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Determination of the full elastic tensor of single crystals using shear wave velocities by Brillouin spectroscopy

Dawei Fan[1,2,3,*], Zhu Mao[4,*], Jing Yang[2] and Jung-Fu Lin[2,3]

[1]Key Laboratory for High Temperature and High Pressure Study of the Earth's Interior, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, Guizhou 550002, China
[2]Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, Texas 78712, U.S.A.
[3]Center for High Pressure Science and Technology Advanced Research (HPSTAR), Shanghai 201203, China
[4]Laboratory of Seismology and Physics of Earth's Interior, School of Earth and Space Sciences, University of Science and Technology of China, Hefei, Anhui 230026, China

Abstract

Single-crystal elasticity of candidate minerals in the Earth's mantle, such as that of ferropericlase and bridgmanite, etc., is very important for understanding the seismic observations, geodynamic flow patterns, and testing geochemical and mineralogical models of the planet's deep interior. Determination of the full elastic tensor typically requires measuring both compressional and shear wave velocities (v_P and v_S) of the candidate single crystal as a function of crystallographic orientations at high pressures, but it has been a huge technical challenge obtaining v_P at pressures above 25 GPa using Brillouin light scattering coupled with in a diamond-anvil cell due to the spectral overlap of the sample v_P with the v_S of the diamond window. In this study, we present a new method to derive the full elastic tensor (C_{ij}) of single crystals using only measured v_S of a given crystal platelet as a function of the azimuthal angle. Experimentally determined v_P and v_S results from Brillouin measurements for cubic periclase (MgO) and spinel ($MgAl_2O_4$), tetragonal stishovite (SiO_2), and orthorhombic zoisite [$Ca_2Al_3Si_3O_{12}(OH)$] at ambient conditions are used as examples to demonstrate the application of our approach from theoretical analyses and experimental prospective. For high-symmetry cubic minerals, such as cubic MgO and spinel, a suitable crystallographic plane with small tradeoffs between any two C_{ij} in v_S is required for the method to work well such that the obtained C_{ij} using measured v_S velocities alone can be within 3% of the values derived from using both v_S and v_P. Our analyses show that the (–1,0.5,0.2) platelet for periclase and the (1,1,0) platelet for spinel are respective optimal orientations for applying our method. For lower symmetry minerals, such as tetragonal stishovite and orthorhombic zoisite, three crystallographic planes, that are orthogonal to each other and are tilted at least 20° from the principal crystallographic planes, can be used to provide reliable constraints on C_{ij} using measured v_S alone. We have extended this method to derive C_{ij} of the (–1,0.5,0.2) platelet for periclase at pressures of 5.8 and 11.3 GPa, in a high-pressure diamond-anvil cell to demonstrate the usefulness of the approach in studying the elasticity of Earth's mantle minerals at relevant pressure-temperature conditions. Our proposed approach can be extended to all other crystal systems at high pressures to overcome the constant lack of experimental v_P velocities at above 25 GPa, potentially providing new experimental and theoretical approaches in constraining the elastic tensor of the materials in the Earth's deep interior, which will be an effective strategy to solve one of the most relevant difficulties involved in the experimental study of the elastic properties (especially elastic anisotropy) of minerals of the lower mantle.

Keywords: Single-crystal elasticity, periclase, spinel, zoisite, stishovite, Brillouin light scattering