High-pressure/high-temperature radial XRD of low-spin ferropericlase

H. Marquardt1,2, L. Miyagi3, S. Speziale1, and H.-P. Liermann4

1Deutsches Geoforschungszentrum, Telegrafenberg, 14473 Potsdam, Germany
2now at Bayerisches Geoinstitut BGI, Universität Bayreuth, 95440 Bayreuth, Germany
3Dept. of Geology and Geophysics, The University of Utah, 115 S 1460 East, Salt Lake City, UT 84112 U.S.A.
4Photon Science, DESY, Notkestrasse 85, 22607 Hamburg, Germany

Ferropericlase (Mg,Fe)O is thought to be the second most abundant mineral phase in Earth’s lower mantle. Due to its strong elastic anisotropy and potentially weak rheological behavior it may play a key role in controlling rheology of the lower mantle and in generating seismic anisotropy [e.g. 1, 2]. At pressures between approximately 40 GPa and 70 GPa at 300 K, the ferrous iron in ferropericlase undergoes a spin crossover from high spin to low spin state [3]. Our understanding of the impact of the spin crossover on strength and texture development in ferropericlase is incomplete, in particular experimental data are lacking at mantle-relevant pressure/temperature conditions. A detailed quantitative understanding of (1) texture development (lattice preferred orientation) and (2) strength in low-spin ferropericlase at high-temperatures is needed, because:

(1) It has been shown that the change of spin state significantly enhances the elastic anisotropy [2] and makes (Mg,Fe)O much more anisotropic than post-perovskite, the other major lowermost mantle phase. Therefore, ferropericlase is a likely candidate to explain seismic anisotropy observations, but its deformation behavior in the lower mantle is unclear. There is no agreement about the most active slip systems in ferropericlase at relevant conditions, particularly experimental results at 300 K [4, 5] do not match recent computational predictions [6].

(2) (Mg,Fe)O is traditionally assumed to be the weakest phase. If ferropericlase exists as an interconnected weak phase it will likely control rheology [e.g. 7, 8]. A previous radial XRD study through the spin transition [5] at 300 K suggested that the strength of (Mg,Fe)O decreases throughout the spin crossover region. However, more recent experiments at 300 K suggest that the strength of ferropericlase increases when iron changes from high to low-spin state [9].

We performed high-pressure/high-temperature radial XRD experiments at the Extreme Conditions Beamline (P02.2) of PETRA III on ferropericlase powders. We have measured differential strains, shear strength and preferred orientation of (Mg0.8Fe0.2)O to pressures of 70 GPa and temperatures of up to 1125 K.

The experiments were conducted by loading (Mg0.3Fe0.2)O powders in customized Mao-Bell diamond anvil cells without any pressure-transmitting medium in order to enhance texture and differential stress. We took measurements using angle dispersive x-ray diffraction (energy ~43KeV) and the available fast Perkin Elmer detector. In order to allow studies of lattice preferred orientation as well as lattice strains, the DAC was aligned with the diamond axis at approximately 90° to the incoming x-ray beam (radial geometry). We used a graphite heater to achieve high-temperatures, using the heating setup available at P02.2, including a vacuum chamber, water-cooling and power-supply [10]. We collected radial x-ray diffraction patterns at constant temperature (isothermal) while increasing the load (pressure and deformation) with a gas membrane setup specifically designed for radial diffraction [11]. The gas
membrane device allowed us to collect diffraction patterns at a large number of experimental pressures with a very good pressure-resolution through the spin crossover.

We completed one isothermal compression experiment at 825 K, where a maximum pressure of 70 GPa was reached before failure of the diamonds. Figure 1 shows a diffraction image collected on the Perkin Elmer Detector XRD1621 at the peak pressure/temperature conditions of this experimental run. In a second isothermal run at 1125 K, diamond failure limited the peak pressure to 40 GPa. Further experiments at higher pressures and temperatures are needed to complete this study and unambiguously determine the effect of the spin-cross over on the strength and texture.

Figure 1: (left) Radial XRD pattern of (Mg0.8Fe0.2)O at 70 GPa and 825 K. (right) Unrolled spectrum indicating differential strains (curvature of the diffraction “rings”) and texture (intensity variations along the “rings”).

References