氏　　名	張　友悦
授与した学位	博　士
専攻分野の名称	学　術
学位授与番号	博甲第　　６６４１　　号
学位授与の日付	２０２２年　３月　２５日
学位授与の要件	自然科学研究科　　地球惑星物質科学専攻 （学位規則第４条第１項該当）
学位論文の題目	Experimental study on thermal properties of planetary constituent materials （惑星構成物質の熱特性に関する実験的研究）
論文審査委員	教授　神崎　正美　　教授　芳野　極　　准教授　山﨑　大輔 准教授　MANTHILAKE GEETH

学位論文内容の要旨

Knowledge of thermal conductivity (λ) helps understand the thermal history of the past of a planet, the nowadays thermal dynamics in planetary interior and predicts the future scenario of the activity level of a planetary dynamo. I have carried out determination of thermal properties of main minerals forming terrestrial mantle by a pulse heating method, which allows precise simultaneous measurement of thermal conductivity and thermal diffusivity (κ) under high pressure and high temperature.

Thermal conductivity and thermal diffusivity of polycrystalline olivine with different Fe contents were measured up to 10 GPa and 1100 K. With increasing Fe in olivine, λ of olivine first decreases and then slightly increases. The composition dependent λ of olivine suggests a warmer upper mantle and thicker crust of Mars than expected. The Fe-poor mantle of Mercury would lead to a faster cooling rate. Olivine dominant asteroids with high Fe content have longer cooling history and smaller thermal inertia on the surface.

Thermal conductivity and thermal diffusivity of polycrystalline ferropericlase with different Fe contents were measured up to 23 GPa and 1100 K. The measurement results revealed dramatic effect of Fe that even small addition will decrease the absolute value and pressure dependence by several times compared with end member MgO. Fe substitution also reduces the temperature sensitivity of λ leading to a unique nonmonotonic behavior of temperature response. The strong composition dependence of λ implies that the crystallization sequence and depth of ferropericlase may influence the magma ocean cooling of terrestrial planets and results in thermal heterogeneity in the deep mantle.

Simultaneous measurements of λ and κ of post spinel and bridgmanite with five different compositions were performed up to 24 GPa and 1100 K. The results shows that initial small amount adding of impurity leads to almost halved λ values. Impurity will decrease not only absolute value of λ, but also result in smaller pressure, temperature dependence of λ. The impurity influence is not simple linear relationships with substitution amount. Different λ values of bridgmanite in MORB, harzburgite, and pyrolite layers in a stagnant slab can lead to different conductive heating efficiency during different stalling stage. After peeling of MORB layer, larger λ of harzburgite bridgmanite will result in quick completion of transition to denser phase inside the slabs due to faster temperature equilibrium and trigger restart of sinking of a stagnant slab. Temperature-sensitive λ value of Mg end member bridgmanite may cause the magma ocean cooling rate difference of Earth and Venus from the initial crystallization of impurity depleted bridgmanite.

論文審査結果の要旨

Youyue Zhang has studied heat transport mechanism of the main mantle minerals in planetary interior during 5-years PhD course. Thermal conductivity of nominally anhydrous mantle minerals has been thought to be sensitive to Fe content or some impurities in their crystal structure. However, laboratory measurements investigating effect of impurities on thermal conductivity of major mantle minerals have shown a large discrepancy between some laboratories. One problem is that the methods auquired by previous studies have not determined thermal conductivity directly. To solve this problem, she has studied effect of impurities on thermal conductivity of mantle minerals at various pressure and temperature conditions based on pulse heating method, which allows simultaneous measurements of thermal conductivity and diffusivity.

This thesis is composed of 3 parts as follows: 1) Thermal conductivity of olivine $(Mg_x,Fe_{1-x})_2SiO_4$ aggregates with various Fe contents. 2) Thermal conductivity of ferropericlase $(Mg_x,Fe_{1-x})O$ aggregates with various Fe contents. 3) Thermal conductivity of bridgmanite aggregates including various Al and Fe contents and postspinel. Thermal conductivity of olivine was varied by different Fe contents and the lowest value appeared at composition about Fo_{31} at room temperature. The composition dependent thermal conductivity of olivine suggests that the Fe-poor mantle of Mercury would lead to a faster cooling rate than other terrestrial planets, whereas olivine dominant asteroids with high Fe content have longer cooling history and smaller thermal inertia on the surface. Thermal conductivity of ferropericlase also shows the minimum value at which is similar to that of olivine. She established a universal equation as an applicable tool to estimate thermal conductivity of ferropericlase with variable compositions as functions of temperature and pressure. The results of thermal conductivity measurements for bridgmanite aggregates show that small amount of impurity (5 mol% Al or 3 mol% Fe) leads to almost halved λ values. This result gives a new insight on peeling process of subducted slab.

Ph D. defense for Youyue Zhang was held on 10th February. We considered that this thesis includes the new insights on significant effects of impurities, pressure and temperature on thermal conductivity of mantle minerals and contributes to thermal evolution of the Earth and planets. Therefore, we judged that this thesis is suitable to be accepted as a dissertation of Doctor of Philosophy in Okayama University.