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Si and O self-diffusion in stishovite

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Seismological studies revealed the seismic reflectors in the lower mantle at the depth from 900 to 1850 km (e.g., Kaneshima and Hellfrich, 1999; Niu et al., 2001; Castle and Creager, 1999). These reflectors are interpreted as pieces of subducted ancient oceanic crust (Kaneshima and Hellfrich, 1999), indicating the high viscous oceanic crust to inhibit the deformation during subduction and further mixing with the lower mantle. At lower mantle depth, stishovite is as much as 20 % in the basaltic composition and 40 % in the sedimental rocks (Irifune and Ringwood, 1993; Ono et al., 2001; Irifune et al., 1994). Therefore, the viscosity of stishovite may be one of the key parameter to constrain the viscosity of the ancient oceanic crust in the lower mantle. Viscosity of solid is thought to be controlled by diffusion of the constituting elements. To know the viscosity of stishovite, thus, diffusivity of Si and O was studied by means of high pressure experiments in this study.

Single crystals of stishovite (˜500 μm in size) were synthesized at 12 GPa in a Kawai-type high pressure apparatus by slow-cooling method (Shatskiy et al., 2010). The polished $\{110\}$ surfaces were coated with ˜150 nm ^{29}Si and ^{18}O enriched SiO_2 layer in a high-vacuum thermal evaporator. The coated crystals were again compressed at 14-21.5 GPa and 1673-2073 K in the Kawai-type apparatus for diffusion. The recovered samples were measured by secondary ion mass spectroscopy (SIMS) to obtain diffusion profiles by the depth profile method. The obtained profiles were fitted to semi-infinite diffusion model and the fitting results were ΔE, ΔV and logD_0 to be 178.6$\pm$4.4 kJ/mol, 6.0$\pm$0.2 cm^3/mol and -12.9$\pm$0.14 m^2/s, respectively, for Si diffusion, and 262.7 kJ/mol, 5.0$\pm$1.6 cm^3/mol and -10.1 m^2/s, respectively, for O diffusion, where ΔE, ΔV and D_0 are the activation enthalpy, activation volume and pre-exponential factor, respectively.

Our results show that Si diffusion in stishovite is slower than O under mantle conditions and hence the deformation of stishovite is controlled by Si diffusion. The diffusivity of Si in stishovite is ˜3 orders of magnitude smaller than that in wadsleyite and garnet (Shimojuku et al., 2009, 2013), ˜4 orders of magnitude smaller than that in ringwoodite (Shimojuku et al., 2009) and perovskite (Yamazaki et al., 2000). We can conclude that stishovite is the hardest mineral among the main mantle minerals. The survival of the subducted slab observed as seismic reflector at the lower mantle might be supported by the significantly high viscous stishovite.

Keywords: stishovite, diffusion, viscosity, subducted oceanic crust