Elasticity of MgO to 130 GPa: Implications for Lower Mantle Mineralogy

The average composition and structure of the Earth's deep mantle can be approached by comparing the observed seismic velocities with appropriate laboratory data collected for candidate minerals under relevant pressure and temperature conditions. It is widely believed that the Earth's lower mantle is primarily composed of silicate perovskite (Pv) and ferropericlase (Fp). Precise knowledge of the elastic properties of $MgSiO_3$ perovskite and MgO periclase, major end-members of constituent mineral phases of the lower mantle, under high-pressure condition is therefore crucial for constructing the accurate mineralogical model of the Earth's lower mantle. However, only few experimental acoustic measurements exist under lower mantle pressure condition. Recent technical advances in high-pressure Brillouin spectroscopic measurements using diamond anvil cell apparatus extended significantly the upper pressure limit for acoustic measurements. It is now possible to measure the aggregate shear wave velocity profiles of both $MgSiO_3$ perovskite and post-perovskite phases up to a pressure of 172 GPa [1,2]. Available experimental data for MgO from the direct sound wave velocity measurements under the lower mantle pressure regime are, however, still limited to a maximum pressure of 55 GPa on a single crystal [3]. Owing to the lack of acoustic data on MgO under the whole pressure range of the lower mantle, the pressure dependence of elastic velocities or moduli has thus far been poorly constrained. In this report, we show the results of elastic wave velocity measurements on MgO collected by Brillouin spectroscopy in a diamond anvil cell (DAC) in conjunction with synchrotron X-ray diffraction technique throughout the entire lower mantle pressure regime approaching 130 GPa.

High-pressure Brillouin scattering measurements of sound velocities in a diamond anvil cell were conducted using the newly developed acoustic measurement system, recently installed at **BL10XU** [4]. Six separate series of high-pressure Brillouin scattering experiments on polycrystalline MgO were performed using a symmetric-type diamond anvil cell. In all the experiments, we collected Brillouin spectra on the polycrystalline MgO, sandwiched with pressure medium of NaCl, at eighteen pressures from 14 to 128 GPa with simultaneous angle-dispersive X-ray diffraction measurements for phase identification and pressure determination. A representative Brillouin spectrum at the high-pressure condition is shown in Fig. 1. Figure 2 shows the pressure dependence of the aggregate shear velocities (V_S) for the MgO. Our new results on high-pressure elasticity of MgO have shown that the aggregate shear wave velocity and shear moduli at ambient pressure are highly consistent with earlier studies. However, the pressure derivative of the shear modulus/velocity (G'_0) of MgO is distinctly lower than that of previous lower-pressure experiments.

The large pressure range over which the aggregate shear wave velocity measurements of MgO periclase were performed in this study [5] thus allows us to put tighter constraints on mineralogical models of the Earth's lower mantle. On the basis of our new results, we have calculated the V_S profile appropriate for an adiabatic lower mantle geotherm in the three-component system MgO-SiO_2-FeO in the same manner as in Ref. [1]. The calculated V_S profiles for Pv [1] and Fp under the lower mantle condition are shown in Fig. 3, along with the 1-D global seismic lower mantle model (PREM). By applying the fairly low G'_0 of MgO determined in this study, the V_S profile of Fp remarkably ascents gently with pressure, as shown in Fig. 3. The PREM profile in the lower mantle is then best fitted within ±0.14% on average for V_S using a model with X_{Pv} = 0.92 (red line in Fig. 3). Given that the best fit profile using the previously reported higher G'_0 value (=2.2) of MgO resulted in X_{Pv} =0.90 (dotted line in Fig. 3), the best fit velocity-depth profile calculated in this study using the lower G'_0 value of MgO requires the more silicate perovskite component in the lower mantle constituents than

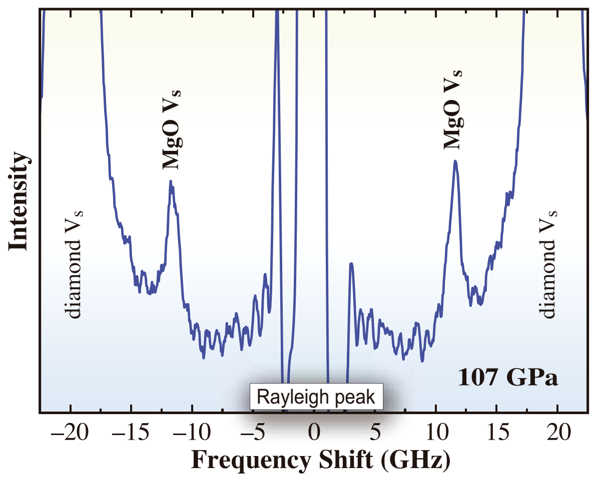

Fig. 1. Representative high-pressure Brillouin spectrum at 107 GPa. V_S, shear acoustic mode of the Brillouin shift.

previously considered, owing to the relatively moderate incline of the shear velocities of ferropericlase with depth.

