Ultrasonic interferometry and X-ray measurements on MgO in a new diamond anvil cell

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ABSTRACT

The compressional sound wave velocity, $v_p$, of synthetic MgO in the (100) direction and the unit-cell parameter have been measured up to a maximum pressure of 6.1 GPa using a new type of diamond-anvil cell. The main feature of the cell is the transverse access of the X-ray beam into the sample chamber. This allows us to undertake single crystal X-ray measurements while the ultrasonic attachment is mounted on the diamond-anvil cell. The sound velocity and the elastic parameter $c_{11}$ have been determined from these measurements; the variation with pressure can be described by $dc_{11}/dp = 9.35(13)$, in good agreement with previous studies.

INTRODUCTION

Our knowledge of the Earth’s structure is based upon seismological data. Comparison between laboratory data and seismological data can provide information about the chemistry and mineralogy of Earth’s interior.

Silicate perovskite and (Mg,Fe)O are likely to be important constituents of the lower mantle (e.g., Anderson 1989). Because of its wide stability field and its simple rocksalt structure the elastic properties of the end-member periclase (MgO) have been examined intensively in experimental and theoretical studies (e.g., Jackson and Niesler 1982; Duffy et al. 1995; Karki et al. 1997; Chopelas 1992; Chen et al. 1997; Chen et al. 1998). Moreover, although MgO is cubic and therefore optically isotropic, it shows a large elastic anisotropy of about 10% between the [100] and [111] directions at ambient conditions (Jackson and Niesler 1982).

In the following we report measurements of the pressure derivative of the elastic constant in the (100) direction and the unit-cell parameter of MgO under high pressures. The experiments were performed in a newly built diamond-anvil cell, which enables us to perform ultrasonic interferometry and single crystal X-ray measurements simultaneously.

EXPERIMENTAL METHODS

Cylindrical MgO (100) samples, which were oriented with an accuracy of 0.5º, were cut from a synthetic, clean single crystal obtained from Roditi, Hamburg. The thicknesses of the samples we used in the DAC ranged from about 60 to 150 µm, their diameters were between 200 to 250 µm. The MgO pieces were polished optically flat on both sides to obtain good ultrasonic echoes from the sample.

New diamond-anvil cell

The requirements for X-ray diffraction and ultrasonic measurements in a DAC are very different. For successful high precision measurement of unit-cell parameters a wide angular access to the sample by X-rays is required. By contrast, ultrasonic signals must be transmitted to the sample through one of the diamonds by means of a buffer rod and associated potentially bulky alignment mechanism. To be able to perform ultrasonic and X-ray measurements we built a new diamond-anvil cell with only two guide rods. The main feature of this new cell is the transverse access of the X-ray beam to the sample (Fig. 1). The upper and lower platen provide an opening angle of approximately 65º on each side, and the two support rods provide an access angle of about 120º on each side of the DAC in the equatorial plane. Although this cell has only two guide rods and therefore does not have the stability compared to more conventional cell designs with three or more posts (e.g., Merrill and Bassett 1974; Allan et al. 1995) we reached a pressure of 6.1 GPa using diamond culets of 0.6 mm. Using culets of 0.5 mm diameter a pressure range of 9–10 GPa should be achievable. Stainless steel gaskets with initial thicknesses of 250 µm were used.

Further, the cell can be heated through molybdenum wires 0.25 mm in diameter wound around the tungsten carbide diamond seats, and temperature can be measured by K-type thermocouples fixed directly onto the two diamond anvils. For X-ray diffraction measurements the cell is attached to a modified x-y goniometer head by four ceramic posts (for heat insulation) and an intermediate steel plate to act as a heat shield. Because this attachment is made via the lower platen of the cell, the buffer rod can be left in place during diffraction measurements, and ultrasonic measurements can be made while the cell is mounted on the single-crystal X-ray diffractometer (Fig. 2).

Ultrasonics

The technique of ultrasonic interferometry measurements (Spetzler et al. 1993) has been adopted for use in the diamond-anvil cell (Spetzler et al. 1996). Briefly, ultrasonic signals from a 1.5 µm thin ZnO transducer are introduced to the sample by means of single-crystal sapphire rod (cut with its long axis parallel to c) which is pressed against the table face of the dia-