Self-diffusion of hcp-iron and viscosity of the inner core

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The size of the earth’ s inner core of the earth is much smaller than that of mantle and hence geophysical observation of the inner core is difficult, for example, rheological properties of the inner core is poorly understood. Therefore, viscosity of the inner core is not well-constrained, for example, <10^16 Pas, >10^20 Pas (Buffett, 1997), or ~10^17 Pas (Dumberry and Bloxham, 2002). The inner core is composed of a solid iron alloy with the crystal structure of hcp, hcp-iron. The alloying is mainly done with Ni and other light elements, but primarily the rheological properties of pure iron are thought to represent the inner core properties. Therefore, in this study, we focused on the self-diffusion coefficient of iron in hcp-iron because viscosity is strongly controlled by diffusion of constituent elements. Since hcp-iron is a stable phase only under high pressure, a diffusion experiment was conducted at a pressure up to 60 GPa and a temperature of 1100-1400 by means of high pressure and temperature experiment combined with the isotope diffusion method. In the high-pressure experiments, Kawai-type assemblies composed with “binderless” tungsten carbide and sintered diamond material of the second stage anvils to generate pressure up to 45 GPa and 60 GPa, respectively, were compressed in a DIA-type high pressure apparatus at Okayama University. Because the upper limit of temperature for the stability field of hcp-iron (e.g., ~1300K at 45 GPa), which is relatively low temperature to observe the thermally activated process, we needed diffusion duration more than 500 hours to obtain reliable diffusion length. The diffusion profile was obtained on the recovered specimen by analysis with the isotope microscope IMS1270 + SCAPS installed at Hokkaido University. In order to calibrate the irregular deformation of the specimen under high pressure and the spatial resolution of the analysis, a 30-minute diffusion sample was used as a reference. At 60 GPa and 1400 K, as a result, the diffusion coefficient was determined to be 10^-18.32 m^2/s. In order to extrapolate the diffusion coefficient obtained by the experiment to the inner core condition, we used a homologous temperature scaling and thus diffusion coefficient under inner core conditions are estimated to be 10^-12 m^2/s. By assuming the dominant deformation mechanism in the inner core to be Harper-Dorn creep, the viscosity is estimated to be ~10^10 Pas. This value is slightly lower than the previous result estimated by the mineral physics approach using analogue material (Yunker and Van Orman, 2007) but not by geophysical approach.

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