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高温高圧下における Fe-S-Si 系の元素分配：地球核への応用
Elemental partitioning in the Fe-S-Si system at high pressure and temperature: Implications for the Earth's core

坂入 崇紀 [1*] ; 大谷 栄治 [1] ; 境 毅 [2] ; 鎌田 誠司 [1] ; 宮原 正明 [3] ; 平尾 直久 [4]
SAKAIRI, Takanori[1*] ; OHTANI, Eiji[1] ; SAKAI, Takeshi[2] ; KAMADA, Seiji[1] ; MIYAHARA, Masaaki[3] ; HIRAO, Naohisa[4]

[1] 東北大学大学院理学研究科地学専攻, [2] 愛媛大学地球深部ダイナミクス研究センター, [3] 広島大学理学研究科地球惑星システム学専攻, [4] 財団法人高輝度光科学研究センター
[1]Department of Earth science, Tohku University, [2]Geodynamics Reserch Center, Ehime University, [3]Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University, [4]JASRI

It is widely accepted that the Earth's core is mainly composed of iron and contains light elements to account for the core's density deficit. Alloying with light elements significantly affects the physical properties of iron and the arguments on the chemical structure of the Earth's core. Therefore, the melting relation of the Fe-light elements system is the key to clarifying the chemical structure of the core because the inner core has formed by crystallization of the molten outer core. Although there are many candidates for light elements in the core, based on geochemical modeling and high-pressure partitioning experiments, sulfur and silicon are considered to be the major light elements. Despite the importance of the effect of sulfur and silicon on the physical properties of iron, previous studies, including high-pressure melting experiments in the Fe-S-Si system, did not cover the pressure conditions of the core. To better understand the properties of the core, we investigated the melting relations of the Fe-S-Si system under high-pressure conditions corresponding to the Earth's core.

We report on the melting relations in the Fe-S-Si system up to 135 GPa. Melting experiments were performed in the pressure range of 37-135 GPa and the temperature range of 1800?4100 K using a double-sided laser-heated diamond anvil cell. The composition of the starting material was $Fe_{80.1}S_{12.7}Si_{7.2}$ (Fe-8 wt.% S-4 wt.% Si). Melting relations were examined on the basis of quenched textures of the recovered samples and chemical analysis of observed phases. The chemical composition of the coexisting phases in the samples was obtained with an energy-dispersive X-ray spectroscopy (EDS) system attached to the FEG-SEM. We determined the compositions of the coexisting phases and investigated the partitioning behavior of sulfur and silicon between the metallic melt and the coexisting iron alloy.

We consistently found that a quenched melt with a dendritic texture coexists with a solid Fe alloy in the recovered samples, implying that the samples were partially melted under the experimental pressure and temperature conditions. Based on the present results, the partition coefficients of sulfur and silicon between the liquid and solid Fe alloy were determined in the pressure range from 37 to 135 GPa. The value obtained for D_{sulfur} at 37 GPa was 0.032(28), whereas $D_{silicon}$ was 4.53(73), which is significantly higher than D_{sulfur}. The obtained values of Dsulfur were between 0.032(28) and 0.135(35) and those of $D_{silicon}$ were between 2.63(12) and 5.58(56) in this study. The present results indicate that the solid Fe alloy is silicon rich whereas the metallic melt is enriched in sulfur. We can find that this trend continues up to the core-mantle boundary (CMB) pressure.

The information on partitioning of light elements between the metallic melt and hcp-Fe is the key for clarifying the chemical structure of the Earth's core because the inner core is considered to have crystallized from the liquid outer core during cooling of the Earth. Moreover, previous studies strongly implied that both sulfur and silicon were the plausible candidates for the light elements in the core. Therefore, our experimental results in the Fe-S-Si system offer important clues for understanding the composition of the Earth's core. Based on the present results, if the Earth's core cools down below the melting temperature of the core material, silicon could be preferentially partitioned into hcp-Fe from the Fe-S-Si liquid during crystallization of the inner core. The present data demonstrated that if the Earth's core contains both sulfur and silicon as light elements, the present-day Earth has a sulfur-rich outer core and a silicon-rich inner core.

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