Effect of iron content on thermal conductivity of olivine with implications for cooling history of rocky planets

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Knowledge of thermal transport properties of mantle materials is essential for understanding the thermal state and dynamics of the Earth and planetary interiors. Previous studies have suggested that temperature and pressure dependences of thermal conductivity can affect mantle convection and plate tectonics involving subduction dynamics. Olivine is the most abundant mineral in the Earth's upper mantle and chemical composition of olivine in the Earth's upper mantle is characterized by high forsterite content around Fo_{90}. For other terrestrial planets, Mercury is believed to have a FeO-poor mantle along with end member silicates, whereas olivine in the Martian mantle would be more Fe-rich, speculated to be Fo_{67}. Recent studies suggested that surface of some asteroids is dominated by olivine of composition from Fo_{49} to Fo_{70}. Hence, the effect of Fe content in olivine on thermal conductivity could be significant for understanding the thermal structure and cooling history of these terrestrial planets and asteroids.

In this study, thermal conductivity and diffusivity of olivine were determined simultaneously by combining multi-anvil high pressure experimental technique and pulse heating method. Thermal properties of olivine with six different Fe contents (Fo, Fo_{90}, Fo_{70}, Fo_{50}, Fo_{31}, Fo_0) were measured under the Earth's upper mantle condition in a 5000-ton Kawai type multi-anvil press. The minimum λ was found to be at composition near Fo_{31}; the absolute λ value of Fo_{31} is about 65% lower than that of Fo. Small amounts of minor elements can strongly reduce the thermal conductivity at low temperature; λ value of Fo90 is about 50% of Fo at room temperature. As temperature increases, the difference in λ among olivine samples with various Fe contents tends to become smaller. Thermal conductivities of polycrystalline olivine have smaller absolute values and weak pressure and temperature dependences, compared with those of natural single crystal olivine determined by previous studies. Heat capacity of olivine calculated from λ and κ is independent of pressure and is controlled by nearly constant thermal expansion coefficient of Fo_{70} and Fo_{50} with increasing temperature. Smaller λ of olivine aggregate with high Fe content would produce thicker crust in the Fe-rich Mars, while heat in the Fe-poor Mercury can escape faster than the other terrestrial planets. Olivine-dominant asteroids with high Fe concentration could have longer cooling history and lower thermal inertia on the surface.

Keywords: Thermal conductivity, Olivine, Heat capacity, High pressure, Mantle

