Single-crystal elasticity of (Al,Fe)-bearing bridgmanite up to 82 GPa

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ABSTRACT

Thermoelastic properties of mantle candidate minerals are essential to our understanding of geophysical phenomena, geochemistry, and geodynamic evolutions of the silicate Earth. However, the lower-mantle mineralogy remains much debated due to the lack of single-crystal elastic moduli ($C_p$) and aggregate sound velocities of (Al,Fe)-bearing bridgmanite, the most abundant mineral of the planet, at the lower mantle pressure-temperature ($P$-$T$) conditions. Here we report single-crystal $C_p$ of (Al,Fe)-bearing bridgmanite, Mg$_{0.88}$Fe$_{0.1}$Al$_{0.14}$Si$_{0.90}$O$_3$ (Fe$_{10}$-Al$_{14}$-Bgm) with Fe$^{3+}$/2Fe = ~0.65, up to ~82 GPa using X-ray diffraction (XRD), Brillouin light scattering (BLS), and impulsive stimulated light scattering (ISLS) measurements in diamond-anvil cells (DACs). Two crystal platelet orientations of (−0.50, 0.05, −0.86) and (0.65, −0.59, 0.48), that are sensitive to deriving all nine $C_p$, are used for compressional and shear wave velocity ($v_P$ and $v_S$) measurements as a function of azimuthal angles over 200° at each experimental pressure. Our results show that all $C_p$ of single-crystal Fe10-Al14-Bgm increase monotonically with pressure with small uncertainties of 1–2% (±1σ), except $C_{55}$ and $C_{33}$, which have uncertainties of 3–4%. Using the third-order Eulerian finite-strain equations to model the elasticity data yields the aggregate adiabatic bulk and shear moduli and respective pressure derivatives at the reference pressure of 25 GPa: $K_S = 326 ± 4$ GPa, $\mu = 211 ± 2$ GPa, $K_S' = 3.32 ± 0.04$, and $\mu ' = 1.66 ± 0.02$ GPa. The high-pressure aggregate $v_S$ and $v_P$ of Fe10-Al14-Bgm are 2.6–3.5% and 3.1–4.7% lower than those of MgSiO$_3$, bridgmanite end-member, respectively. These data are used with literature reports on bridgmanite with different Fe and Al contents to quantitatively evaluate pressure and compositional effects on their elastic properties. Comparing with one-dimensional seismic profiles, our modeled velocity profiles of major lower-mantle mineral assemblages at relevant $P$-$T$ suggest that the lower mantle could likely consist of about 89 vol% (Al,Fe)-bearing bridgmanite. After considering uncertainties, our best-fit model is still indistinguishable from pyrolitic or chondritic models.

Keywords: Single-crystal elasticity, bridgmanite, lower mantle, pyrolite, pyrolite, chondrite

INTRODUCTION

Earth’s lower mantle, the most voluminous region of the planet, plays a key role in regulating physical, chemical, and dynamic interactions between the core and upper mantle as well as the crust. Geochemical and petrological observations indicate that the upper mantle likely consists of pyrolite with approximately 89 vol% (Al,Fe)-bearing bridgmanite, Mg$_{0.88}$Fe$_{0.1}$Al$_{0.14}$Si$_{0.90}$O$_3$ (Fe$_{10}$-Al$_{14}$-Bgm), ~18 vol% ferropericlase [(Mg,Fe)O, Fp], and ~7 vol% CaSiO$_3$ (Mashino et al. 2020; Murakami et al. 2012) could provide important insights into the lower-mantle mineralogy. In the lower mantle could likely consist of about 89 vol% (Al,Fe)-bearing bridgmanite. After considering uncertainties, our best-fit model is still indistinguishable from pyrolitic or chondritic models.

Bridgmanite is suggested to be the most abundant lower-mantle mineral (Ringwood 1975). Despite extensive theoretical studies on its elasticity at high $P$-$T$ (Karki et al. 1997; Shukla and Wentzcovitch 2016; Wentzcovitch et al. 2004), experimental investigations on this subject are still limited to polycrystalline samples or single crystals at relatively low pressures. In addition, Si as a light element in the core (Allègre et al. 1995) and/or a Si-rich lower mantle (Hofmann 1997) have been proposed previously. Moreover, some recent studies suggest that comparisons of velocity and density profiles between seismic observations (Dziewonski and Anderson 1981; Kennett et al. 1995) and mineral physics models (Irifune et al. 2010; Kurnosov et al. 2017; Mashino et al. 2020; Murakami et al. 2012) could provide important insights into the lower-mantle mineralogy. This would require a complete and reliable elasticity data set of the lower-mantle candidate minerals with small uncertainties.

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