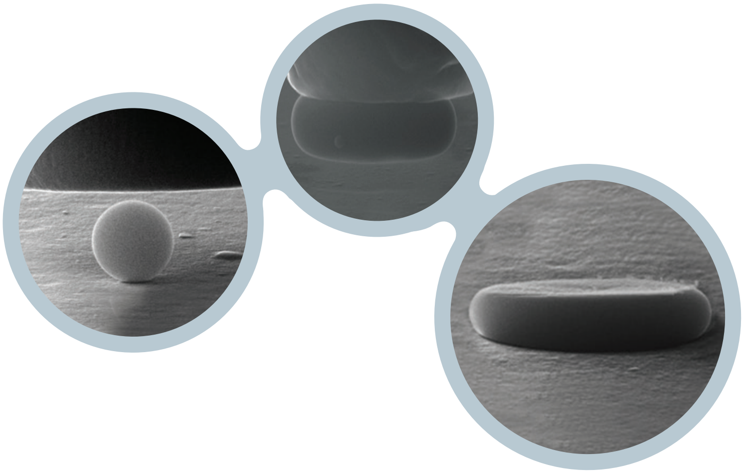


Application Note #1534

The Influence of Stress and Electron Irradiation on the Mechanical Properties of Silica

Radiation-induced plastic flow in amorphous silica glass is important in glass science and technology, and has been studied for decades using high-energy ions and particles. However, the deformation behavior of such material irradiated by low-energy electrons is not well understood. In comparison to heavier particles and ions, electrons have much greater penetration depths. Therefore, they can generate uniform damage and structural changes throughout a material. This application note investigates plastic flow of silica particles under a combined effect of compressive stress and electron radiation inside a scanning electron microscope (SEM).

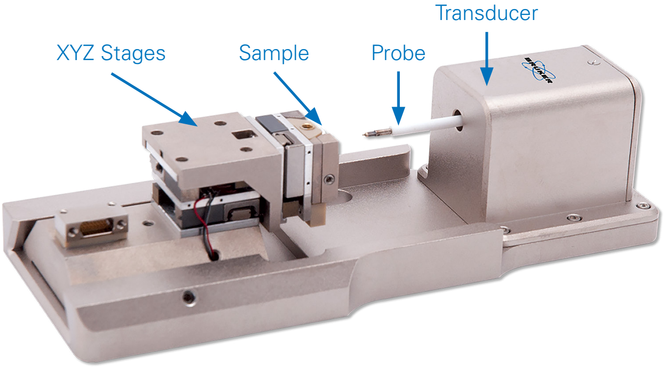


Figure 1. Hysitron PI 85L SEM PicoIndenter.

In-Situ Compression Testing

In-situ compression experiments were conducted on 1 µm diameter silica particles using Bruker's Hysitron PI 85L SEM PicoIndenter equipped with a 5 µm flat punch diamond probe (see Figure 1). SEM imaging, in concert with the XYZ sample staging of the Hysitron PI 85L, was used for tip-sample alignment. Once proper alignment was achieved (Figure 2), load-controlled quasi-static compression experiments were conducted to peak forces of 1 mN and 4 mN under several beam dosages.

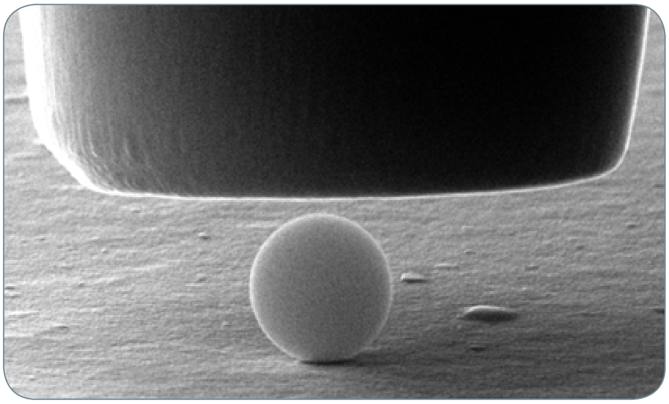


Figure 2. A 1 µm silica particle prior to compression with a 5 µm flat punch probe.

Figure 3a shows a typical load function used to control the compression experiments, and Figure 3b shows a comparison of the acquired compression data under beam-on and beam-off conditions. The highly uniform particles, approximately 1 µm diameter, can be considered identical for the purposes of this testing.

Plastic Flow and Fracture Behavior

Figures 4a–h show load-displacement curves and deformation behavior of the particles before (inset) and after the experiments with beam-off and beam-on conditions. Considerable variation in the plastic strain was observed with varying peak loads and beam conditions. Plastic strain (ε) is calculated as *d/D*, where *D* is the original diameter of the particle and *d* is the amount of compression along the indentation axis. At 1 mN load and beam-off condition, the particle showed negligible strain (<0.05%, Figure 4b). However, similar diameter particles deformed plastically to 47% and 67% strain when beam currents of 30 pA and 480 pA were applied (Figure 4c and 4d). This can be compared to the "beam off" condition for the higher load experiments, where considerable plastic strain, almost 36%, occurred in conjunction with fracture that separated the particle (Figure 4f). The 30 pA beam-on condition also shows conjunctive plasticity (57%) and separation fracture (Figure 4g). However, when the beam current is raised to 480 pA, fracture is completely suppressed (Figure 4h).

