

HIGHER-PRESSURE GENERATION TO SIMULATE THE EARTH'S DEEP INTERIOR

Astronauts have collected rocks on the Moon, while some specimens from asteroids have been obtained by unmanned spacecraft. However, mankind has not yet reached even the surface of the Earth's mantle, which only lies at a 30 km depth under our feet. Therefore, we cannot obtain rock samples from the Earth's deep interior directly. There are several approaches to investigate and study such an inaccessible location from which no direct rock samples can be obtained. One of the most important approaches is seismology. Seismic observation enables us to obtain a CT scan of the Earth's interior in terms of the seismic wave velocity and density. However, to understand the chemistry and mineral composition of the Earth's interior and discuss its dynamics and evolution, it is necessary for us to have a fundamental knowledge about the Earth building materials. High-pressure and high-temperature experiments reproduce the deep Earth's condition and synthesize the Earth's building materials in a laboratory built on the Earth's surface. In the investigation of the Earth's interior, high-pressure experimental devices play a role as a "sub-ground research ship," similar to a spacecraft in space exploration. Thus, samples synthesized by high-pressure and high-temperature experiments are equivalent to the Moon rocks returned to the Earth by astronauts.

The Kawai-type multi-anvil apparatus (KMA; Fig. 1) is one of the most popular experimental devices to reproduce the deep Earth's conditions. KMA was originally developed in Japan and is now widely used throughout the world; it is a sophisticated system using 6-8 type double-staged multi-anvils to generate the quasi-hydrostatic pressure in a large volume. This large compressed volume is an important feature of KMA; it enables us to build a resistance furnace, which produces uniform high-temperature conditions and provides a great advantage in simulating the Earth's interior and in sample synthesis. Because of these features, KMA has played important roles in high-pressure Earth science, particularly in understanding the 660 km seismic discontinuity (e.g., Ref. [1]). Although the KMA can accurately reproduce the Earth's interior, the generated pressure has been limited to <30 GPa by the mechanical strength of the tungsten carbide (WC) second-stage anvils. In other words, the Earth simulator "KMA" had been stagnant just below the 660 km discontinuity (i.e., top of the



Fig. 1. Kawai-type apparatus called "SPEED-Mk.II", which is installed at BL04B1.

lower mantle) for a long time. However, recently, with the use of the sintered diamond (SD) as the material for second-stage anvils, the pressure limits of experiments using KMA has considerably increased to more than 60 GPa (e.g., Ref. [2]).

Here, we briefly report on the technical developments related to high-pressure generation using KMA with SD anvils. High-pressure experiments were conducted at beamline **BL04B1** using a KMA called "SPEED-Mk.II". The 14.0 mm SD cubes with truncated edge lengths of 1.5 mm were used as second-stage anvils. Uniaxial oil pressure was concentrated to the pressure media placed into the center of second-stage SD anvils through six first-stage WC anvils. Semi-sintered MgO (+ 5 wt% Cr₂O₃) or Al₂O₃ was used for pressure media, and pyrophyllite heated at 700°C for 30 minutes was also used as a gasket. The generated pressure was measured using Au internal standard, which was placed into the center of the pressure media, and the EOS (Tsuchiya, 2003). A schematic illustration of the cell assembly is shown in Fig. 2. We systematically varied the volume of the pressure media and gaskets to determine the optimum setting in terms of thickness and width of the gaskets.

As a result of a series of experiments, we observed changes in the efficiency and limitations of high-

pressure generation with varied cell assemblies. Figure 3 shows the results of high-pressure generation as a function of press load for each experimental condition. At first, the pressure generating efficiency increases with decreasing gaskets width because smaller gaskets consume less press load. Secondly, the pressure generation limits also change with gasket thickness, and the effect is significant above 40 GPa. In addition, we successfully used an Al_2O_3 pressure media, and the pressure limit increased to ~ 10 GPa at 8 MN in comparison with that using MgO at each optimum setting. Al_2O_3 with larger bulk modulus than that of MgO would enable this expansion.

High-pressure generation techniques using SD anvils in KMA have been further developed to reach 70 GPa (i.e., at a depth of 1660 km in the Earth). The new experimental method maintains the original advantages of KMA and is characterized by excellent stability at high pressure and high temperature with a large sample volume. This improved sub-ground ship will clarify the nature of the ocean in the Earth's lower mantle.

