Elastic Wave Velocity Measurements at Lower-mantle Conditions

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Introduction

Simultaneous x-ray diffraction, x-ray imaging, and ultrasonic measurements enable us to measure pressure, volume, Vp, Vs, temperature, and sample length (P-V-Vp-Vs-T-L) at high pressures and temperatures [1, 2]. However, pressures are still limited to less than 15 GPa. The newly installed 1000-ton press with a T-25 double-stage anvil system will expand such measurements to lower-mantle conditions (P of >20 GPa and T of ~2500K). A wide pressure and temperature range will eliminate extrapolating elastic properties to greater depth for studying the composition, dynamics, and structure of the Earth's interior.

Methods and Materials

We have conducted feasibility studies of ultrasonic experiments at a P of >20 GPa in this apparatus on a polycrystalline ringwoodite. Figure 1 is a schematic diagram of the cell assembly used in this study. A piezoelectric transducer is mounted at the corner that is opposed to the corner that is pressing the pressure medium, and it stays stress-free during the experiment. The transducer serves as both signal transmitter and receiver. When a pulse is applied to the transducer, acoustic waves are transmitted into the sample through the tungsten carbide (WC) anvil and the glass buffer rod. Reflections from the WC anvil/buffer rod and from the buffer rod/sample interfaces as well as those from the end of the sample result in a series of echo trains. The apparent travel time through the sample can be obtained by measuring the delay time needed to superimpose the buffer rod echo and the first sample reflection immediately after.

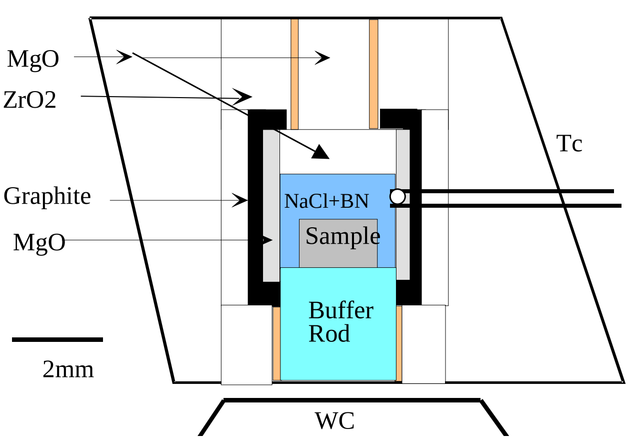

FIG. 1. Schematic cross section of the ultrasonic experiment cell assembly.

The polycrystalline $(MgFe)_2SiO_4$ ringwoodite sample (hot-pressed by using USSA-2000 at SUNY Stony Brook) is surrounded by NaCl + BN. The NaCl serves as a pressure marker from which the pressure is obtained by using a Decker pressure scale. An acoustic buffer rod is inserted into the MgO octahedral pressure medium to minimize the energy loss along the wave propagation path to the sample. A 2-μm-thick gold foil is inserted between the buffer rod and sample to enhance their mechanical coupling. The surrounding NaCl provides a pseudohydrostatic stress environment for the sample during cold compression in addition to serving as the pressure standard. A W5%Re-W26%Re thermocouple is fed into the center of the cell from the gap between two horizontal anvils. The pressure effect on the electromotive force (emf) reading of the thermocouple was not corrected.

Results

Examination of the recovered cell indicated that the center of the specimen is located in the center of the cell and that the thermocouple junction is right next to the center of the sample. At a moderate oil load (600 tons), a sample pressure of 22 GPa has been reached. Figure 2 shows the recorded signals for the P wave, demonstrating a high signal-to-noise ratio at this pressure. The first echo is from the end of the anvil, the second is from the buffer rod, and the third is from the sample. A precise determination of sample travel time can be obtained by using the ultrasonic interferometry method from the phase delay between the buffer rod echo and sample echo. By combining the measured travel time, sample length, and x-ray diffraction data, the elastic wave velocities at high pressure and temperature can be precisely determined. Applying this technique to the candidate mantle minerals provides experimental data that can be directly compared with seismic data without extrapolating pressure and temperature.

Acknowledgments

This research was supported by a National Science Foundation (NSF) grant to B. Li (EAR00003340).

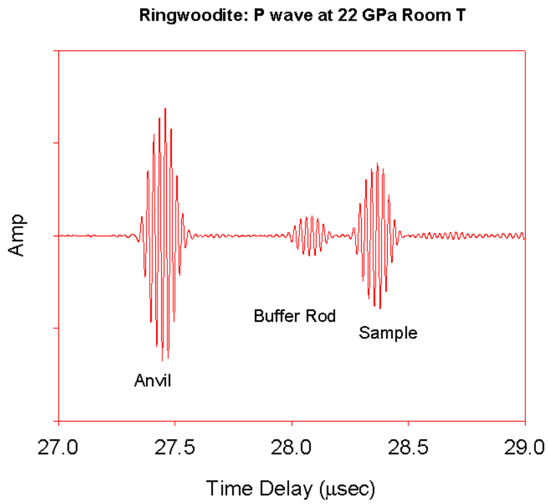

FIG. 2. Acoustic signals on ringwoodite at 22 GPa and room temperature (50 Mhz) in a 1000-ton press with T-25. Precise time delay between buffer rod and sample can be measured by interferometry method.

Support was from SUNY at Stony Brook and the NSF Science and Technology Center for High Pressure Research (EAR89-20239). Use of the APS was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38. We also thank the GeoSoilEnviro Consortium for Advanced Radiation Sources (GSECARS) for technical support.

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