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High accuracy measurement of activation energy of creep and electrical conductivity of olivine aggregate

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It is believed that creep rate of peridotite being major rock in the Mantle is controlled by diffusion of the slowest ion which is Si^{4+}. However it is suggested that diffusion of the second fastest ion controls the deformation rate in the system of which not only olivine but it including pyroxene also consists (Sundberg and Cooper (2008)). As seen above, the controlling process has not been understood well. Besides the activation energy being indication for deciding the mechanism is often obtained with a large error range. Therefore, in a case of extrapolating the experimental to the Earth's interior value, the large error will produce a large uncertainty. To solving the two problems, we have conducted the compression experiment and electrical conduction test for olivine simultaneously under a continuously changing temperature.

The sample used for the experiment was synthetic olivine composed of forsterite (90vol %) + enstatite (10vol %), which imitates a material in upper Mantle. To inhibit to grain growth during the experiment, the sample was annealed at 1360 ℃ for 24 hours in the furnace before the test conducted. During the experiment, the sample was kept loaded at constant stress, 20MPa, and temperature changed from 1360 ℃ to 1240 ℃ and then increased from 1240 ℃ to 1360 ℃ in order to confirm reproducibility of measurements. Measurement of impedance of the sample was also conducted simultaneously. The sample applied at 20V every ten degree from 1360 ℃ provided us current response, which was used for measurement of impedance of the sample.

The result of the experimental data provided us viscosity and electrical conductivity of the sample. Viscosity was obtained by the relation of stress and strain rate. Arrhenius plot of reciprocal viscosity shows a linear distribution. This indicates that deformation mechanism of the sample did not change at the applied temperature range in the experiment. Electrical conductivity in the sample was obtained by the resistivity derived from the data by impedance measurement. Assuming that the conduction is thermally-activated process, the relation of conductivity times temperature and temperature shows a linear relation in Arrhenius plot. From each these slopes of lines, Activation energy of 627$\pm$15 kJ/mol was obtained about creep and that of 297 $\pm$12 kJ/mol was obtained about electrical conduction, respectively. This difference of the activation energies indicates that the creep rate and electrical conduction were controlled by different ion or/and different diffusion in the sample.

Sundberg and Cooper (2008) suggested that deformation mechanism is Mg^{2+} + O^{2-} ion diffusion but not Si^{4+}diffusion in a case of the sample of olivine + pyroxene. Therefore we compare our result with previous works. Activation energy of lattice diffusion of Si^{4+} and O^{2-}in olivine are $\approx$530 kJ/mol and $\approx$340 kJ/mol(Dohmen et al. 2002), respectively and that of Mg^{2+}lattice diffusion is about 400$\pm$60 kJ/mol (Chakraborty et al. 1994). On other hand, 627$\pm$15 kJ/mol was obtained in this study, so that we can infer that lattice diffusion of Si4+ controlled creep rate. ten Grotenhuis et al. (2004) obtained that activation energy of 315$\pm$39 kJ/mol by measuring electrical conductivity of olivine aggregate which has the same composition and almost same grain size of ours, and relation of increase electrical conductivity and decrease in grain size. Consequently, from the grain size is the same one of us, we can infer that grain boundary diffusion of Mg^{2+}ion contributed to the conductivity of our sample.

Keywords: olivine, creep, electrical conduction, activation energy, diffusion, polycrystal