

Influence of Iron on the Stiffness of Silicate Glasses: Insights from All-Optical Density Measurements of Enstatite–Ferrosilite Glasses at High Pressure

Konstantin SOLOVEV (GFZ Helmholtz Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany; Institute of Geosciences, University of Potsdam, Karl-Liebknecht-Str. 24-25, 14476 Potsdam-Golm, Germany),

Sergey LOBANOV (GFZ Helmholtz Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany; Institute of Geosciences, University of Potsdam, Karl-Liebknecht-Str. 24-25, 14476 Potsdam-Golm, Germany)

Abstract

The density of silicate melts is crucial for comprehensive modeling of the early Earth's evolution and for explaining mantle anomalies. It governs gravitational differentiation in the solidifying magma ocean, the migration of melts through the lithosphere, and their stabilization in the transition zone and near the core–mantle boundary. However, no systematic experimental data exists on the influence of iron on the compressibility of silicate melts — iron is one of the most abundant elements in the Earth's mantle — across the full mantle pressure range. This lack of systematic, self-consistent information about volume of silicate melts reflects significant experimental challenges in measuring the compressibility of silicate melts at mantle pressures and temperatures, including extremely small sample sizes, chemical reactivity of the melts, and the absence of long-range crystalline structure. Some of these experimental challenges may be overcome by using quenched glasses as structural proxies of their melts.

Here we report the compressibility of Fe-rich pyroxene glasses along the enstatite–ferrosilite compositional binary, with up to 7 at. % Fe ($\text{En}_{65}\text{Fs}_{35}$) and $\text{Fe}^{3+}/\Sigma\text{Fe}$ ratios of 0.45–0.55, measured at room temperature over a pressure range up to 60 GPa for all compositions and up to 120 GPa for the $\text{En}_{80}\text{Fs}_{20}$ composition. Compressibility was determined using the recently developed all-optical method in a diamond-anvil cell, where refractive-index and absorption-coefficient measurements are combined with image analysis of the sample inside the diamond anvil cell [1, 2].

Comparison of the compressibility of the studied Fe-rich pyroxene glasses with that of MgSiO_3 glass shows they are nearly indistinguishable within experimental uncertainty between 10 and 60 GPa (and up to 120 GPa for $\text{En}_{80}\text{Fs}_{20}$). Notably, the compressibility of MORB glass matches that of the studied glasses up to ~30 GPa. More generally, these results suggest that adding iron to silicate glasses— even in greater amounts than found in pyrolite or MORB — does not substantially alter their stiffness. Nevertheless, the individual roles of Fe^{2+} and Fe^{3+} require further careful examination: their ionic radii differ markedly, and they are expected to play different structural roles in silicate glasses, potentially affecting the stiffness.

Future all-optical measurements of the compressibility and optical properties of $\text{MgO-SiO}_2\text{-Fe}_2\text{O}_3\text{-FeO}$ glasses will provide experimental constraints for models of the physical properties of complex glasses and melts. Such data will substantially improve our understanding of primordial magma-ocean solidification, the evolution of physical and chemical heterogeneity in the mantle, and the migration or stabilization of melts at varying depths within Earth's interior.

[1] S. S. Lobanov, S. Speziale, B. Winkler, V. Milman, Refson, K., and L. Schifferle, Electronic, structural, and mechanical properties of SiO_2 glass at high pressure inferred from its refractive index, *Phys. Rev. Lett.* 128, 077403 (2022).

[2] L. Schifferle, S. Speziale, B. Winkler, V. Milman, and S.S. Lobanov, Reduced charge transfer in mixed-spin ferropericlase inferred from its high-pressure refractive index, *Am. Mineral.* 109, 1145-1152 (2024).