Development of the rotational diamond anvil cell for high-pressure deformation experiments and its measurement systems

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The mechanical 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 a new deformation apparatus named rotational diamond anvil cell (rDAC). This deformation apparatus can apply the torsional deformation to a sample, thus the rDAC can theoretically produces an infinite strain within the sample under ultra-high pressure conditions, corresponding to those of core-mantle boundary [Nomura et al., 2017]. The rDAC is the most suitable deformation apparatus with which to investigate the mechanical properties of deep-Earth materials. In this presentation, we will mainly present the measurement systems, technology and idea which were applied to the rDAC.

Deformation apparatuses used in Earth science need high-pressure and high-temperature techniques, the constant strain rate, and the measurement systems of the stress and strain. The rDAC can apply high pressure and torsional deformation to a sample with constant strain rate by a gearbox and diamond anvils with grooves [Azuma et al., 2018]. In situ strain measurements are conducted using X-ray laminography techniques at BL47XU, SPring-8 [Nomura and Uesugi, 2016]. High-temperature conditions and stress measurements have not been achieved in rDAC. Recently, however, the vacuum chamber newly designed for rDAC was installed for high temperature experiments, and stress measurements using X-ray Diffraction (XRD) were applied to deformation experiments in rDAC at SPring-8 (Japan).

To test the high temperature technique and stress measurements using XRD with the new vacuum chamber, the mixture of bridgmanite (Mg,Fe)SiO$_3$ and ferropericlase (Mg,Fe)O, which was synthesized from San Carlos olivine, was deformed under torsion geometry using the rDAC at BL47XU, SPring-8. The vacuum chamber has a removable Kapton window for incident and diffracted X-ray, and can keep the vacuum state (<~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. Stress was measured by collecting X-ray diffraction pattern at twelve different azimuthal angles, $\Psi = 0^\circ, \pm30^\circ, \pm60^\circ, \pm90^\circ, \pm120^\circ, \pm150^\circ$, and $180^\circ$.

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 performed in reducing atmosphere produced by inactive gas (e.g., Argon gas) or internal heating system should be developed for the rDAC.

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 [e.g., Girard et al., 2016].
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