 0C to generate Si-rich gas. In some runs, silica glass mixed with alumina was heated at ~1675C. A chip of single crystal of forsterite (~4 x 4 x 0.5 mm) or a couple of chips of single crystal of forsterite (~4 x 2 x 0.5 mm) were put ~250 mm above the gas source, and heated at 900-1000C, which is within the typical range of enstatite formation in protoplanetary disks, by an infrared furnace from behind.
Results: The EDS and EBSD analyses of the surface of run products show that Si-rich amorphous oxide was formed in all the runs (Fig. 1). No enstatite was found even at the interface between forsterite and surface deposit (Fig. 2), suggesting that no reaction occurred between forsterite and Sirich gas in the present experiments. No crystallization of Si-O rich amorphous layer occurred either.
Discussion: The present results are inconsistent with previous experiments, where enstatite formed. The difference between this study and is the temperature for reaction. The temperature range in this study is within the plausible range for enstatite formation in protoplanetary disks and even higher than that for mass-loss winds from evolved stars. Although the data we obtained are still preliminary, the present studiy implies that formation of enstatite via a reaction between forsterite and Si-rich gas under realistic temperature conditions is kinetically less favored and that Si-rich amorphous oxide forms instead. If this is the case, enstatite may form either by direct condensation from gas or by crystallization at the interface between forsterite and condensed Si-rich amorphous oxide due to annealing. We are currently working on annealing experiments of run products to test the latter possibility. We expect to report on the results at the conference.

Keywords: forstrite, gas reaction, fractionation, solar nebula