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In-Situ Fracture of Silicon Nanoparticles

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Characterizing the mechanical properties of nanoscale volumes of materials, which are known to vary from those of bulk, can be difficult to test because of the inherent challenges imposed by the size of the samples involved. The properties of silicon nanostructures are of particular importance because of the frequency with which this material finds use in practical applications in the semiconductor industry. Over the last decade, the development of TEM sample holders capable of quantitative *in-situ* nanomechanical testing has spurred a number of studies on the mechanical properties of nanoscale structures [1-3]. Nanomechanical testing with simultaneous TEM imaging has the added benefits of direct imaging of the structure and of electron diffraction information.

In this work a specimen holder capable of *in-situ* nanomechanical testing was used to compress individual single-crystal silicon nanospheres in the TEM. The spheres have been tested previously using both traditional nanoindentation and qualitative *in-situ* indentation techniques and are thought to exhibit enhanced mechanical properties compared to bulk Si [4-5]. However, the shortcomings of each of these methods independently left a number of questions about the true mechanical response of the particles. This study presents the results of extensive *in situ* testing of particles with diameters ranging from 50-400 nm. The particles were deposited on carbon-coated sapphire and compressed with a boron-doped diamond indenter probe while simultaneously imaging with an FEI Tecnai T12 TEM.

On compression the particles were observed to exhibit predominantly elastic behavior followed by fracture and then additional plastic deformation. The particle shown in Figure 1A, which had an initial diameter of approximately 200 nm, was compressed nearly 75 nm prior to fracture. The particle fractured twice, the result of which is shown in Figure 1B. The fracture events are visible both in the TEM video, and they correspond to the two load drops in the load–displacement curve shown in Figure 2. The particle adhered to the substrate on retraction of the probe, indicated by the below-zero drop in load in the plot in Figure 2. Fracture events were observed in the majority of the particles tested, and the present work will discuss the fracture mechanics of these small structures.

References

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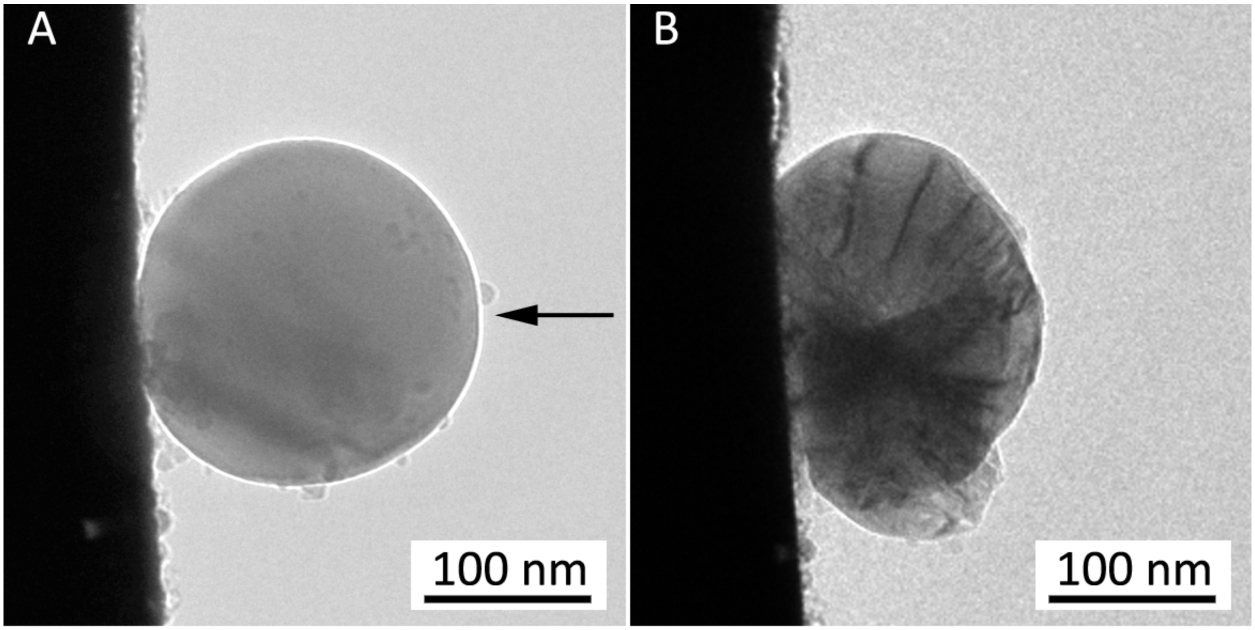

Figure 1: (A) Si particle prior to compression. The black arrow indicates the direction of compression. (B) The same particle after nanomechanical testing.

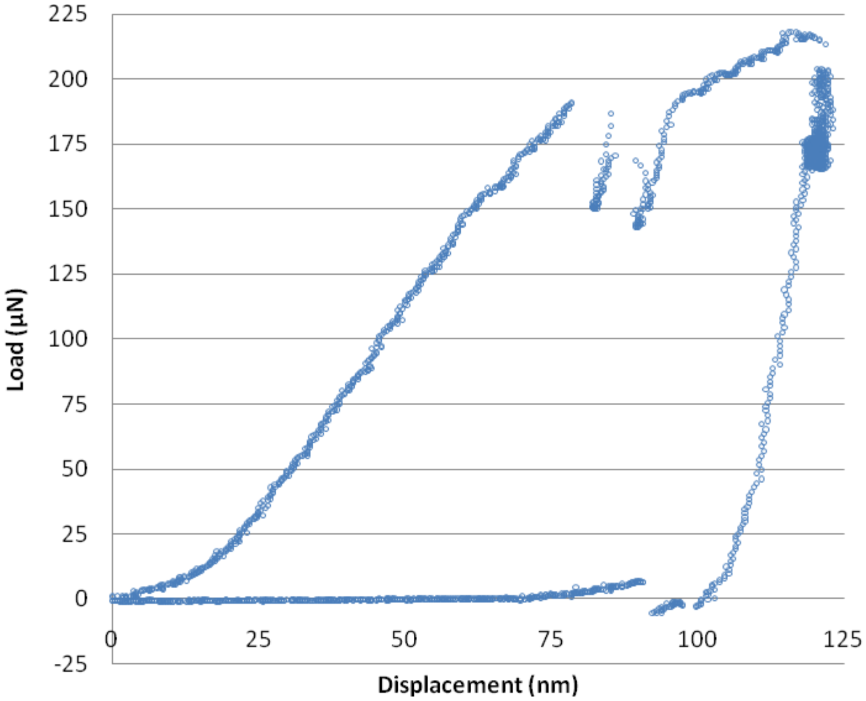

Figure 2: Plot of load vs. displacement for the particle shown in Figure 1. The two drops in load during loading correspond to two fracture events.