Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SGC56-05 Room:415 Time:April 30 15:15-15:30

Grain boundary diffusion of polycrystalline ice Ih under confining pressure of 100 MPa

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Ice I_h is a primary constituent of surfaces of the icy Galilean satellites and ice sheets at the Antarctica. Thus understanding rheological behavior of ice Ih will contribute to better knowledge about the dynamics and tectonics of the surface of the icy satellites and ice sheets. Stress applied by the tidal deformation to the surfaces of the icy satellites was predicted to be very low, ˜1 MPa (Sotin and Tobie 2004), and diffusion and grain-size-sensitive creeps probably control the deformation of the surfaces of the ice satellites. The deformation map under such a low stress condition can be constructed, based on two diffusion constants, grain boundary and volume diffusion coefficients, of polycrystalline ice I_h. The volume diffusion coefficient of ice I_h was determined from experiments using a single crystal of ice I_h (Ramseier 1967; Itagaki 1967), while the grain boundary diffusion coefficient has not been determined yet. Thus we carried out experiments to determine directly the grain boundary diffusion coefficient of polycrystalline ice I_h.

The diffusion couples have been composed of a pair of disks of pore-free polycrystalline H_2O and D_2O ices. The glass beads with a diameter of 2 μm were doped in the diffusion couples to prevent the grain growth during diffusion experiments by Zener pinning effect. The volume fraction of the glass beads was approximately 1 %. The diffusion experiments were carried out under the confining pressure of 100 MPa using a gas apparatus surrounded with a cryostat (Durham et al. 2001). Temperatures were set in the range from 235 K to 256 K. After keeping the diffusion couples in the deformation instrument for 20 ˜94 hours, we shaved off thin sections from the diffusion couples. Two-dimensional diffusion profiles of the thin section were determined with micro- and imaging- Raman spectroscopes and a cryo-stage. The Raman mapping or Raman imaging measurements were carried out with keeping the thin sections at -90 ℃. The concentration of deuteron can be determined from the relative intensity of Raman band of OH stretching mode to that of OD stretching mode using a quantitative curve. The two-dimensional distribution showed enrichment of deuterium at the grain boundaries near the H_2O/D_2O boundary. It indicates that grain boundary diffusion of ice I_h is rapid. The diffusion profiles obtained by the experiments enable to estimate the grain boundary diffusion coefficient of ice I_h which is essential to construct the deformation map.

Keywords: ice, diffusion, grain boundary diffusion, hydrogen isotope, Raman spectroscopy, rheology