Dissolution of multi light elements in iron-silicate system using high pressure and high temperature experiments: Implications for the Earth's evolution

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Introduction

The Earth’ s outer core is considered to consist of Fe-Ni alloy and some light elements (O, S, Si, H, C). Hydrogen is the most abundant element in the solar system and one of the promising candidates of the light element in the Earth’ s core. However, the amount of hydrogen dissolved in the core and its process are still unknown because hydrogen cannot be detected by X-ray and it easily escapes from iron by the release of pressure. Recently, hydrogen content in fcc-Fe at high pressure and temperature has been determined using in-situ neutron diffraction measurements at J-PARC [1,2]. Furthermore, it was observed that the water which is released from hydrous mineral at about 4 GPa reacts with iron and they form both iron oxide and iron hydride. The formation of iron hydride occurred below 1000K, at the temperatures where no materials melted. This suggests the possibility that hydrogen had preferentially dissolved into iron before any other light elements have dissolved in the very early stage of Earth’ s evolution. For future prospects, it is important to study the partitioning of the other light elements between iron hydride and silicates. In this study, we focused on sulfur and investigated its effect on hydrogenation.

Experimental

As a starting material, the powder mixture of iron (#300 mesh), quartz, $Mg(OD)_2$ (or MgO) and S (or FeS) was used. The mixing ratio was slightly changed.

High-pressure and high-temperature quench-experiments were carried out using a 500-ton press at ISSP. A multi-anvil 6-6 type (MA6-6) assembly was used with an improved anvil assembly optimized for the neutron experiments [2]. The second-stage anvils were made of Ni-binded cylindrical tungsten carbide with truncated edge lengths of 10 mm. A hybrid pressure medium made of a Cr-doped MgO cube and a ZrO_2 cylinder was used. A graphite cylinder and disks were used as a furnace, and the electrodes were molybdenum foils. Preformed gaskets made of pyrophyllite, which were fired in advance at 700˚C for 15 min were used. The pressure was increased up to 6 GPa and heated up to 750-1650˚C. The quenched samples were analyzed by XRD and SEM-EDS.

In-situ X-ray diffraction measurements were also conducted at PF-AR, NE7A and NE5C. The products were identified under high pressure (4-6 GPa) and high temperature (up to 1050˚C).

Results and discussion

From the quench experiments, liquid Fe-FeS was observed in the recovered sample from >1000˚C. Liquid iron and solid FeS coexisted in the recovered sample from 950˚C. This was in good agreement with the Fe-FeS binary system. In the recovered sample from 750˚C, solid FeS and solid Fe coexisted and the iron contained many small vacant holes of a few microns in diameter, indicating the evidence of hydrogen dissolved into iron.

From in-situ XRD observations, Fe transformed from bcc into fcc phase at <500˚C. At the same time, dehydration of $Mg(OD)_2$ and formation of FeS were observed. At 850˚C, fcc-Fe started to melt and FeS and olivine remained in the recovered samples. For the sample, which does not include water, FeS

formation occurred before the phase transition of Fe from bcc into bcc at ~600˚C. Melting of fcc-Fe started at ~900˚C and the recovered sample from 1050˚C consisted of FeS and FeC. The results between in-situ experiments and quench experiments were well consistent.
The cell volume of fcc-Fe in the Fe-silicate-water system was several % larger than that of pure Fe at the same condition, which suggested the obvious hydrogenation. In the presentation, hydrogen content in fcc-Fe and FeS will be discussed to more clarify the formation process of iron hydride and FeS and the effect of sulfur on hydrogenation.

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