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Influence of crystallographic anisotropy on the electrical conductivity of apatite at high temperatures and high pressures

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Abstract

The electrical conductivity of apatite single crystals along three main crystalline directions was measured in situ using a YJ-3000t multi-anvil apparatus and a combined system consisting of the impedance/gain-phase analyzer (Solartron 1260) and dielectric interface (Solartron 1296) at 973–1373 K and 1.0–3.0 GPa. The obtained results indicate that the relationship between the electrical conductivity and temperature conforms to the Arrhenius relation. At 2.0 GPa, the electrical conductivity of apatite with relatively high activation enthalpies of 1.92–2.24 eV shows a significant anisotropy with an extremely high anisotropic degree (τ = ~8–16) value. For a given [001] crystallographic orientation, the electrical conductivity of apatite slightly decreases with increasing pressure, and its corresponding activation energy and activation volume of charge carriers are 2.05 ± 0.06 eV and 9.31 ± 0.98 cm^3/mol, respectively. All of these observed anomalously high activation enthalpy and positive activation volume values suggest that the main conduction mechanism is related to the monovalent fluorine anion at high temperature and high pressure. Furthermore, three representative petrological average schemes, including the parallel, Hashin-Shtrikman upper bound, and average models were selected to establish the functional relation for the electrical conductivity of the phlogopite-apatite-peridotite rock system along with the volume percentages of apatite ranging from 1 to 10% at 973–1373 K and 2.0 GPa. For a typical Hashin-Shtrikman upper bound model, the electrical conductivity-depth profile for peridotite containing the 10% volume percentage of apatite was successfully constructed in conjunction with our acquired anisotropic electrical conductivity results and available temperature gradient data (11.6 and 27.6 K/km) at depths of 20–90 km. Although the presence of apatite in peridotite cannot explain the high-conductivity anomalies in western Junggar of Xinjiang autonomous region, it may provide a reasonable constraint on those of representative apatite-rich areas.

Keywords: Apatite, electrical conductivity, anisotropy, fluorine conduction, high pressure; Physics and Chemistry of Earth's Deep Mantle and Core