Si self-diffusion in wadsleyite

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1. Introduction

The diffusion experiments of mantle minerals are important for understanding the rheological properties of the Earth's mantle, because the atomic diffusion in the crystals controls some physical properties, e.g., plastic deformation, transformation kinetics, electrical conductivities. Wadsleyite is a major constituent mineral in the mantle transition zone. Hence experimental examination of the diffusion rates in wadsleyite is essential for the rheology of mantle transition zone. Silicon is the slowest diffusing species in olivine (Houlier et al., 1988; Dohmen et al., 2002.). Because the slowest diffusing species controls the deformation rate, it is very important to investigate the Si diffusion rate of silicate minerals. In this study, we report experimental results on Si self-diffusion rates at 18 GPa, 1473-1873K using isotopic tracer (29Si). From this result, we discuss deformation mechanisms of mantle transition zone and dynamics subducting slabs.

2. Experimental procedure

High-pressure experiments were performed using a multi-anvil apparatus at Tohoku University. Truncated edge length of the second-stage tungsten carbide anvil is 5.0 mm. Pyrophyllite gaskets were used. The sample assembly was composed of sintered zirconia (ZrO2) pressure medium and LaCrO3 heater. Temperature was monitored with W3%Re-W25%Re thermocouple located in the furnace without the correction of pressure effect on emf of the thermocouples.

First, we synthesized the starting material of anhydrous wadsleyite polycrystals with the composition of Mg2SiO4 from forsterite powder. Its surface was polished and coated with 29Si enriched SiO2. After the diffusion annealing at 18 GPa and 1473-1873K for 1-52 hours, 29Si profiles from the surface of wadsleyite were measured by the depth profiling method using Secondary Ion Mass Spectroscopy (SIMS).

3. Results and discussion

The obtained depth profiles are composed of two regions. It could be interpreted that volume diffusion is the dominant mechanism in the region near the sample surface, whereas grain-boundary diffusion is dominant in the deeper region. The volume diffusion coefficients were calculated using the solution of thin film diffusion model (Crank, 1975). The grain-boundary diffusion was calculated by the model of LeClaire (1963). The volume diffusion coefficient (Dv) and grain boundary diffusion coefficient (deltaDgb) were determined to be Dv = 2.45*10^-12[m2/s]exp(-257[kJ/mol]/RT) and deltaDgb = 1.56*10^-18[m3/s]exp(-236[kJ/mol]/RT), respectively. Si self-diffusion rates of wadsleyite are about six orders of magnitude slower than Mg-Fe interdiffusion rates in wadsleyite, and about one order of magnitude faster than Si diffusion rates of olivine (Dohmen et al., 2002) and almost identical with Si diffusion rates of perovskite (Yamazaki et al., 2000).

We calculated the viscosity deformed by diffusion creep from obtained Si diffusion rates. The viscosity deformed by dislocation creep was calculated from creep law parameter by Karato et al. (2001). Compared with geophysical observations, the result imply that both diffusion creep and dislocation creep mechanisms can be dominant in the mantle transition zone. In cold subducting slabs, diffusion creep is the dominant deformation mechanism. Therefore, the slab possibly weaken if the grain size is reduced after the olivine-spinel transition.