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Pressure dependence on thermal conductivity and thermal diffusivity of mantle materials and their values in the upper mantle

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We have measured the thermal conductivity and the thermal diffusivity of mantle candidate minerals under high pressures and at high temperatures. On the basis of results we present values of thermal diffusivity and thermal conductivity in the upper mantle.

A pulse method has been applied to simultaneous thermal diffusivity and thermal conductivity measurements. The sample in the form of three identical thin disks is instantaneously heated by a pulse current in a thin heater inserted into one joint of the stacked disks. Change of temperature is observed on the other joint by a thermocouple. Thermal diffusivity is determined from decay time of the temperature profile, and thermal conductivity is calculated from the rise of temperature and a power of the current. The experiments were performed using a uniaxial split-sphere high-pressure apparatus (USSA-1000) at ISEI. A magnesia octahedron with a edge length of 18 mm was used as a pressure medium in tungsten carbide anvils with a truncation of 11 mm. Dimensions of the sample were 4 mm in diameter and 1 mm in height.

For olivine and garnet single crystals the experiments were made under pressures up to 8.3 GPa. At this terminal pressure the measurements at high temperature were performed up to 1100 K. The olivine from northern Pakistan shows an idomorphic shape and has a composition of 93% forsterite and 7% fayalite in molar fraction. The garnet from Brazil has a composition of 73 % almandine and 25 % pyrope in molar fractions. Each sample was cut so that the end of the surface was perpendicular to the crystallographic axis.

It is known olivine reveals high anisotropy in thermal conductivity or thermal diffusivity at ambient pressure. In this study we found that the anisotropy in olivine, difference of 1.5 times in the magnitude, holds throughout the conditions of pressure and temperature of our experiments. We could predict this behavior maintains at the whole its stable pressure, i.e. to about 15 GPa. Pressure dependences in thermal diffusively or thermal conductivity of olivine is about 5 per cent increase per 1 GPa for all of the directions to the crystallographyc axes. This shows that the thermal conductivity or the thermal diffusivity increases 70 % from the top to the bottom in the upper mantle by the pressure effect. In fact this increase will be reduced by the temperature effect.

It is shown that the pressure derivatives of thermal diffusivity or thermal conductivity of garnet tend to decrease as pressure increases. At 5 GPa they are 2 per cent a 1 GPa for thermal diffusivity and 3 per cent a 1 GPa for thermal conductivity. In addition, the thermal diffusively or the thermal conductivity of garnet decreases moderately with temperature increase unlike normal insulators in the T-inverse law of thermal conductivity. This means that change in the thermal conductivity or the thermal conductivity of garnet is smaller than that of olivine in the mantle.

From our results, we estimate the thermal diffusivity and the thermal conductivity of a simplyfied mantle which consists of olivine, garnet and pyroxene. Data for pyroxene are not sufficient at present, however, measurements by Kobayashi (1974) are applied, and this mineral is supposed to have similar behavier to olivine in the pressure dependence of thermal conductivity. A temperature profile by Ito and Sato (1992) is used. The thermal diffusivity and the thermal conductivity in the mantle are calculated for the upper and the lower bound coming from the anisotropy of olivine and pyroxene. At a depth of 200 km the thermal diffusivities are 0.7 x 10^-6 m^2s^-1 (lower bound) and 1.2 x 10^-6 m^2s^-1 (upper bound), and the thermal conductivities are 2.3 W/m K (LB), and 3.7 W/m K (UB). They will be 0.9 x 10^-6 m^2s^-1 (LB) and 1.2 x 10^-6 m^2s^-1 (UB), and 2.8 W/m K (LB), and 4.3 W/m K (UB) at around 380 Km depth, the bottom of the upper mantle.