

The Effect of Temperatures of Gas and Condensed Phase on Condensation Kinetics of Metallic Iron

Ryuichi Nomura[1]; Hiroko Nagahara[1]; Shogo Tachibana[2]

[1] Dept. Earth Planet. Sci., Univ. Tokyo; [2] Earth and Planet. Sci., Univ. of Tokyo

Metallic iron is one of the most abundant phases that condense from cooling gas of the solar abundance, and its size distribution and number density are crucial parameters to determine thermal structures of protoplanetary discs because of its large opacity. Kinetic hindrance of condensation controls the timescale of the process. When a surface reaction is the rate-limiting process, the growth rate of condensed phase is expressed by the Hertz-Knudsen equation based on the classical kinetic theory of gases. Kinetic hindrance is defined as the ratio between the measured growth rate and the ideal growth rate, which is called a condensation coefficient. The coefficient is unity if no kinetic hindrance exists.

Ikeda et al. [1] carried out condensation experiments on metallic iron under controlled supersaturation conditions and showed that the condensation coefficient is close to unity at the supersaturation ratio ranging from 10 to 30. The gas was formed at $\sim 1300^\circ\text{C}$, and the condensation temperature was 962°C .

In this study, we carried out condensation experiments on metallic iron on a substrate of alumina at the same temperature as [1] but with different incoming gas temperature. Furthermore, we have carried out an experiment at 1064°C with a smaller supersaturation ratio than in [1] because the condensation behavior close to the equilibrium condition may differ from that at high supersaturating ratios. Note also that the condensation temperatures in this study are close to that of metallic iron in protoplanetary discs.

A pellet of metallic iron, of which diameter was 2 mm and thickness was about 0.5 mm, was put in the bottom of an alumina crucible, of which inner and outer diameters were 4 and 6 mm, respectively, and length was 46 mm. The iron pellet was heated in the center of a tungsten-mesh heater, and quenched after desired duration in a vacuum chamber. The evaporated gas flow through the alumina tube condensed on an alumina substrate placed in cooler regions of the vacuum chamber. The supersaturation ratio at the surface of the substrate was calculated based on the measured evaporation rate of the source iron and the flux distribution of the iron vapor emerged out of the crucible [2]. The pressure in the chamber was kept below 10-3 Pa during experiments. The temperature of condensation was determined by calibrating against melting points of Ag (962°C) and Au (1064°C). Surface of the condensates was observed with FE-SEM and analyzed with EDS.

EDS analysis shows that all the condensates are metallic iron. FE-SEM observations show that step structure is developed on all the surface, suggesting the presence of kinetic hindrance for condensation at 962°C . The steady growth of heating duration 9~54 hours enables us to calculate the growth rate by using the weight gain of condensed phase. The condensation coefficient is calculated to be ~ 0.8 at 962°C . [1] showed that the condensation coefficient is close to unity at 962°C for the gas temperature of $\sim 1300^\circ\text{C}$, and thus the present result may suggest an importance of the difference in temperature between gas and condensed phase.

Metallic iron condensed with a small saturation ratio $S \sim 5$ at temperature of 1064°C from gas at $\sim 1320^\circ\text{C}$ also showed surface steps, which are also suggestive of the presence of kinetic hindrance for condensation. The condensation coefficient is calculated to be ~ 0.5 although further experiments for various heating durations are necessary. The small condensation coefficient prolongs the formation time of metallic-iron dust compared to that estimated by [3].

References:

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