Chemical reaction between ferropericlase (Mg,Fe)O and water under high-pressure-temperature conditions of the deep lower mantle

ZIQIANG YANG1, HONGSHENG YUAN1†, LU LII, NICO GIORDANO3, YONGJIN CHEN1, AND LI ZHANG1,*

1Center for High Pressure Science and Technology Advanced Research, 201203 Shanghai, China
2Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany

ABSTRACT

The presence of water may contribute to compositional heterogeneities observed in the deep lower mantle. Mg-rich ferropericlase (Fp) (Mg,Fe)O in the rock-salt structure is the second most abundant phase in a pyrolitic lower mantle model (Irfune et al. 2010; Ringwood 1975). Evidence from seismic tomography shows that pieces of slab materials can penetrate into the deep lower mantle (DLM) down to the core-mantle boundary (CMB) (Van der Hilst et al. 1997; Zhao 2012) and such deep subduction processes may carry water to the deepest lower mantle (Ohtani 2015). Remnants of a primordial layer contain volatiles, including hydrogen that, if exist, can be modified over time by chemical reactions with the surrounding mantle (Garnero et al. 2016; Labrosse et al. 2007). The high-water contents in komatiites and picrites originated from large igneous provinces (LIPs), and the presence of water may contribute to compositional heterogeneities observed in the deep lower mantle (Irifune et al. 2010; Ringwood 1975). Evidence from seismic tomography shows that pieces of slab materials can penetrate into the deep lower mantle (DLM) down to the core-mantle boundary (CMB) (Van der Hilst et al. 1997; Zhao 2012). However, how much Mg can be incorporated into FeO2H (x ≤ 1, Py-phase) is unknown due to the lack of detailed characterization of the run products. To clarify the reaction between water and the lower mantle system, we carried out experiments on a rather simple system MgO–FeO–H2O in a laser-heated diamond-anvil cell (LH-DAC) over a P–T range of 95–121 GPa and 2000–2250 K. The run products were then characterized by combining in situ synchrotron X-ray diffraction (XRD) measurements at both high-P and room-P with ex-situ chemical analysis on recovered samples.

INTRODUCTION

Ferropericlase (Fp) (Mg,Fe)O is the second most abundant phase in a pyrolitic lower mantle model (Irfune et al. 2010; Ringwood 1975). Evidence from seismic tomography shows that pieces of slab materials can penetrate into the deep lower mantle (DLM) down to the core-mantle boundary (CMB) (Van der Hilst et al. 1997; Zhao 2012) and such deep subduction processes may carry water to the deepest lower mantle (Ohtani 2015). Remnants of a primordial layer contain volatiles, including hydrogen that, if exist, can be modified over time by chemical reactions with the surrounding mantle (Garnero et al. 2016; Labrosse et al. 2007). The high-water contents in komatiites and picrites originated from large igneous provinces (LIPs), and the presence of water may contribute to compositional heterogeneities observed in the deep lower mantle (Irifune et al. 2010; Ringwood 1975). Evidence from seismic tomography shows that pieces of slab materials can penetrate into the deep lower mantle (DLM) down to the core-mantle boundary (CMB) (Van der Hilst et al. 1997; Zhao 2012). However, how much Mg can be incorporated into FeO2H (x ≤ 1, Py-phase) is unknown due to the lack of detailed characterization of the run products. To clarify the reaction between water and the lower mantle system, we carried out experiments on a rather simple system MgO–FeO–H2O in a laser-heated diamond-anvil cell (LH-DAC) over a P–T range of 95–121 GPa and 2000–2250 K. The run products were then characterized by combining in situ synchrotron X-ray diffraction (XRD) measurements at both high-P and room-P with ex-situ chemical analysis on recovered samples.

MATERIALS AND METHODS

Fp with chemical compositions of (Mg0.9Fe0.1)O, (Mg0.8Fe0.2)O, and (Mg0.6Fe0.4)O were synthesized as the starting materials following the procedures as previously described (Fei et al. 1991), denoted as Fp10, Fp20, and Fp40, respectively. The composition and homogeneity of these samples were confirmed by both XRD and scanning electron microscope (SEM) coupled with energy-dispersive X-ray spectroscopy (EDS) analysis. We used Bohler-Almax anvils with a flat culet diameter of 150 μm beveled at 10° up to 300 μm in a symmetric DAC for our high P–T experiments. Each Re gasket was pre-compressed to about 30 μm in thickness, and 50–70 μm drilled holes formed the sample chambers. Each starting material was pre-compressed to ~15 μm in thickness, and a thin sample disk was loaded into the sample chamber. A tiny piece of gold was placed on the sample surface or post-perovskite (pPv) through reaction between Fe-bearing olivine and water (Chen et al. 2020; Hu et al. 2021). Olivine (Mg,Fe)2SiO4 breaks down to Bdg and Fp under high-pressure-temperature (P–T) conditions of the lower mantle, but whether H2O reacts with Bdg or Fp is unclear. A small amount of Py-phase (~3 vol%) was found coexisting with the pPv phase but absent in the Bdg-bearing assemblage in the system of 60 mol% MgSiO3–30 mol% Al2O3–10 mol% Fe2O containing ~7 wt% H2O (Yuan et al. 2019), implying that the stability of the Py-phase is dependent on not only P–T conditions but also chemical compositions in the lower mantle. Recent high-P–T experiments suggest the formation of a pyrite-structured (Mg,Fe)O2H (x ≤ 1) phase through chemical reactions between (Mg,Fe)O and water under high P–T conditions (Hu et al. 2021). However, how much Mg can be incorporated into FeO2H (x ≤ 1, Py-phase) is unknown due to the lack of detailed characterization of the run products.

Previous experimental results show that adding water into the multi-component systems could significantly change phase relations in the lower mantle systems and after phase chemistry in the assemblages (Ohira et al. 2014; Walter et al. 2015; Yuan et al. 2019). The pyrite-structured phase FeO2H (x ≤ 1, Py-phase) has been synthesized through reactions between water and iron in a wide range of oxidation states, from Fe to Fe2O3, at pressures above 85 GPa under high-temperature conditions (Hu et al. 2016; Mao et al. 2017; Nishi et al. 2017; Yuan et al. 2018), indicating that the formation of Py-phase is independent of the oxidation state of iron in starting materials. Furthermore, the Py-phase was observed coexisting with bridgmanite (Bdg)