

Development of rotational diamond anvil cell and large strain deformation experiments of lower-mantle materials

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The rheological properties of lower-mantle materials are key to understanding the dynamics and evolution in the Earth's interior. However, the pressure range of deformation apparatuses which can achieve large strain is limited to ~30–40 GPa due to a technical reason. We developed the rotational diamond anvil cell (rDAC) which can conduct deformation experiments with large strain under ultra-high pressure conditions, corresponding to those of core-mantle boundary [Nomura et al., 2017]. The rDAC can apply the torsional deformation to sample with constant strain rate by a gearbox and diamond anvils with grooves [Azuma et al., 2018]. However, the stress measurement and high temperature conditions has not been achieved in rDAC. To solve these problems, the vacuum chamber newly designed for rDAC was installed and the stress measurements using X-ray Diffraction (XRD) were applied to deformation experiments in rDAC at SPring-8 (Japan). In this presentation, we will present the preliminary results of stress measurements, high temperature techniques in rDAC, and the results of deformation experiments of lower-mantle materials.

In this study, the mixture of bridgmanite (Mg,Fe)SiO₃ and ferropericlase (Mg,Fe)O, which was synthesized from San Carlos olivine, was deformed under torsion geometry using the rDAC. The experimental conditions are ranging 26–130 GPa, 300–673 K. Starting material was grooved by FIB and the groove was deposited by Pt as a strain-marker. Recovered samples were cut by FIB to observe the deformation microstructures in each cross-section. Deformation experiments were conducted at BL47XU, SPring-8 (Japan) and 3D visualization of strain marker within samples was performed every rotation angle of upper anvil of 5–30 degree using X-ray laminography technique [Nomura and Uesugi, 2016]. Stress was measured by collecting X-ray diffraction pattern at twelve different azimuthal angles, $\psi = 0^\circ, \pm 30^\circ, \pm 60^\circ, \pm 90^\circ, \pm 120^\circ, \pm 150^\circ, \text{ and } 180^\circ$. Testing of the new vacuum chamber was also performed at SPring-8. The vacuum chamber has a removable Kapton window for incident and diffracted X-ray, and can keep the vacuum state ($< \sim 10$ Pa) to prevent the diamond anvils from oxidation during high-temperature deformation experiments. Platinum wires were used as a resistance heater surrounding the sample and Rhenium gasket.

The geometry of strain-marker in cross-section of deformed samples show nearly simple shear (or general shear). Deformed microstructure of recovered samples was observed using FE-SEM and we determined the 2D surface area of ferropericlase and aspect ratio of bridgmanite. The deformation microstructures of the recovered samples showed that ferropericlase highly deformed and formed an interconnected weak layer. On the other hand, the aspect ratio of bridgmanite did not change with the strain, indicating that bridgmanite has high viscosity compared with ferropericlase. These results imply that ferropericlase dominates the deformation in the regions where large shear strain occurs under relatively low-temperature conditions in the lower mantle (e.g., mantle portion in subducted slabs).

Stress in bridgmanite was estimated by using diffraction peaks (110) and (112) at $P = 50$ GPa and $T = 673$ K. Shear stress in bridgmanite was relatively constant values, whereas uniaxial stress changed during

deformation experiments. This preliminary experiment was performed under low-temperature and high-pressure conditions, thus the equivalent stress in bridgmanite was about three times higher than that in previous studies [Girard et al., 2016].

In heating experiments using new vacuum chamber, temperature was monitored by Pt/Rh thermocouple placed close to the sample and we succeeded in increasing temperature up to ~ 1000 K. However, the resistance heater (Pt) was unstable in vacuum. In the future, high-temperature deformation experiments using rDAC will be conducted in reducing atmosphere produced by inactive gas or internal heating system should be developed for rDAC.

Keywords: Lower mantle, Rotational diamond anvil cell, Deformation