Report for the Joint Use/Research of the Institute for Planetary Materials, Okayama University for FY2024

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Category: ☑International Joint Research ☐General Joint Research ☐Joint Use of Facility ☐Workshop

Name of the research project: Radiative conductivity of ferric iron-rich bridgmanite under lowermost mantle conditions

Principal applicant: Motohiko Murakami

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Collaborator

Name: Daisuke Yamazaki

Affiliated institution and department: IPM, Okayama University

Research report:

To understand Earth's thermal history over the past 4.6 billion years, it is essential to elucidate the mechanisms of heat transfer in the deep Earth. These mechanisms are driven primarily by the immense gravitational energy released during core formation and the radiogenic decay energy from radioactive elements presumed to reside in the deep interior. The core-mantle boundary (CMB), where the liquid outer core meets the solid mantle, is considered the most critical thermal boundary in the Earth's interior, as efficient heat transfer via convection is not possible across this interface.

However, the heat transport mechanisms—particularly radiative thermal conductivity—of bridgmanite, the dominant lower mantle mineral under conditions of the lowermost mantle, have remained experimentally unresolved. This has posed a significant obstacle to a comprehensive understanding of Earth's thermal evolution. To address this issue, we successfully conducted the first measurements of radiative thermal conductivity of iron-bearing bridgmanite under lowermost mantle pressure-temperature conditions in collaboration with Prof. Daisuke Yamazaki in 2022 (Murakami et al., 2022, EPSL). Our results demonstrated that the contribution of radiative heat transfer, previously thought to be negligible, is in fact significant. This implies that heat transfer across the CMB is more efficient than previously believed, suggesting that the Earth is cooling at a faster rate.

Nonetheless, our recent valence state analyses of iron in bridgmanite with more realistic chemical compositions—containing not only iron but also aluminum—strongly suggest that approximately half of the iron exists in the trivalent state (Fe^{3+}). Thus, to better constrain the thermal transport properties of bridgmanite, it is essential to extend the 2022 study (which focused primarily on divalent iron) to bridgmanite rich in trivalent iron and aluminum.

In the present joint research project, we will again collaborate with Prof. Daisuke Yamazaki, who previously succeeded in synthesizing single crystals of iron-bearing bridgmanite, to synthesize single crystals of iron- and aluminum-bearing bridgmanite enriched in Fe^{3+}—a prerequisite for radiative thermal conductivity measurements. These crystals will then be used as starting materials for high-pressure, high-temperature experiments in collaboration with Dr. Goncharov at the Carnegie Institution for Science. We aim to quantitatively determine the effect of Fe^{3+} on radiative thermal conductivity under lowermost mantle conditions and apply the findings to refine models of Earth’s thermal evolution.

The results of this study will provide critical insights into the rate of Earth's cooling and have significant geophysical implications.

With the cooperation of Prof. Daisuke Yamazaki, we successfully synthesized single crystals of bridgmanite enriched in Fe^{3+}. TEM–EELS analysis revealed that the sample contains approximately 40% trivalent iron. We are currently preparing the sample by thinning it for use in diamond anvil cell experiments.

Dr. Alexander Goncharov of the Carnegie Institution was invited to ETH in March to discuss the details of the measurement techniques and scheduling. We are currently coordinating to carry out the radiative conductivity measurements during a stay of approximately two weeks in July–August.