Electrical conductivity of single crystal hydrous olivine

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The oceanic asthenosphere has very high electrical conductivity with high anisotropy in some locations. In the directions of parallel and normal to the plate motion, respectively, the conductivity is orders of 10e-1 and 10e-2 S/m, which cannot be explained by conductivity of anhydrous olivine. Because hydrogen can be incorporated in olivine at mantle pressures, the observation has been usually interpreted by the olivine hydration, which would cause anisotropically high conductivity by proton migration. In order to examine this hypothesis, here we report effect of water on electrical conductivity and its anisotropy for hydrogen-undoped and -doped olivine at 500-1500 K and 3 GPa.

The starting materials were prepared from a single olivine crystal with a (Mg0.92Fe0.08)2SiO4 composition from China. Initial H2O contents are less than 1 ppm. Two experimental series (hydrogen-doped and -undoped conditions) were conducted to assess the effect of hydrogen on the conductivity. The single-crystal samples parallel to [100], [010] and [001] were cored from the optically inclusion-free portion by an ultrasonic drilling machine. Hydrous olivine single crystals were synthesized by doping hydrogen to the single crystal cores. The single crystals were surrounded by a talc+brucite mixture with a 100 micron thick Ni foil and welded in Pt capsules, which were kept at pressure P = 3GPa and temperature T = 1373K for 6-8 hours. The concentration of hydrogen in samples was determined by Fourier-transform infrared (FT-IR) spectroscopy both before and after each conductivity measurement. H2O contents in the hydrogen-doped olivine are around 230 ppm except for the cylindrical core oriented to [010] (approximately 100 ppm).

The hydrous olivine has anisotropically much higher conductivity and lower activation energy than anhydrous olivine in the investigated temperature range. The hydrogen-doped olivine has higher conductivity by 2 orders of magnitude than the hydrogen-undoped olivine. The activation energies of the hydrogen-undoped olivine in the high temperature region are around 1.4 eV. In this temperature region, small polaron should be the dominant conduction mechanism. The activation energies of the hydrogen-doped olivine in each crystallographic axis are found to be E[100] = 0.73, E[010] = 0.97, and E[001] = 0.87 eV. At higher temperature corresponding to the top of the oceanic asthenosphere, the intrinsic (small polaron) conductivity of olivine could be masked by extrinsic (proton) one due to difference of the activation energy between these two mechanisms.

Extrapolation of the experimental results to higher temperature suggests that conductivity of hydrous olivine at the top of the asthenosphere should be nearly isotropic and only order of 10e-2 S/m. Thus, the hydrous olivine cannot account for the geophysical observations. The observation could be attributed to presence of partial melt elongated in the direction of plate motion.