REACTION WITH FORSTERITE AND SiO GAS AND Mg/Si FRACTIONATION IN THE EARLY SOLAR SYSTEM.

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Introduction: The solar nebula experienced high temperature in the early stage of its evolution, where evaporation, condensation and gas reaction played important roles for chemical fractionation that might have inherited to chemical diversity of planetesimals and planets. The reaction between previously condensed forsterite and residual Si-rich gas to form enstatite is one of the most crucial reactions responsible for Mg/Si fractionation.

Purpose of the study: In order to obtain the reaction rate of forsterite and Si-rich gas to form enstatite, we have carried out gas reaction experiments under controlled conditions by using a newly developed equipment. We have investigated the degree of kinetic barrier for enstatite formation, possibility of formation of metastable phase(s), and the role of oxygen on the reaction.

Experiments: Experiments were carried out in a molecular beam epitaxy type condensation apparatus, where the gas and condensation temperatures are independently controlled and the gas flux is known as to estimate condensation coefficients. The SiO gas generated by heating SiO_2-Al_2O_3 at 1680°C attacked a substrate of forsterite of which temperature ranged from the room temperature to ~1000°C with or without O_2 gas. The experimental duration ranged from 10 to 48 hours. The condensates were observed with SEM with EDS and crystallinity and phase determination were done with EBSD. Some were observed with FIB-TEM in more detail.

Results: We got condensates in all the experiments with the thickness of 0.5 um or less. The condensates are identified to be amorphous SiO regardless of the experimental conditions, that is, the gas molecules of SiO attached to the forsterite without chemical reaction. No enstatite was formed, suggesting a large kinetic barrier for the reaction with forsterite and SiO gas to form enstatite. The thickness of the condensates decreases with increasing temperature, and the condensation coefficient at ~900°C is ~0.2 compared to the room temperature.

Some run products annealed at 1000°C in air formed clinoenstatite in 48 hours, but some formed tridymite in the same condition, which suggests a sluggish reaction.

Discussion: The decrease of the condensation coefficient of SiO with increasing temperature suggest that it is close to zero above ~1000°C, the reaction temperature of forsterite and gas to form enstatite in the solar nebula in equilibrium. The restriction of enstatite formation reaction results is chemical fractionation between forsterite condensate and residual Si-rich gas, which would condense as crystalline or amorphous SiO-rich material at much lower temperature. The results are taken into a model calculation of kinetic condensation of the solar nebula, which suggests cooling time scale of the nebula of 10^{2-3} years and the critical separation size of forsterite of 1 to 100 µm for generate chemical fractionation.