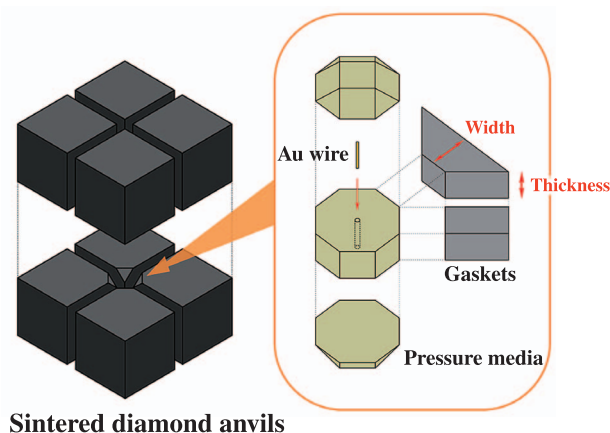


Fig. 2. Schematic of second-stage SD anvils, pressure media and gaskets. Pressure media are totally surrounded by the two types of gasket. The Kawai-cell composed by eight anvils including pressure media is loaded into a large volume press (Fig. 1). High-pressure cell assembly is optimized in terms of width and thickness of the trapezoidal gasket. Au pressure standard was placed into the center of the pressure media.

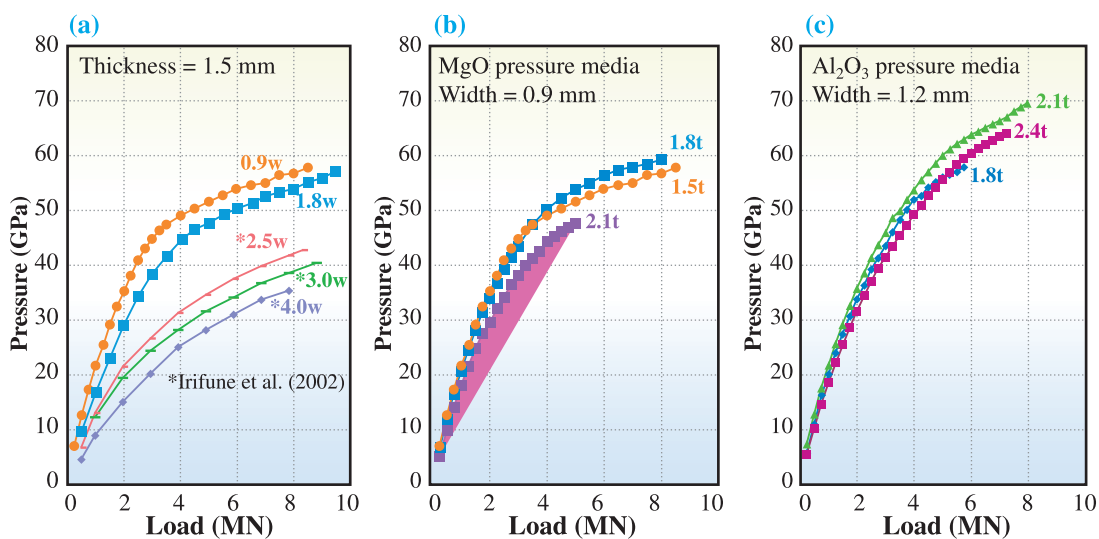


Fig. 3. High-pressure generation curves using 14 mm SD anvils with 1.5 mm of truncated edge. Errors of measured pressure were similar to each symbol. In each curve, the indexed value indicates the width (w) or thickness (t) of the gasket used. (a) Pressure vs. press load for various gasket widths using MgO pressure media. Pressure generating efficiency increases with decreasing gasket width. (b) Optimization of gasket thickness using MgO pressure media. Pressure generation reached a plateau at ~ 50 GPa. (c) Optimization using Al_2O_3 pressure media. The use of Al_2O_3 pressure media broke the plateau observed in the case of MgO pressure media.

Yoshinori Tange* and Tetsuo Irifune
 Geodynamics Research Center, Ehime University

*E-mail: tan@sci.ehime-u.ac.jp

References
 [1] E. Ito and E. Takahashi: J. Geophys. Res. **94** (1989) 10637.
 [2] E. Ito *et al.*: Advances in High-Pressure Technology for Geophysical Applications, (eds. J. Chen, Y. Wang, T.S. Duffy, G. Shen and L.F. Dobrzhinetskaya) (Elsevier 2005) 451.
 [3] T. Irifune *et al.*: Phys. Chem. Minerals **29** (2002) 645.