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Sound velocity measurements of solid iron under high pressure and high temperature using an ultrasonic method

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The Earth's interior has been directly investigated by seismic wave propagation and normal mode oscillation. Based on those observations, the distributions of density and sound velocity of the Earth's interior have been estimated (e.g. PREM). The core, which is located at the center of the Earth, is believed to consist of metallic iron with a certain amount of light elements, such as hydrogen, carbon, oxygen, silicon, and sulfur. A large number of experiments on the compressibility of iron and iron-light element alloys have been carried out in order to constrain the abundances of the light elements in the core. In the past fifteen years, the sound velocities of the iron and iron alloys have also been measured intensively at high pressure. Although the sound velocity consists of longitudinal (V_P) and transverse (V_S) components, most discussions about the core composition have been based on the only V_P data because of the technical issues of the high-pressure experiments. In order to estimate the abundances of the light elements more correctly, the precise measurement of V_S as well as V_P is necessary. In this study, we measured the V_P, V_S, and density of solid iron under high-pressure and high-temperature conditions using an ultrasonic method, and X-ray radiography and diffraction techniques.

Simultaneous ultrasonic measurements, and X-ray radiography and diffraction experiments were carried out at BL04B1 beamline, SPring-8 in Japan. High-pressure and high-temperature were generated using a 1500-ton Kawai type multi-anvil apparatus installed at BL04B1 beamline. The experimental conditions were up to 7 GPa and 800 K (stability field of bcc-Fe). The Fe powder or rod was used as the sample. Ultrasonic V_P and V_S measurements were performed using the pulse reflection method. P- and S-wave signals with a frequency of 57 MHz and 30 MHz, respectively, were generated and received by a 10 degree Y-cut $LiNbO_3$ transducer. The sample was first compressed to the target pressure and heated up to the maximum temperature in each press load in order to reduce the deviatoric stress. Then, we got the ultrasonic data, X-ray radiography image, and X-ray diffractions from the sample and the pressure marker (MgO + hBN) at each about 150-200 K temperature step on decreasing temperature.

Our high-pressure V_P and V_S data are good agreement with the previous ambient-pressure results measured using the same ultrasonic method [Dever, 1972]. In contrast, our V_P data are slightly smaller than the results obtained by high-energy resolution inelastic X-ray scattering (HERIX) technique [Liu et al., 2014]. The values of both V_P and V_S at high temperature are lower than the linear relationship of a velocity-density, i.e., Birch's law, at room temperature, which is the same trend as the previous HERIX result [Liu et al., 2014].

Keywords: high pressure, planetary core, iron, sound velocity