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Huge plastic deformation of SiO_2 glass at room temperature

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Covalent solids are known to be hard but brittle. Moreover, glasses do not deform plastically by dislocation movement seen in crystals due to the lack of long-range order. However, SiO_2 glass, a highly covalent glass, has long been known to be densified up to about 20% by applying high pressure. This phenomenon is called permanent densification, which is some kind of phase transformation caused by the reconstruction of the network structure consisting of SiO_4 tetrahedra [e.g., Wakabayashi et al., 2011], and could be considered as plastic deformation in a broad sense. Recently, the differential strain of SiO_2 glass in its intermediate-range structure, corresponding to the first sharp diffraction peak, was measured under uniaxial compression by a radial X-ray diffraction method, in which X-rays irradiate the sample from a direction perpendicular to the compression axis (i.e., from a radial direction) [Sato et al., 2013]. In those measurements, very large differential strains were observed under pressure and surprisingly also after decompression. This residual strain may be attributable to the anisotropic reconstruction of the network structure (i.e., anisotropic permanent densification).

In this study, the change in size of bulk samples was measured for uniaxially-compressed SiO_2 glass to clarify whether SiO_2 glass undergoes plastic deformation in a narrow sense, i.e., without density change. X-ray diffraction measurements were also conducted in a wide Q-range with 50 keV monochromatic X-rays by irradiating the recovered sample from the radial direction to clarify whether a differential strain remains only in the intermediate-range network structure or also in the short-range SiO_4 tetrahedral structure. Pressures were generated by using a diamond-anvil cell. The starting material was in the form of a disk, and was adjusted to have an appropriate initial thickness to be compressed under uniaxial conditions, i.e., pinched directly by the two anvils, above a certain pressure. Three independent experiments were conducted with an argon pressure medium up to 20 GPa in run 1, 12 GPa in run 2, and 6 GPa in run 3. The change in size of sample was measured with an optical microscope. X-ray diffraction measurements were carried out at PF AR-NE1. All the experiments were conducted at room temperature.

In runs 1 and 2, the diameter of sample was found to increase significantly with pressure from 6-8 GPa, where uniaxial conditions were achieved, to the maximum pressure of each run without fracturing, and it became about 15% larger at 20 GPa than at 0 GPa. The macroscopic differential strain was about an order of magnitude larger than the microscopic differential strain reported in the previous study [Sato et al., 2013], suggesting that SiO_2 glass deformed plastically at room temperature. The X-ray diffraction measurements clarified that the recovered samples were in the fully densified state (about 20% densified). It was also revealed that a residual differential strain was observed only in the intermediate-range network structure and its magnitude was consistent with the previous study [Sato et al., 2013]. On the other hand, in run 3, the sample did not deform plastically by uniaxial compression from 2-3 GPa to 6 GPa. The X-ray diffraction pattern of the recovered sample was the same as that of the ordinary SiO2 glass. Permanent densification is known to begin at about 9 GPa under hydrostatic conditions [e.g., Wakabayashi et al., 2011], and it is suggested that permanently densified SiO_2 glass easily undergoes plastic deformation even at room temperature.

D. Wakabayashi et al., *Phys. Rev. B* **84**, 144103 (2011).
T. Sato et al., *J. Appl. Phys.* **114**, 103509 (2013).

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