According to the lower mantle model by applying the previous low-pressure experimental results on G'_0 of both $MgSiO_3$ perovskite and MgO, a superadiabatic geotherm and/or non-uniform bulk composition with depth in the lower mantle should be required in order to meet the global seismic model. Our result, however, strongly supports that the shear velocity profile can remarkably well reproduce the 1-D global seismic model with simple assumptions of an adiabatic geotherm and uniform composition model within the lower mantle. The shear velocity profile calculated from the pyrolitic mantle model with X_{Pv} of 0.80 is also shown in Fig. 3 (green line) for comparison. This profile is ~1.9% lower than that of the PREM model on average throughout the pressure range of the lower mantle, which is clearly incompatible with PREM. Although further experimental explorations particularly on thermoelastic parameters will be required for more strict constraints, our new results strongly offer the possibility that the lower mantle is predominantly composed of Mg-silicate perovskite phase (~92 vol%), and the bulk composition of the lower mantle could be close to chondritic rather than pyrolitic composition.

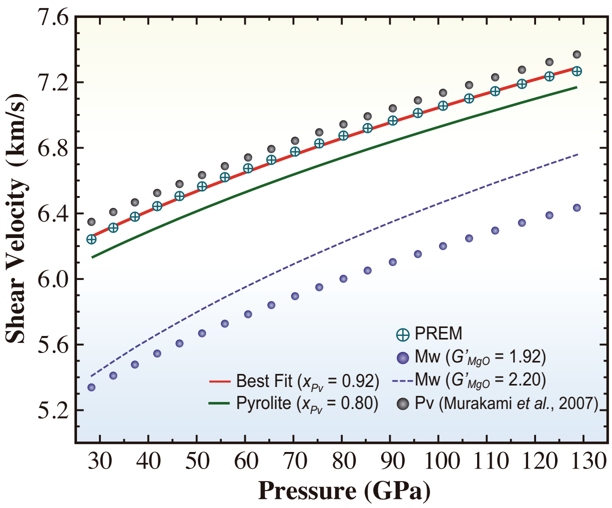

Fig. 3. Calculated shear wave velocity profiles of Fp and Pv as a function of pressure along the representative mantle geotherm, along with the PREM lower mantle seismic model. Blue circles, Fp with X_{Mg} of 0.79; black circles, Pv with X_{Mg} of 0.94 [1]; white circles with cross, PREM. The red line indicates the best fit profile to PREM (X_{Pv} = 0.92). The shear wave velocity profile of the simplified pyrolite model (X_{Pv} = 0.80) is also indicated by the green line. The dotted line shows the profile of Fp calculated from G'_0 = 2.20 of MgO for comparison.

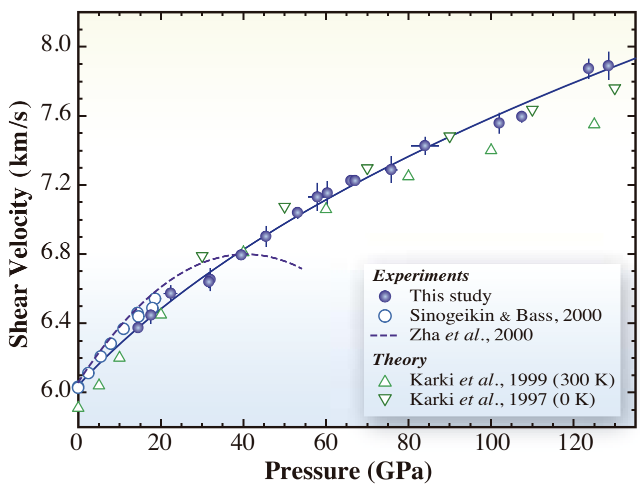

Fig. 2. Shear acoustic wave velocities of MgO as a function of pressure at 300 K (black circles). Third-order Eulerian finite strain fit is indicated by the black line. Open circles and dotted line indicate previous experimental results obtained by Brillouin scattering measurements. Open upward- and downward-pointing triangles indicate the results obtained by computational calculations using first principles at 0 K and 300 K.

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