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Anomalous behavior of low-density SiO2 in helium under high pressure

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Properties of SiO2 crystals and glass are one of the most classical and important issues in Earth science. Numerous studies on the high-pressure behavior of these materials have been conducted because of their importance not only in Earth science but also in materials science and condensed-matter physics. It is well known that SiO2 crystals, such as cristobalite, tridymite, and quartz, and the glass obtained at ambient pressure have three-dimensional network structures consisting of SiO4 tetrahedra. Considering the fact that the density of quartz is 2.65 g/cm3 (at ambient pressure) and that of stishovite is 4.29 g/cm3, it can be assumed that fourfold-coordinated structures contain a large amount of voids. If small gas molecules such as helium and hydrogen dissolve in these voids, it is expected that the compressional behavior of these materials may be changed and/or new structures may appear. In this presentation, we will report anomalous behavior of SiO2 glass and cristobalite, fourfold-coordinated SiO2 having especially low densities (2.20 and 2.33 g/cm3, respectively), in helium at high pressures. All experiments were conducted using a diamond-anvil cell.

The pressure dependence of the volume of SiO2 glass was determined by measuring the change in the size of the bulk sample in microscope images [Meade & Jeanloz, 1987]. The result up to 10 GPa shows that the volume change of SiO2 glass in a helium medium is much smaller than in a mixture of methanol-ethanol medium, suggesting that the voids in SiO2 glass are prevented from contracting because a large amount of helium penetrates into these voids. The solubility of helium in SiO2 glass is estimated to be more than 1 mol per mole of SiO2 glass at 10 GPa. X-ray diffraction measurements also show that the pressure-induced shift of the position of the first sharp diffraction peak (FSDP) in helium is significantly smaller than that in previous studies. The FSDP is associated with the presence of the intermediate-range order and considered to arise from the periodicity of ordering of the rings consisting of SiO4 tetrahedra [Elliott, 1991; Mei et al., 2008]. Therefore this small shift of the FSDP is consistent with the small volume change. The result of Raman scattering measurements is also significantly different from those in the previous studies with argon and other mediums.

On cristobalite, x-ray diffraction measurements were conducted. At around 10 GPa, a new phase, which has diffraction peaks at larger d values, was observed. It may be possible that the volume increases as helium dissolves in cristobalite. Above 20 GPa, another new phase, which has very broad diffraction peaks, was observed. At this pressure range, the transformation to a stishovite-like structure was observed in argon and other mediums [Yamakata and Yagi, 1997]. This second new phase might have a sixfold-coordinated structure. We are planning to obtain more precise data in order to determine the structures of these two new phases.

References
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