Generation of pressures to \( \sim 60 \) GPa in Kawai-type apparatus and stability of MnGeO\(_3\) perovskite at high pressure and high temperature

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ABSTRACT

To obtain higher pressures in a Kawai-type apparatus, we explored and tested high-pressure cell assemblies suitable for experiments using sintered diamond (SD) anvils. As a result, we succeeded in generating pressures exceeding 55 GPa at temperatures of \( \sim 1000 \) °C in a Kawai-type apparatus (SPEED Mk-II) at SPring-8. Using the optimized cell assembly, we examined the stability field of MnGeO\(_3\) perovskite, an analog of MgSiO\(_3\) perovskite, which was recently found to transform to a new high-pressure form under the \( P-T \) conditions near the core-mantle boundary. From our in situ X-ray observations, MnGeO\(_3\) perovskite was found to be stable at pressures up to 56–57 GPa at temperatures of 800–1050 °C.

Keywords: Pressure generation, high pressure and temperature, manganese germanate, perovskite

INTRODUCTION

The Kawai-type multianvil apparatus (KMA; Kawai and Endo 1970) is widely used in the field of high-pressure physics, mineral sciences, and material physics. This type of high-pressure apparatus has the advantage of generating uniform pressure in a fairly large volume compared to the diamond anvil cell (DAC). Moreover, the sample can be heated uniformly by an electric resistance furnace embedded in the pressure medium. However, the pressures available in KMA by using conventional anvil material, such as tungsten carbide (WC), has been limited to \( \sim 30 \) GPa (e.g., Irifune et al. 1992). Sintered diamond (SD) was introduced as the anvil material for KMA, and generation of pressures as high as \( \sim 40 \) GPa (Ohnati et al. 1989; Kondo et al. 1993) were achieved due to the greater hardness of the SD anvils relative to conventional WC anvils. More recently, SD anvils with larger dimensions (14 mm edge length; Ito et al. 1998; cf. 5–10 mm edge length in earlier studies) became available. As a result, a larger press load can be applied, producing pressures greater than 40 GPa in KMA (e.g., Kubo et al. 2003). Pressures even higher than 60 GPa were produced in KMA (Ito et al. 2005), but generation of pressures above 50 GPa has only been achieved at room temperature or at relatively low temperatures below 600 °C.

The most dominant mineral in the Earth’s lower mantle is (Mg,Fe)SiO\(_3\) perovskite and thus its mineral physics is very important in understanding the constitution and composition of the lower mantle (e.g., Ringwood 1991). Recent laser-heated DAC (LHDAC) experiments revealed that MgSiO\(_3\) perovskite (space group: \( \text{Pbnm} \)) transforms into a different structure, so-called post-perovskite phase (\( \text{Cmcm} \)), around 120 GPa (Murakami et al. 2004). This discovery should have significant implications for mantle structure and dynamics (e.g., Matyska and Yuen 2005), but the precise phase boundary between perovskite and post-perovskite phases and the physical properties of the latter phase have not been well determined. Thus further experimental and theoretical studies should be conducted on these topics with accuracies greater than those achievable by LHDAC.

In this paper, we report the progress in high pressure generation using SD anvils in a Kawai-type apparatus, with special emphasis on the technical development for in-situ X-ray diffraction measurements under simultaneous high-pressure and high-temperature conditions above 50 GPa. Using this technique, we examined the stability of MnGeO\(_3\) perovskite at pressures approaching 60 GPa. MnGeO\(_3\) is often used as an analog material of MgSiO\(_3\) (Liu 1976), which adopts the post-perovskite structure at pressures of 50–60 GPa using LHDAC (Tateno et al. 2005).

EXPERIMENTAL PROCEDURE

We carried out in-situ high pressure experiments using SPEED Mk-II installed at BL04B1 SPring-8 (Katsura et al. 2004), where intense white X-ray of synchrotron radiation is available. An X-ray beam with dimensions of 50 \( \mu \)m horizontally \( \times 100 \mu \)m vertically was directed to the sample through the gaps of the second stage SD anvils and the first stage WC anvils. An energy dispersive system with a Ge solid state detector was used for powder X-ray diffraction measurements, together with a CCD camera for radiographic imaging of the sample. A multi-channel analyzer was used to acquire photons in a range of 20–130 keV, which was carefully calibrated with characteristic X-ray lines from some reference metals. The precision of the energy measurements was about \( \pm 30 \) eV per channel. The detector was located at 20–6° with respect to incident beam direction, and the 20 angle was accurately calibrated using known diffraction peaks from standard materials such as gold. The uncertainty of the diffraction angle was typically \( \pm 0.002° \) in each experiment.

We adopted SD cubes as second stage anvils with edge length of 14 mm and truncated corners of 1.5 mm (TEL = 1.5 mm), which were supplied by Sumitomo Electric Co. Ltd. MgO was used as pressure medium. Pyrophylite and MgO were