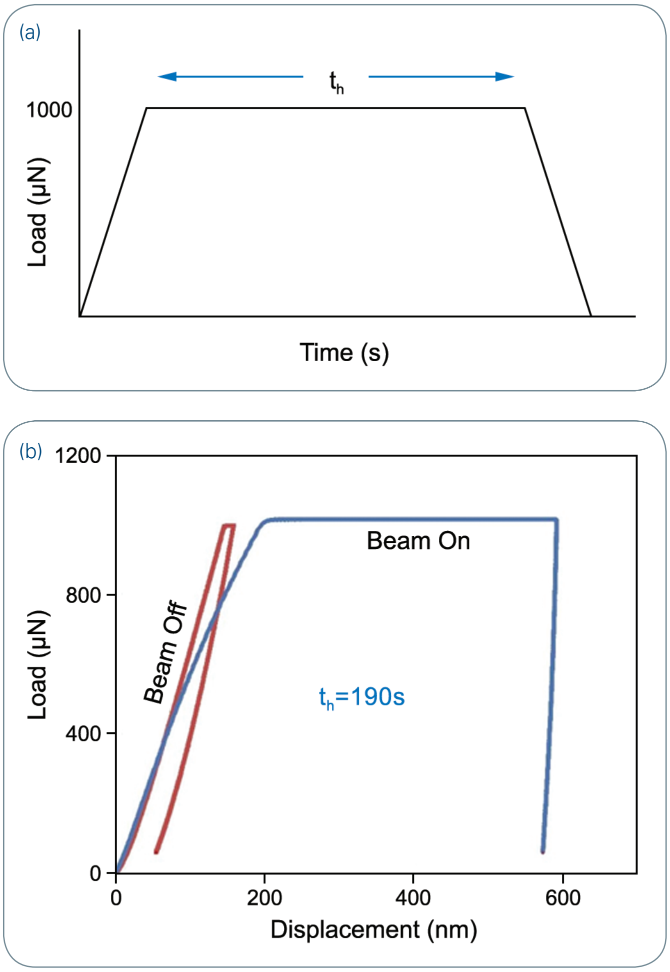
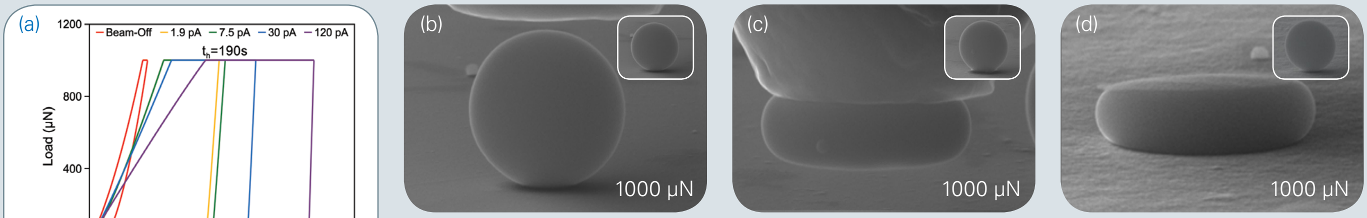


Figure 3. (a) A typical load function; (b) p–h curves show the dramatic effect of the electron beam.

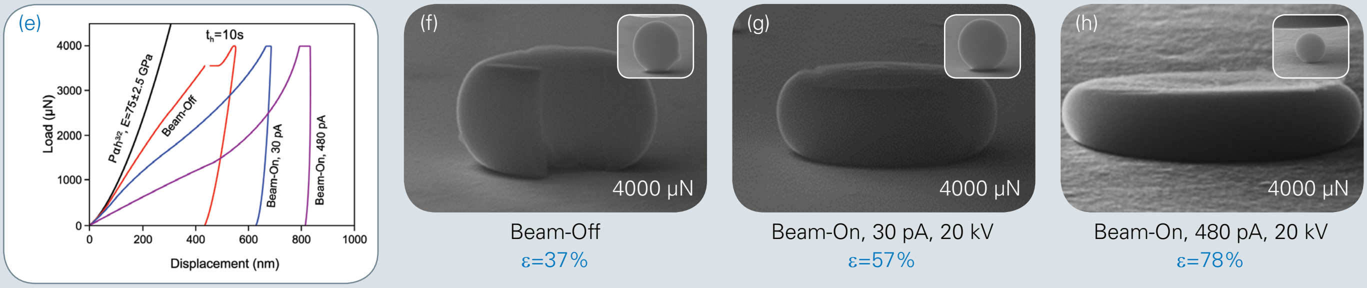
Effect of Electron Beam and Applied Load



Beam-Off
ε=1%

Beam-On, 30 pA, 20 kV
ε=47%

Beam-On, 480 pA, 20 kV
ε=67%



Beam-Off
ε=37%

Beam-On, 30 pA, 20 kV
ε=57%

Beam-On, 480 pA, 20 kV
ε=78%

Figure 4. Load-displacement curves and a selection of corresponding pre- and post-test SEM images from the compression tests. The extent of plasticity in the particle appears to be closely linked to the condition of the incoming electron beam.

Conclusions

In this study, the compression behavior of micron-sized silica spheres was observed in-situ using a Hysitron PI 85L. The data shows that the mechanical properties of small-scale silica spheres is strongly dependent on the conditions of the incoming electron beam. It was found that fracture behavior of this normally brittle solid material can be almost entirely suppressed by increasing the beam current in the range of hundreds of pA. Furthermore, by dynamically switching the beam on and off during the hold segment of the test, it was also possible to quantify the transient behavior in plastic flow as a function of incoming beam current. Such behavior could be made advantageous in applications where the shaping of silica glasses by conventional methods is impractical and a transient, highly localized ductility is desired.

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