Texture Development in Binary Mixtures of Lower Mantle Perovskite and Ferropericlase at High Pressures and Temperatures

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Texturing is the development of crystals’ preferred orientation in a rock, and inside the Earth, it is the result of plastic deformation of rocks and minerals subject to convective dynamics in the mantle [1]. Due to the intrinsic anisotropy of mantle minerals, texturing is one of the main causes of elastic anisotropy detected in the Earth mantle by seismic studies [2]. In order to use seismic results to extract quantitative information on the plastic behavior of mantle rocks and make inferences on the convective flow of the mantle, we need a thorough knowledge of the main deformation mechanisms of the single minerals and their relative strength as a function of pressure and temperature at conditions relevant for the deep Earth [3]. However, until now this information is still largely missing [1].

Radial X-ray diffraction in the diamond anvil cell has emerged in the last ten years as the most viable approach to investigate texture development and strength of minerals in response to pressures of the lower mantle [3,4]. However, the majority of the studies conducted to date focused on room temperature experiments and on single mineral phases. Fundamental questions about the effect of temperature, multiphase mineralogy, iron electronic transitions and chemical partitioning on the deformation behavior of lower mantle materials have still to be addressed experimentally.

We have investigated texture development and stress in binary mixtures of (Mg,Fe)SiO₃ perovskite and (Mg,Fe)O ferropericlase, the two main minerals of the lower mantle, in a series of radial x-ray diffraction experiments conducted at the Extreme Conditions Beamline (ECB) P02.2 of PETRA III. In these experiments we have measured differential strain and preferred orientation in the two phases up to 38 GPa at 1000 K.

In three different experimental runs, San Carlos olivine (Mg₀.⁹Fe₀.¹)₂SiO₄ was ground to a homogeneous grain-size smaller than 5 μm and loaded in Mao-Bell type diamond anvil cells (DAC) modified for radial x-ray diffraction. The sample chamber was obtained by laser drilling a 50 μm-diameter circular hole in a composite B-epoxy – kapton gasket. The sample was loaded together with a fragment of Pt foil as a pressure calibrant. The starting material was compressed at room temperature to 30 GPa and converted into a mixture of perovskite and ferropericlase by off-line laser-heating at the Extreme Conditions Science Infrastructure (ECSI) at PETRA III. After complete conversion, the samples were resistively heated and radial x-ray diffraction images were collected along isothermal compression paths. Heating was achieved through a graphite heater completely surrounding the gasket. The DAC’s were placed in a vacuum vessel specifically designed for simultaneous resistive heating and radial x-ray diffraction, which are part of the unique setup at the ECB [5]. Pressure increments at high temperatures were finely controlled by using a gas-membrane driving system designed to fit the vacuum chamber. Angle-dispersive x-ray diffraction images were recorded using a fast CsI bonded amorphous silicon area detector XDR1621 from Perkin Elmer [5].

Our new measurements show that in a simplified (silica-poor) peridotite rock, perovskite presents a 100 compression texture developed during its synthesis and that is preserved up to 38 GPa at 1000 K. This means that the (100) lattice planes of perovskite crystals tend to align perpendicular to the direction of maximum stress. Ferropericlase does not develop a visible texture. The new results partially contradict compression experiments conducted using the same method on a similar material at room temperature. In those experiments perovskite shows a transition from an initial
100 to a final 001 compression texture. Also at room temperature ferropericlase does not develop a texture [6].

The results of our new experiments are the first in situ observations of texture in a perovskite–ferropericlase mixture at conditions comparable to those in the upper part of the lower mantle. The texture that we observe is compatible with slip along the (100) plane. This is qualitatively different from the results of stress relaxation experiments conducted on perovskite at 25 GPa and 1700 K [7] and perovskite synthesis recovery experiments [8], both showing evidence of dislocations compatible with (001) slip.

Figure 1: (a) Example of map plot of the amplitude of x-ray diffraction (that is a stack of azimuthal sectors of the x-ray diffraction photo integrated in sectors of 5 degree 2θ) showing both non-hydrostatic strain (the waviness of the diffraction lines) and preferred orientation (amplitude heterogeneity along the diffraction lines). (b) Comparison of the inverse pole figures of the compression direction of perovskite and ferropericlase at 1000 K and at ambient temperatures and at 300 K, showing the difference in the behavior of perovskite.

References