CONDENSATION OF METALLIC IRON: THE ROLE OF TEMPERATURES OF GAS AND CONDENSED PHASE. R. Nomura[1], H. Nagahara[1] and S. Tachibana[1] [1]Department of Earth and Planetary Sciences, University of Tokyo (7-3-1 Hongo, Tokyo 113-0033, Japan, s62620@geoph.eps.s.u-tokyo.ac.jp).

Introduction: Metallic iron is one of the abundant phases that condense in cooling gas of the solar abundance. Since condensation is a kinetic process, kinetic hindrance of evaporation and condensation controls the timescale of the process.

The net grain growth flux called condensation flux (growth rate), J_c, is expressed by the Hertz-Knudsen equation based on the classical kinetic theory of gases,

$$J_c = \alpha_c J_{in} - \alpha_e J_{out} = \frac{p^{eq}}{\sqrt{2\pi mkT}}(\alpha_c S - \alpha_e) \quad (1)$$

where J_{in} is the flux of gas to the surface of the solid, J_{out} is the flux of the evaporating molecules from the surface of the solid, S is the supersaturation ratio defined as $S=J_{in}/J_{out,}$ p^{eq} is the equilibrium vapor pressure, m is the weight of condensing gas molecule, k is the Boltzmann constant, and T is the temperature. α_c and α_e are condensation and evaporation coefficients, respectively, which represent kinetic hindrance of condensation and evaporation. These coefficients are unity if no kinetic hindrance exists.

Many experimental studies have been carried out for evaporation of metallic iron [e.g., 1], which shows that the evaporation coefficient of metallic iron is almost equal to unity. However few condensation experiments have been done because of technical difficulties.

Ikeda et al. [2] 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 ~1310°C, and the condensation temperature was 962°C.

In this study, we carried out condensation experiments on a substrate at the same temperature as [2] but with different gas temperature. Furthermore, we have carried out an experiment at smaller supersaturation ratio in order to obtain the lowest value for heterogeneous condensation, which [2] has not succeeded in determination.

Method: 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 and length was 46 mm. It was heated in the center of a tungsten-mesh heater, and quenched after desired duration in a vacuum chamber. The evaporated gas flew through the alumina tube and condensed onto an alumina substrate placed in cooler regions of the vacuum chamber. The pressure in the chamber was kept below 10^{-3} Pa during experiments. The temperature of condensation was precisely determined by calibrating against melting points of Ag (962°C) and Au (1064 °C).

The gas temperature in this work was ~1360°C, condensation temperature was 962°C, and the experimental duration was 9, 18, or 36 hours. The experiment for small supersaturation was made at the gas temperature of ~1320°C and the condensation temperature of 1064°C for 12 or 24 hours.

The weight loss of the iron pellet and the weight gain of the alumina substrate were measured. The surface of the condensates was observed with FE-SEM and analyzed with EDS.

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 [3].

Results: We found that all the condensates are metallic iron in the present work. Figure 1 shows FE-SEM images of the surface of metallic iron condensed at 962°C with S ~ 23 for 9 (a), 18 (b), and 36 (c) hours. The step structure on all the surfaces suggests the presence of kinetic hindrance, and the grain growth appears to reach a steady state in 18 hours. The steady growth of Fig. 1(b) and 1(c) enables us to calculate the growth rate, J_c, by using the weight gain of the substrate and the calculated incoming flux. Figure 2 shows J_c as a function of S under an assumption that $\alpha_c = \alpha_e$.

The experiment with small supersaturation ratio (S ~ 4) was done with gas at temperature of ~ 1320°C and the condensation temperature of 1064°C. The steps are also suggestive of the presence of kinetic hindrance for condensation. The calculated condensation rate is shown in Fig. 2(b). Although two experiments were carried out, one of them shows a transient surface microstructure, and only an experiment with longer duration was used for calculation. Therefore, the results in Fig. 2(b) may contain a significant error.

