High-pressure electrical conductivity and elasticity of iron-bearing δ-AlOOH

XIAOWAN SU1,†, JIN LIU2,3,*, YUKAI ZHUANG2,4, CHAOJIA LYU2,5, XUYONG PANG6, FUYANG LIU2, XIAOHUI YU6, and QIANG SUN4,1,*

1School of Earth and Space Sciences, Peking University, Beijing 100871, China
2Center for High Pressure Science and Technology Advanced Research (HPSTAR), Beijing 100094, China
3CAS Center for Excellence in Deep Earth Science, Guangzhou, 510640, China
4Institute of Atomic and Molecular Physics, Sichuan University, Chengdu 610065, China
5Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China
6Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

ABSTRACT

The electrical conductivity and elasticity of deep hydrous phases are essential to constraining water distribution, as well as deciphering the origins of conductivity anomalies in the lower mantle. To uncover the impact of iron-bearing δ-AlOOH on the geophysical properties of the lower mantle, we carried out synchrotron X-ray diffraction and electrical conductivity measurements on δ-(Al0.52Fe0.48)OOH and (Al0.46Fe0.54)OOH in diamond-anvil cells at pressures up to 75 GPa at room temperature. A sharp volume reduction of ~6.5% was observed in δ-(Al0.52Fe0.48)OOH across the spin transition at 40.8–43.3 GPa, where its electrical conductivity increases steadily without abrupt changes. The electrical conductivity of δ-(Al0.46Fe0.54)OOH is greater than that of pure δ-AlOOH at high pressure, suggesting that both small polaron and proton conduction mechanisms dominate in iron-bearing δ-AlOOH. Furthermore, the high-pressure electrical conductivity profiles are comparable between δ-(Al0.46Fe0.54)OOH and δ-(Al0.52Fe0.48)OOH, indicating that high-iron content only marginally influences the conductivity of iron-bearing δ-AlOOH. Notably, the electrical conductivity of iron-bearing δ-AlOOH along the North Philippine geotherm is greater than the average 1D electrical conductivity profile in the mantle (Ohta et al. 2010a). This result suggests that δ-(AlFe)OOH is a promising candidate to account for high conductivity in some subducting slabs.

Keywords: Hydrous minerals, spin transition, high pressure, X-ray diffraction, electrical conductivity

INTRODUCTION

Knowledge of water distribution in the mantle is fundamental to the understanding of our planet’s evolution and geodynamics (Mao and Mao 2020; Ohtani 2020). It is widely believed that water is transported to the lower mantle via slab subduction in the forms of various hydrous phases such as δ-AlOOH (Duan et al. 2018; Sano-Furukawa et al. 2008), phase D (Pamato et al. 2015), phase H (Liu et al. 2019b) (FeH)1−xTiO2 (Nishihara and Matsukage 2016), pyrite-type (Mg,Fe)O (Hu et al. 2019), and hexagonal (Mg,Fe)2O3H (Liu et al. 2020). The δ-AlOOH phase, one of the most important hydrous minerals in subducting slabs, is stable at least up to 134 GPa and 2300 K, that is at the high pressure and temperature (P-T) conditions of the Earth’s lowermost mantle (Duan et al. 2018; Sano-Furukawa et al. 2008). Thus, it has been considered an important deep-water carrier throughout the lower mantle (Ohtani et al. 2001; Sano-Furukawa et al. 2008; Tsuchiya and Tsuchiya 2011; Tsuchiya et al. 2002). Additionally, δ-AlOOH forms a solid solution with the isostructural hydrous phase ε-FeOOH in multicomponent systems (Kawazoe et al. 2017; Ohira et al. 2019; Liu et al. 2019b; Buchen et al. 2021).

The incorporation of FeOOH greatly influences the physics and chemistry of δ-AlOOH. Because of pressure effects on the electronic spin states of 3d transition metal iron, the δ-(AlFe)OOH phase undergoes a high-spin to low-spin (HS-LS) transition of iron at ~40 GPa (Ohira et al. 2019; Hsieh et al. 2020; Su et al. 2021a). Intriguingly, the unit cell volume, compressibility, and thermal conductivity of δ-(AlFe)OOH exhibit abnormal behaviors throughout the electronic spin-pairing transition. For instance, δ-(Al0.90Fe0.06)OOH1.14 and δ-(Al0.83Fe0.17)OOH1.15 both display gradual volume collapses across the HS–LS transition (Ohira et al. 2019). The thermal conductivity of δ-(Al0.86Fe0.11)OOH drastically decreases at 30–45 GPa and approaches an exceptionally low value of ~10 W m−1 K−1 in the LS state at 66 GPa (Hsieh et al. 2020). Moreover, the incorporation of 5 mol% FeOOH decreases the shear-wave velocity of δ-AlOOH by ~5% at 20–135 GPa (Su et al. 2021b). However, the effect of iron on the electrical conductivity of δ-AlOOH has not yet been reported under high pressures.

The electrical conductivity values of iron-free δ-AlOOH remain almost the same, up to 50 GPa, which indicates proton conduction is the primary conduction mechanism (Zhuang et al. 2020). ε-FeOOH exhibits much higher conductivity than δ-AlOOH up to 20 GPa at high temperatures (Wang and Yoshino 2021). We note that the electrical conductivity of mantle...