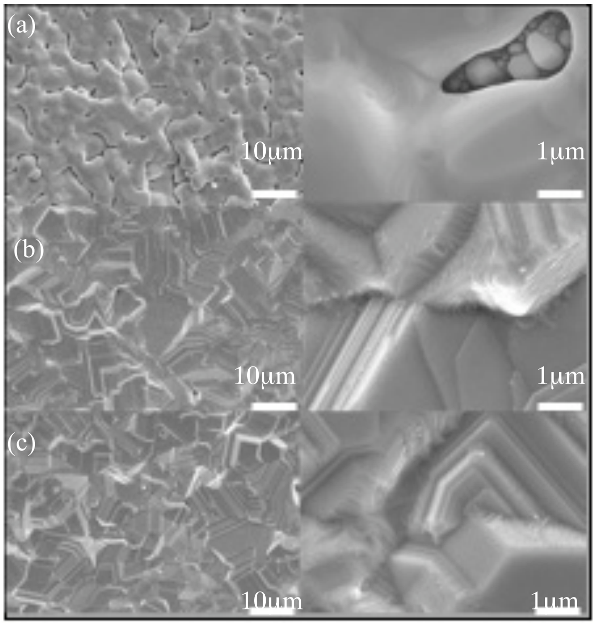

Fig. 1. FE-SEM images of the surface of the condensates at 962°C with S ~ 23 from gas at ~ 1360°C. Heating duration is (a) 9 hours, (b) 18 hours and (c) 36 hours, respectively.

Discussion: The results of the experiments shown in Fig. 2 (a) suggest that the kinetic hindrance of condensation increases as the temperature of the gas increases for a constant condensation temperature. The excess energy of gas molecules at higher temperature than the substrate can be easily excluded in the experimental equipment and the condensation temperature can be roughly regarded as the substrate temperature. The present results, however, suggest an importance of the difference in temperature between gas and substrate in heterogeneous condensation, which can happen in astrophysical environments where metallic iron condenses onto previously condensed forsterite or more refractory materials such as CAI. It, however, should be noted that the result was obtained from only two data, and the error can be large. Further experiments for various heating durations are necessary.

The small condensation coefficient at low supersaturation condition (Fig. 2b) is newly obtained, which has not been obtained previously because of experimental difficulties. The results are very important in that condensation in the protosolar disc might be preceded in such a condition. The small condensation coefficient prolongs the formation time of metal dusts, which linearly correlates with the value of the coefficient. We have discussed in a companion abstract [4] that heterogeneous condensation of metal on previously condensed forsterite largely affects the phases formed in a cooling gas. The present results suggest a possibility that the mode of condensation of Fe metal is either homogeneous condensation at low supersaturation conditions or heterogeneous condensation on silicates or oxides at high supersaturation ratio conditions. The mode of condensation depends on the total gas pressure and cooling time of the gas, and further experiments will give critical information on the formation and growth of dust in the protosolar disc.

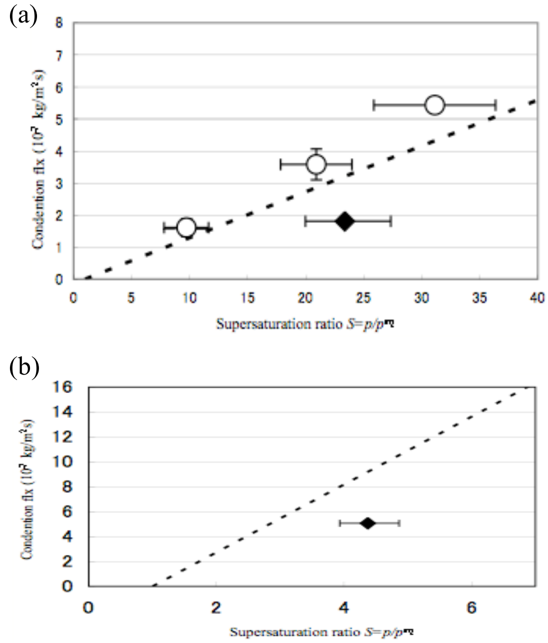

Fig. 2 Condensation flux of metallic iron as a function of supersaturation *S*. The ideal condensation flux (Eq. (1) with $\alpha_c=\alpha_e=1$) is shown by a broken line. (a) The present work with gas temperature of ~ 1360°C (filled diamond) and the results of [2] with the gas temperature of ~ 1310°C (open circle). (b) The flux at small supersaturation ratio for gas temperature of ~1310°C and condensation temperature of 962°C.

References: [1] Tsuchiyama A. and Fujimoto S. (1995) *Proc. NIPR Symp. Antarct. Meteorites, 8,* 205-213. [2] Ikeda Y. (2007) *LPS XXVIII,* 2403–2404. [3] Dayton B. B. (1956) *Natl Symp. Vac Tech. Trans.,* 5-11. [4] Nagahara, H. and Ozawa, K. (2008) *LPS XXXIX.*